Myanmar Soil Fertility and Fertilizer Management

CONFERENCE PROCEEDINGS

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Organized By:

Fertilizer Sector Improvement Project,
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Division of Soil Science, Water Utilization
and Agricultural Engineering,
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Ministry of Agriculture, Livestock and Irrigation

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Opening Session

Opening Address by the Permanent Secretary of the Ministry of Agriculture, Livestock and Irrigation

Dr. Tin Htut

The minister of MOALI asked me to convey this message on his behalf. I asked him, “What is the message you want to deliver to our international audience at this important event?” He said, “What I want is *sustainable agriculture through fertilizer management*.” These are very important words for us. Myanmar needs a mental shift. Myanmar needs good practices in fertilizer management and plant nutrition management.

In fact, this is the very place I originated. I spent 37 years in the Ministry, and I spent more than 30 years in this institution [Department of Agricultural Research, DAR] as a plant breeder and agronomist. And later, I had a dream of breeding nitrogen use efficient rice varieties. But technically, Myanmar is very much behind.

It is my pleasure to welcome you all to this Soil Fertility and Fertilizer Management Conference. It is also my pleasure to be here for the first conference to be held in this splendid new auditorium.

Let me start by thanking the organizers, DAR and IFDC, for what is expected to be a landmark event for agriculture in Myanmar. I also want to thank the donors, USAID and ACIAR for their support.

I understand that this conference is referred to as a national conference, but I can see it has an international flavor and there are scientists here from the USA, Australia, Thailand, Vietnam, Bangladesh, Kenya, and Nepal. I welcome you. You will have a chance to see some of our beautiful country and its tremendous agriculture resources and potential for development. Agriculture accounts for about one-third of our GDP and two-thirds of our employees. I thus say 64% of employment is from agriculture.

To place this conference into context, I would like to share with you the Vision of our Agricultural Policy – ensuring food security along with an increase in the production of highly profiting farm products for export. It aims to improve the socioeconomic life of our people under a framework of sustainable development. We want farmers producing and selling products to contribute to the economic growth of the nation as well as ensure its people have a balanced intake of nutritious food. We want this to be done in a manner that will sustain or improve productivity.

In fact, I would just like to update you on what we are doing right now. For more than 50 years, we were blind, closing our eyes and our ears. When we opened our eyes to the world, we have seen that Myanmar is the final frontier in Southeast Asia.

We have tremendous potential but it’s largely frozen. What we need is strong agricultural policy. We need system-wide reform and sector-wide strategies. Without sound agricultural policy, our course of action is not stable. That's why I suggest that the Ministry have a policy division. My vision is to establish a policy think tank under MOALI like in Vietnam. Thus, my dream is to establish the Myanmar Institute of Agricultural Policy.

We are very subjective about agricultural policy. Now, we realize that our legal instruments must be led by policy. We have various agricultural laws but without clear policy.

In these efforts, we need to use the P’s. The P’s are very important. First is peace and prosperity. These two P’s need productivity and profitability (markets). And these two P’s need policy, planning, programs, projects, partnerships, and people. The important thing is passion.

Soil fertility and soil management are basic fundamentals for sustainable agriculture. I want my people, farmers, to be grounded in the right direction for this, and our government investment strategy must be based in the right direction.

Thus, when IFDC visited my office, I asked them to prepare a fertilizer strategy for Myanmar. I must express gratitude to IFDC to assist the Ministry with this event.

Institutions are very, very important. We may know what we have to do and we may know why we need to do it, but we’re not sure how and who. So, I want to see national level soil and plant laboratories.

Ladies and Gentlemen, I would like to conclude my speech with the 3Ds: Let us design, let us demonstrate, and let us deliver. Thank you very much.

USAID Address

Mission Director Teresa McGhie

Permanent Secretary, Dr. Tin Htut; government officials, development partners and esteemed colleagues; Mingalaba and good morning.

I'd like to thank the Ministry, IFDC, and our Australian colleagues for partnering with USAID to sponsor this important event.

Now some may ask, "Why is soil management so important?" From the Fluvents in the delta, to the Oxisols in Shan, simply put, "soils sustain life."

In fact, Thomas Jefferson, our third president, quite rightly stated, "While the farmer holds the title to the land, actually it belongs to all people because civilization itself rests upon the soil."

Throughout the United States history, soil management has directly impacted our economic growth. When tractors were first widely used in the 1920s, farmers didn't fully understand the dangers of water and wind erosion. This resulted in a catastrophic Dust Bowl, where fertile topsoil was largely lost to the wind. The resulting lack of farm production contributed to the severity of the Great Depression in the 1930s. Farmers now practice conservation agriculture and understand that their livelihoods are tied to soil health.

Building on these lessons learned, the U.S. Government supports agriculture-led economic growth, based on a foundation of sustainable production systems.

In fact, this is a fundamental part of the broader U.S. Government's Global Food Security Strategy, which aims to sustainably reduce global hunger, malnutrition, and poverty. To achieve this, we work with government, the private sector, and civil society organizations to:

1. Facilitate inclusive and sustainable agriculture-led economic growth;
2. Strengthen resilience among people and systems; and
3. Promote a well-nourished population, especially among women and children.

By developing and promoting sustainable production systems, Myanmar will be able to meet the challenge of feeding its growing and rapidly urbanizing population. However, these production systems must reduce the yield gap, maintain soil fertility, and be adaptive to market signals and resilient to environmental stresses.

To support this, USAID's works with the Ministry of Agriculture, Livestock and Irrigation to achieve its vison of "an inclusive, competitive, food and nutrition secure and sustainable agricultural system," as described in its forthcoming Agriculture Development Strategy.

It's no secret that Myanmar has a rich endowment of natural resources, including a diverse range of agro-ecological zones with abundant soil and water resources.

In light of sustainably managing these resources, this conference comes at an important time. Recent changes in agriculture production have upset the balance of historical natural resource use.

As Myanmar’s agriculture sector transitions toward commercialization, it is rapidly changing from a “low input – low output” production system to one of higher output requiring higher inputs.

Intensified production practices that use high-yielding short-duration varieties enable farmers to grow up to three crops per year. And while this increases farmer incomes, there are hidden costs that are not often counted. At many farms, the soil organic and mineral nutrient reserves are being mined faster than they are being replaced.

Inorganic fertilizer alone is not the solution. Maintaining soil health requires attention to the chemical, physical, and biological properties of the soil.

That is why this conference is so necessary. It provides a forum where researchers and practitioners can share ideas, data, and resources to help inform on-farm production management decisions.

It is my hope that the important work being presented over the next two days, and the discussion on Friday, will move beyond academia and strategy discussions. Actionable recommendations and outcomes from the conference and workshop are needed to address soil and nutrient management challenges.

Moving this information from research to extension is critical to operationalizing any meaningful management plan at scale. Public and private extension services must provide a consistent message that is informed by primary research. Unfortunately, there is currently a weak linkage between research and extension services.

Bridging this information gap, USAID is helping Myanmar smallholder farmers to understand soil management and the efficient use of inputs. In 2016, USAID trained over 60,000 smallholder farmers on improved production practices.

Working with our partners, we have trained farmers on fertilizer deep placement, integrated pest management, balanced plant nutrition, seed treatment with microorganisms, compost making, and soil conservation measures.

Information makes a dramatic difference in the lives of smallholders. For example, rice farmers using deep placement fertilizer have seen a yield increase of 28 percent, while reducing the total fertilizer applied by 30 percent. Rice farmers receiving extension services have seen a 48 percent increase in their net incomes.

The information gap is closing, but much more needs to be done.

As part of your discussion here today, I encourage you to keep in mind this gap between innovative research and smallholder farmer adoption. We are at a critical point, where farmers need access to information and affordable technologies that will enable them to respond to a rapidly changing agriculture paradigm.

I would like to conclude with a cautionary quote from U.S. President Franklin Delano Roosevelt: “The nation that destroys its soil, destroys itself.”

This is a sobering reminder that the task at hand is an important one. I thank you for your participation in this event and I hope you all enjoy the papers and presentations over the next two days.

Thank you.

ACIAR Address

Dr. Robert Edis
Research Program Manager

Good morning, everybody, and thank you very much for your kind words, Honorable Permanent Secretary Dr. Tin Htut and Teresa McGhie from USAID. It's really a great pleasure to see so many people from all over the world coming here, working with the Myanmar researchers to attend to some really important issues. I'd like to particularly thank the crew from IFDC and DAR, Grahame and Su Su in particular, for this terrific idea of bringing people together. I think, Dr. Tin Htut, you remark often that we don't do enough together, and I think this is an example where your development partners – ACIAR, USAID – are coming together, working together to try to attend to those issues.

I think it makes a lot of sense for Myanmar, Australia, and the United States to work together because the soils and the issues are so similar in many of our different areas. In Myanmar, Australia, and the United States, we have some terrific soils – soils from which plants emerge like a wet tongue through candy floss. We have soils which a farmer in Australia described as boot-sucking, tractor-bogging spew. We have soils that are rich, red and deep, and beautiful, such as those in Shan State, which Ms. McGhie mentioned in her talk. We have these challenges of salinity, of sodicity, of acidity, of alkalinity; more than anywhere else in the world, these three countries share those challenges and can share solutions. So I think we're at a really unique time. This conference is like time zero. We're in the throes of working out a strategy with the whole community – a strategy of investment not just for Myanmar, working with Myanmar government partners and researchers, but also the development partners. It's a really important time to identify what the key investment opportunities and needs are for soils and fertilizer industries, which of course underpin all of our food production systems and the income security of most Myanmar people.

Looking at the schedule, many of these things have been confronted, many of them from working together with U.S., Australian, and Myanmar collaborators. We have many people from all over the world with great expertise, but we also have a bunch of folks here in Myanmar who are well-equipped intellectually to deal with these challenges given sufficient support, resources, and collaborative relationships – people like Daw Thuzar Myint from the Land Use Division; Dr. Thandar Nyi, also from the Land Use Division; Dr. Su Su Win from DAR; and Dr. Soe Soe Thein from YAU. They're really well-established, highly credentialed, and very talented soil scientists. Nutrient management here in Myanmar is at a point where people could easily overshoot the mark. At the moment, it's OK. Probably there needs to be more nutrients supplied to replace the products that are removed. We have seen in China a huge overstep of the amount supplied with really serious consequences. So bringing together soil fertility and fertilizer management to avoid mistakes, to exploit opportunities, to increase sustainable production in Myanmar is really unique at this time.

I hope that everyone is going to engage with the conference open-mindedly, open-heartedly, engaging in debate – robust debate if necessary – to really put the management of the soils, how farmers manage fertilizers into a good place in the near future.

On behalf of the Australian government, through the Australian Centre of International Agricultural Research – and you’ll see some of our badges on the research papers as they come through – we’re really happy to participate. We’re really grateful to Grahame for inviting us to come and chip in with papers and with some money.

Thank you very much.

IFDC Address

Dr. J. Scott Angle
President and Chief Executive Officer

It's my pleasure to have traveled a long distance to be with you here today. This is a great honor for IFDC to be a part of this conference. It's extremely timely, as you have just heard, and I will reiterate a couple of those points in just a minute.

Dr. Permanent Secretary, I would like to thank you for all of the cooperation that you have shown to IFDC over many years. I know we have had a wonderful relationship. To the other departments who are represented here today of the government, to our Australian partners, we are glad that you are here and being a part of this, and particularly to USAID. We have individuals who have been here for many years and individuals who have traveled here just for this meeting, and we are very grateful to all of them for their support and their intellectual contribution to the work that is going on here. I'd also like to thank at this time all the scientists who have traveled many miles to be a part of this. We are going to have a very lively discussion and lively debate. There are several controversial issues that will be discussed over the course of the next two days, and I also look forward to hearing from each and all of you. Lastly, I'd like to thank the private sector representatives who have joined us here today. Ultimately, many of the solutions, if they are going to be permanently embedded into the culture and economy of the country, will come through the private sector. So thank all of you for being here and for your contribution to moving these issues forward.

IFDC was started in 1974 by then Secretary Henry Kissinger to support appropriate soil health technology around the world. At that time, as many of you might remember, the world was going through a food crisis caused by drought and political issues. There were many, many people who were going to bed hungry during that time. Out of that grew the acknowledgement that, in many areas of the world, fertilizers were not being either used in adequate quantities or appropriately. And so we were started at the suggestion of the U.S. Secretary of State at that time as a public international organization (PIO) to support soil fertility research, particularly in developing countries around the world. Since that time, our mandate has expanded. We also now work on seed genetics, water management, appropriate use of technologies for control of insects and pests, and as many of you know, when you start using fertilizers and other appropriate agricultural technologies, yields can easily double, triple, or quadruple. When that happens, the question is what do farmers do with the extra rice, the extra tomatoes, the vegetables that they are producing. So IFDC now also works extensively on output markets and helping farmers achieve the best value for the products that they are producing. We appreciate all the partnerships that we have had with all of you.

We signed a Memorandum of Agreement just yesterday with two Departments in the Ministry and YAU to codify and to celebrate the relationships that have existed in the past but, more importantly, to talk about how we can work together in the future. As you have just heard, and to me this is a particularly salient point, for Myanmar this is a critical time for soil health and use of fertilizers. The data is not that easy to obtain, but as far as we know, fertilizer use needs to expand within the country, particularly in certain sectors. But other countries in Africa, China, and India have some of the similar issues; fertilizers have not been appropriately used. They were overused or used in the wrong way or at the wrong time or at the wrong place. We have something called the

4Rs in the fertilizer industry that directs how fertilizers should be appropriately used, but in many of these instances, the 4Rs refer to the wrong practices that were used for fertilizer application and management. Myanmar is at a very critical point, but has a great opportunity to avoid many of the problems that have been caused by the inappropriate use of fertilizer around the rest of the world. We are making sure that we understand the soil and its needs and we understand the relationship with the crops that will be fertilized and how these fertilizers might impact the environment. Certainly, there are many, many cases in China and around the world where fertilizers have caused water pollution, have degraded soil quality, and have contributed to climate change with the release of nitrogen oxides into the atmosphere. All of these problems can be avoided within the country with the appropriate use of technology. So this is the right time and this is the right place, and the right questions are being asked at the conference. That’s why I’m glad we have some of the world’s experts who have come here today to make sure that the government and the agriculture sector are being appropriately advised and that the appropriate research will be conducted with scientists here in the country.

There is one last opportunity that I would like to mention, and this is something that we have seen extensively both here in Myanmar but also in Africa and other Asian countries. There are soils that we are now finding that we call non-responsive. You can apply appropriate rates of nitrogen, phosphorus, and potassium, and crop yield does not increase. What that tells us is that there is another nutrient lacking in that soil. So when that other lacking nutrient is identified and applied, the full potential of the nitrogen, phosphorus, and potassium can be achieved. Materials and micronutrients like zinc or boron and occasionally sulfur would be important in this country; once they are identified as critically lacking elements in the soil, then the full potential of the macronutrients can be achieved. This isn’t just for crop growth. In this country and other countries throughout the world, there are human nutrient deficiencies that are on the increase right now, because as we mine these soils for zinc, copper, and boron, the concentration of those elements within the edible portions of the plant, the yield, has been continually going down over the last 30 or 40 years. So we have mined those nutrients out of soils. Our food has become less nutritious over the last couple of decades as a result. With soil fertility management, not only are we increasing crop yields, which clearly is the most critical element for the farming community, but we are improving the quality and the nutritional value of the crops that we will produce. Ultimately human health will improve because of what we will be talking about over the next couple of days. So our influence over the human condition, whether it’s through producing calories and carbohydrates or micronutrients, or the alleviation of diseases caused by lack of, will be discussed here. A lot of important things are going to happen over the next couple of days and I’m very grateful to all of you for being here to be part of this really timely discussion.

Thank you very much.

Keynote Address

Soil Fertility and Fertilizers in Sustainable Agricultural Development: What Is the Way Forward for Myanmar?

R.R. Weil

Professor of Soil Science, University of Maryland, College Park, USA

Abstract

Myanmar stands on the brink of potentially dramatic increases in agricultural productivity and profitability, including increased and improved fertilizer use and management. The fertilizer situation in Myanmar seems to be only partially documented with official fertilizer import and manufacture statistics accounting for only a part of the overall actual on-farm usage. For instance, published household survey studies indicate a much higher rate of fertilizer use than do many official statistics.

Opportunities for improved efficiency and profitability of fertilizer use include integration of fertilizer with whole-farm management and other sources of nutrients, improved more realistic interpretations of yield response trials, and improved placement technology, such as deep placement of urea in paddy fields. More emphasis needs to be placed on sulfur as a major nutrient and possibly on the need to supply micronutrients as well. Fertilizer application recommendations should be based on yield and quality response data and correlated soil tests, not simply on replacing all nutrients taken up or removed in harvest.

It is a fortunate fact of agro-ecology that most damaging environmental effects of fertilizers result from their overuse and abuse and mismanagement, not from their optimal and proper use. Therefore, there should not be a conflict between minimizing environmental damages and maximizing productivity and profitability. For example, nitrogen losses through leaching and gaseous emissions are usually closely related to nitrogen surplus. Efficient fertilizer management should eliminate the need for applying more than the amount of nitrogen actually taken up. Such management will both improve profitability and dramatically reduce environmental impacts. There is a need for site-specific testing and recommendations because even the best blanket recommendation will be wrong most of the time. Reliance on blanket recommendations is akin to buying shoes for the entire family based on the average size of the parents and children – in all likelihood, everybody is going to be uncomfortable.

It seems that fertilizer quality and adulteration, at least for compound granulated fertilizers, may not be as great a problem as some have feared. Probably a greater problem that cheats the farmer of value is ignorance of basic fertilizer principles, including an understanding of the nutrient content of different types of fertilizers. Still, there are opportunities and probably many instances of cheating and adulteration in informal fertilizer markets directed toward the poorest farmers. Spot checks using simple analytical instruments and, if compound fertilizers and micronutrient blends

become important, portable X-ray fluorescence (XRF) instruments may be a sensible way to police quality control with on-the-spot inspections and real-time results.

A soil health-oriented whole-farm management approach will be necessary for sustainable development of the agriculture sector in Myanmar. Well-managed fertilizers have an important supporting role to play in this endeavor.

In this keynote address, I will attempt to set the stage for discussions in the four main focus areas of the conference.

1. Soil and Crop Nutrient Management

The key to sustainable management of soil and nutrients is to the treat the soil as a living organism by using a holistic approach that works with the ecology of the soil system. Thus, nutrient management must look beyond just the nutrients themselves. The most critical resources that plants and crops get from the soil in most circumstances are water and air. Nutrients are often second or third in line after those. Of course, some fields may be so depleted that nutrients may rival even water as limiting factors. But the main point is to remember that, even when adding nutrients or improving the availability of those already there, our foremost job is supporting a hospitable soil environment for crop root growth and for all the micro-, meso-, and macro organisms that are part of the biological community in agricultural soils.

A common example of air, water, and physical properties of the soil limiting the availability of nutrients is the impact of compaction. For upland soils in Myanmar's Dry Zone, compaction can place severe restrictions on the ability of crop roots to access nutrients that may be chemically available in both the topsoil and subsoil layers. We need to be aware that it does not require large machines to compact a soil. Applied to wet soil, a plowshare, human heel, or a draft animal's hoof can do the job quite well.

Fertilizers are one of many tools available to the farmer for managing soil and nutrients. Fertilizers should be seen as a secondary source of nutrients, needed when natural soil cycles are incapable of providing sufficient nutrients for optimal profitable crop production. Many isotope tracing studies have been performed in nearly every kind of environment and for many different types of agricultural crops. These studies have clearly shown that, even under high-yield, well-fertilized environments, most of the nutrients harvested in the crop did not come directly from the fertilizer bag. Rather, field crops primarily take up nutrients that come through the natural cycles in the soil. Fertilizer is more like a deposit of funds into the bank or an investment in productive infrastructure. Most of the atoms of fertilizer nutrients will first be used by microbes in decomposing plant residues and producing soil organic matter. These nutrients will later be released during decomposition and will be held for some time on cation exchange sites rather than being taken up by the crop directly from the dissolving fertilizer pellet.

From a broad perspective, soil and crop nutrient management has three basic objectives: First, provide the right nutrients at the right time and place in the right quantities to allow optimum economic production of high-quality agricultural products. Second, minimize or avoid undesirable environmental impacts, especially by nutrients that escaped from the agricultural system to pollute water and air or produce emissions that impact global climate. This objective has to include consideration of the lifecycle greenhouse gas emissions involved with the production of particular fertilizers and with their use and management at the farm level. Third, conserve and recycle the nutrients themselves, especially those whose production involves high costs in terms of energy inputs, monetary inputs, or environmental damages. Special attention must be given to nutrients like phosphorus that are increasingly scarce and difficult to obtain. The 20th century model – mining nutrients from a hole in the ground at one location, transforming them into fertilizers, spreading them on farmland far away, and finally allowing them to wash off the land or down the sewers into estuaries and oceans – is not sustainable in the long-term.

As much as possible, farms should be managed as closed systems with the nutrients eventually returned, on a regular basis, to the field from which they were removed. This means the retention of crop residues and the return of animal and human wastes as well as ashes from biomass cooking fires. Farmers need to be trained to think of their practices in terms of the movement, conservation, and utilization of nutrients. A common example of how this could improve small-scale farming is something I've observed in many countries. Farmers pulling weeds from their fields often throw these weeds on the field margins and on the bunds where the weeds decompose. This practice enriches the soil adjacent to the pathways where crop are not grown while depleting the soil from the center of the field. Many fields in Africa certainly suffer this unfortunate and unintended migration of nutrients to the edges. I suspect the same may be true in parts of Myanmar. Other examples include the burning of crop residues and animal manure rather than their return to the soil – or even the spatially even return of the ashes from said fires. In the long run, the goal should be to build up the level of soil fertility, organic matter, and biological activity so the soil's inherent nutrient cycles can supply most of even a high-yielding crop's requirements with only relatively small need to supplement this with fertilizers from off the farm.

As it is the driver of many of the nutrient cycles, carbon should not be forgotten. That is, soil organic matter must be replenished and maintained in order to sustain high levels of farm productivity at minimal cost. Growing productive crops and leaving as much of the crop residue in place as possible go a long way toward maintaining soil organic matter. However, for most soils and climates, that is usually not enough. Additional crops must be grown primarily to feed the soil. What we in the United States now call cover crops are similar to what more traditionally were called green manures. The main purposes of these plants are to protect and enhance the soil. If cover crops cannot be grown, farmers should at least grow complex rotations including crops that leave a large mass of root residues to help feed the soil food web and build organic matter.

Enhancing soil health is a worthy long-term goal, but a more short-term goal is to be sure that fertilizers purchased by smallholder farmers with their scarce financial resources are, in fact, of a high quality, a suitable formulation, and used efficiently and effectively. Proper management can tremendously impact the profitability of fertilizer use. Agronomic fertilizer use efficiencies in Myanmar have been reported from levels as low as 5 or 10 kilograms (kg) of grain per kg of nutrient applied to over 100 kg grain per kg nutrient applied.

Generally, nutrient use efficiency goes down as the fertilizer application rate goes up, especially if other factors are limiting yields to relatively low levels. One may wonder why nutrient recommendations are almost the same for a rice farmer in Missouri, USA, producing 9,000-10,000 kg of grain per hectare (ha) and a rice producer in Myanmar producing 3,000-4,000 kg/ha. The well-known classic idea of limiting factors of production always needs to be kept in mind. Not only is it wasteful to be supplying more of one nutrient when it is another nutrient that is limiting, it also will be unproductive to supply any nutrients when some other factor is limiting productivity at the present level.

Sulfur (S) is a good example of an often-overlooked nutrient factor that may limit responses to nitrogen (N), or to phosphorus (P) or potassium (K). Reading through what literature I could find on fertilizer use in Myanmar (Aung Naing Oo et al., 2016; Gregory et al., 2014; Lwin et al., 2013; Sanabria, 2017; Zorya, 2016), it appeared that by far the greatest emphasis was on nitrogen, with much less discussion of phosphorus and potassium, and little to no mention of sulfur. Yet sulfur is a very important macronutrient that interacts with nitrogen and is becoming increasingly deficient in the world's agricultural soils. I recommend that proper sulfur trials be conducted on key benchmark soils in Myanmar as the country's most standard soil tests are quite unreliable to indicate where plant responses can be expected. My own research and that in several other labs in the United States suggests that a weak calcium chloride ($CaCl_2$) extraction is better at predicting crop sulfur responses than the widely used Mehlich-3 or ammonium acetate extractions. As a starting point, it looks like the critical level of soil test sulfur is between 10 and 12 milligrams (mg) sulfate-S per kg soil, as extracted with 0.01 M $CaCl_2$ at a 2:1 solution:soil ratio.

If sulfur response trials are undertaken to assess soils around Myanmar, it will be important to recognize that nearly all phosphorus fertilizers do contain some sulfur as a contaminant from the manufacturing process, which begins with the sulfuric acid dissolution of phosphate rocks. When samples are analyzed, both diammonium phosphate (DAP) and triple superphosphate (TSP) often are found to contain 2-3% sulfur. Therefore, in most trials in which treatments are structured to first test nitrogen and phosphorus and then add sulfur, sulfur responses may be masked. That is, trials often compare N-P-K to N-P-K-S to evaluate the S response. However, phosphorus fertilizer supplying 50 kg/ha of P_2O_5 (~22 kg P) usually inadvertently supplies the ~5 kg/ha of S commonly sufficient to overcome most S deficiencies. Therefore, I recommend that when looking for sulfur and phosphorus deficiencies, the treatments should be designed with the critical comparison being between N and N-S and between N-S and N-S-P, rather than between N-P and N-S-P.

Key suggestion: Tie any increases in fertilizer use with improvements in soil organic matter management, nutrient cycling, balanced fertilization, and basic crop agronomy.

2. Fertilizer Recommendations and Their Extension to and Adoption by Farmers

Fertilizer recommendations provide a way for professionals to help farmers and apply science to specific situations to improve farm productivity and profitability. Fertilizers should be thought of as supplemental to the natural cycles of nutrients in the soil. As crop yields are improved and cropping intensity increases, the nutrient removal sometimes gets ahead of the ability of soils to release additional supplies. Nonetheless, most of the nutrients garnered by plants come from biogeochemical cycles in the soil, albeit enhanced by fertilizer additions. One goal of sustainable soil management is to rebuild soil health and organic matter to the point that internal nutrient cycling is such that only relatively small fertilizer additions are needed to maintain high productivity.

The tools available for making fertilizer recommendations and for making wise decisions on fertilizer management include several sources of information. One of those sources of information is the balance between the amount of nutrient removed and the amount that can be supplied by the soil. This is informed by expected or actual yield levels and by actual or typical analyses of the harvested part. Removal of crop residues, although rarely advisable, is often practiced and must also be taken into account in the nutrient balance. However, it is a bit of a myth that the nutrients supplied to the soil need to equal or even exceed the amount of nutrients removed in order to maintain soil fertility. For many nutrients and many soils, there is a capacity to continue to supply nutrients from a vast pool of minerals or biological nitrogen fixation. This capacity can fulfill at least a portion of the crop requirement, allowing farmers to supplement this with fertilizer rates that are less than the rate of removal without instigating a downward cycle of soil fertility. This internal source is likely significant for nitrogen (replenished by biological N fixation) and some nutrients like potassium, calcium, magnesium, and iron (weathered from the near-infinite supply in primary and secondary soil minerals found in many soil profiles).

Soil testing and tissue analysis are two other important tools for making fertilizer recommendations and managing nutrients. Of the two, tissue analysis is generally more precise and a better predictor of plant needs but, of course, is largely performed after the fact and must be conducted when crop plants are present at a suitable stage of growth. Soil analysis is much less accurate but is usually sufficient to point out the majority of fields where a particular nutrient is likely to be limiting. Soil testing tends to be much more accurate for P and K than for other nutrients. It is of little use for predicting nitrogen needs, except in the case of mid-season nitrate accumulation tests (e.g., pre-sidedress nitrate test). For micronutrients, soil tests are better predictors of deficiencies when soil pH and organic matter are also measured and taken into account. Under acid conditions, soil tests tend to be quite a bit less predictive for micronutrient needs. In the very early stages of fertilizer use during agricultural development, regional soil tests may point out nutrients that need attention, but once fertilizer use becomes regularly adopted, soil tests are more reflective of recent management history than of parent material and inherent soil conditions. Therefore, the mode of use of soil testing needs to change toward regular use for individual fields as a region’s agriculture develops.

One of the most reliable soil tests is the soil pH reading. The pH can quite accurately predict fields on which crops are likely to respond to the use of lime materials or on which alkalinity, sodicity, and certain micronutrient problems are likely to exist. Fortunately, this is a very easy test to perform. Extension agents and farmers’ groups should be equipped with simple, inexpensive (< $50) pH meters and guidelines for how to conduct the test. That way, individual fields could be economically tested and those that require lime determined. In tropical regions, pH values need to be < 5.0 before much response is expected from the application of limestone.

For many high-rainfall parts of the world, one answer to acid soil problems is already widely distributed in farming villages – namely, the ashes from fires used for cooking, heating, and brickmaking. These ashes derived from the burning of local firewood resources can be recycled to farm fields and are usually present in amounts sufficient make a significant contribution to overcoming serious aluminum toxicity limitations. The nice thing about ashes is that they are already distributed in the villages and pose an almost zero cost for the material. The labor requirement is also quite low for collecting and distributing this material. It should be noted that significant quantities of potassium, calcium, magnesium, sulfur, and phosphorus are also present in the ashes. Therefore, in humid regions with weathered soils, the yield response to application of ash often exceeds that of lime applications (which provide only calcium and pH amelioration) (Sirikare et al., 2015).

Fuel wood ashes represent only one of many sources of indigenous nutrients for smallholder farmers. Such sources of nutrients should be fully exploited before expensive imported fertilizers are brought into play. Similarly for nitrogen supply, the use of legumes as cover crops, rotation crops, and agroforestry plantings should be fully exploited before nitrogen fertilizers are used as a supplement.

As also suggested, statistics on fertilizer use in Myanmar are so unreliable that we do not really know what kind of fertilizer rates are in common use. However, some studies suggest that nitrogen is being applied at approximately 120 kg/ha for typical rice production even though this is far higher than the ~13 kg of nutrients/ha derived from national annual fertilizer use (~320 million kg of N+P+K) divided by the official statistics on total land area (25 million) in crop production (Gregory et al., 2014). While 120 kg N/ha seems like a reasonable level of fertilization if high yields of rice are being produced (i.e., yields of 8,000-10,000 kg of grain per ha), it is probably an excessive level for the 3,000-4,000 kg of grain more typically recorded in Myanmar. The N surplus would be 120 kg N added minus ~40 kg N removed in rice grain (4,000 * 0.01), or some 80 kg N surplus/ha. Where fertilizer is underused, it is legitimate to encourage farmers to use higher rates – provided that other practices and limitations are also dealt with. Higher rates of fertilizer without improved agronomic practices and improved genetics will be a waste of money and resources and only lead to aggravated climate change and nitrogen pollution of waters and atmosphere.

The fertilizer industry in Myanmar should also be careful about misinterpreting nitrogen response curve data. This has been done in many parts of the world and has led to excessive recommendations. The most common problem is that experiments are conducted at only a few locations and under a few environmental conditions. The highest possible yield is assumed to be the target. Since this is only rarely achieved, in most situations, nitrogen is over-applied. This error of over-optimism about yield goals is compounded when the nitrogen application rate is based on a quadratic or Mitcherlich equation interpretation of the yield response data. There are many examples in which the exact same field data can fit statistically equally well to a linear plateau model or quadratic plateau model, either of which will give substantially lower critical levels of nitrogen application compared to a continuous curve model (Figure 1). Another way of

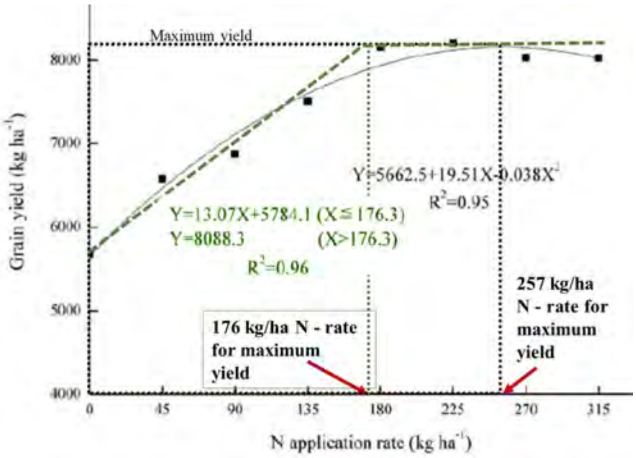

Figure 1. Linear-plateau interpretation of fertilizer response data generally leads to much more efficient, less polluting fertilizer recommendation rates than curvilinear interpretations of the same data using equations such as quadratic curves. Data from Dong et al. (2015).

looking at it is, if you cannot show statistically that a 150 kg rate provides higher yields and higher profits than, e.g., the 120 kg rate, there is no justification for recommending the higher rate – even if that is the rate that a quadratic curve would suggest is the point of maximum profit.

Application rate is a major determiner of nitrogen use efficiency and profitability, but application method can have a big impact as well, especially in paddy rice culture. The International Fertilizer Development Center (IFDC) pioneered the technology of urea deep placement from the 1970s. In concept and often in practice, it is a remarkably elegant and effective method of increasing nitrogen use efficiency and reducing nitrogen losses. With suitable application equipment, deep placement can even save labor. Research has been conducted in many Asian countries on the impact of urea deep placement using urea super granules (or briquettes). Deep placement (8 to 10 centimeters) between four rice plants has been shown to typically reduce the optimum nitrogen rate by approximately 30% while often increasing yields. It seems that newly designed equipment may be about to overcome labor bottlenecks in the adoption of this technology.

Finally, recommendations will need to be much more site-specific in the future to overcome the inefficiencies of blanket recommendations that are common today. This will involve improvements in soil testing itself and improvements in the accessibility of soil testing to farmers. I understand there have been some initial inquiries in Myanmar about the use of near-infrared spectral soil testing methods based on large libraries of spectra vs. wet chemistry correlations (such as those done by Soilcares®).

As with most countries, the literature that I've seen indicates that fertilizer trials continue to be conducted in Myanmar. It also indicates that these trials are usually done on just a few sites, often at research stations associated with government or university land. One has to wonder why fertilizer trials continue to be carried out since their effectiveness was shown very clearly at least a century ago, and most of the fertilizers in use today are indeed effective sources of plant nutrients, causing there to be little question that fertilizers work to improve plant growth where they are needed. Really, that is all that a fertilizer trial will show us – namely, that when you apply fertilizer, plants will grow larger if the nutrient being applied is in insufficient supply naturally from the soil. The plants will grow larger with higher rates of fertilizer up to the point that the nutrient is no longer the limiting factor, after which applying more fertilizer generally will have little or no effect on plant yields or possibly even a negative effect if the excess causes imbalances or toxicities.

What is really needed is site-specific indications of how much and what types of fertilizers are required. Unfortunately, an experiment testing different nutrients or fertilizers on a research station field only answers the question about what is needed for that particular field. Fertilizer response trials have value only where they are correlated with widely used soil tests or where they are conducted on a wide variety of soils under farmer conditions. The aim is to determine how widespread and likely to be encountered a particular nutrient deficiency is. A more precise aim would be to develop an appropriate soil testing protocol or possibly even plant testing protocol that would indicate, for individual farm fields, what nutrients are needed and in what amounts. Site-specific testing may even be justified for parts of a single field where spatial variability is large and identifiable.

Therefore, rather than traditional replicated plot work on a research station, I would recommend that plant and soil surveys be conducted based on a stratified random sampling method. Such a sampling scheme would indicate effects, such as past management, soil parent materials, landscape position and proximity to animal housing, and human dwellings. Such a survey could be based on soil tests where appropriate tests are available to reliably predict crop responses. However, plant tissue tests can be much more revealing because the plant has already reliably defined "availability."

Regional and localized models of fertility requirements could be developed as a substantial step forward but these would still not be as good as individual field testing, which takes into account the past management, such as last year's fertilizer or manure applied five years ago or the previous crop in a rotation. This is where Myanmar needs to head if it plans to use fertilizers efficiently to produce high yields. In addition, as already mentioned, putting a great deal of effort into increased fertilizer use will only be effective if it is accompanied by equal amounts of effort to improve crop agronomy: timeliness, spacing, pest, disease and weed control, tillage, etc. Improved seeds – i.e., genetic potential – are also an essential part of the package needed to allow fertilizers to perform efficiently (and vice versa).

Key suggestion: Increase the site specificity of fertilizer recommendations, basing them on localized soil and plant tissue tests. Keep fertilizer rate within the range necessary for the yields actually being produced, remembering that fertilizers should be considered only a supplement to nutrients provided from internal soil processes such as mineral weathering and biological N fixation.

3. Environmental Impacts of Fertilizer Application

> *"Among the measures recommended for lowering N losses and enhancing NUE are the application of N at a later growth stage, adjusting the N rate based on chlorophyll readings, applying controlled-release N fertilizer, using urease inhibitors, planting highly efficient rice varieties, and combined organic and inorganic fertilizer applications."*
>
> – Moe et al. (2017)

Fertilizers around the world are having major environmental impacts primarily on aquatic systems but also on the soil, atmosphere, and climate change. In addition, some fertilizers pose risks to human health and the quality of the food supply. The biggest environmental impact is undoubtedly eutrophication due to nitrogen and phosphorus. The good news with respect to environmental impacts is that eutrophied water is a sign of nutrient overuse and not a necessary accompaniment to high-yield agriculture. If nutrients are managed carefully and used in only the necessary quantities, very little nitrogen or phosphorus is likely to escape from farm fields and make its way to waterways. Many studies have shown that the leaching of nitrogen and the runoff and leaching of phosphorus increases dramatically only once these nutrients are applied at rates that exceed the uptake and requirement of the crop. The message is clear: since eutrophication is a major impact of agriculture in most parts of the world, agriculture is commonly over-using or mismanaging nutrients. This means that solutions should be available that improve both environmental impacts and profitability (Figure 2).

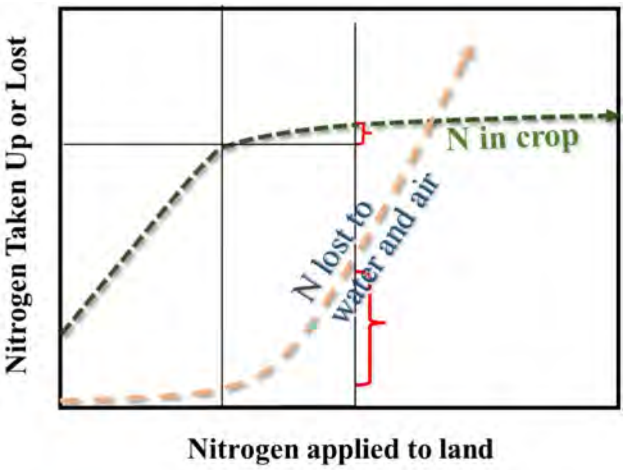

Figure 2. ***Nitrogen losses do not become serious until rates of application exceed the actual capacity of the crop to utilize the nutrient. Thus, high yields, profits, and environmental quality can all be compatible.***

Other environmental concerns include soil acidification, due mainly to overuse of nitrogen fertilizers. In this regard, it is important to realize that although hydrogen ions are released when ammonium is oxidized much of this hydrogen-based acidity may be neutralized when the resulting nitrate ions are taken up by plant roots in exchange for bicarbonate in exudates. Thus, the acidification is mainly caused by the excess nitrate that is not taken up by plants but is instead leached away accompanied by calcium, magnesium, and potassium ions in the leaching solution.

Greenhouse gases, especially the powerful N_2O gas (nitrous oxide) is usually closely related to the application rate of nitrogen fertilizer – as well as with the occurrence of conditions suitable for denitrification (warm, wet soils with high decomposable carbon for energy). Applying fertilizer in a manner that results in a large accumulation of soluble nitrate tends to stimulate these emissions. Careful management of paddy floodwater to moderate soil redox potential (Eh) can also minimize greenhouse gas emissions.

Urea deep placement technology has been shown to dramatically reduce nitrous oxide and ammonium emissions. Yet, farmer adoption remains sparse throughout the world. In Myanmar, a small urea briquette manufacturing capacity is now online. A major effort should be made, in conjunction with farmer advisory boards, to develop a suitable system for making the deep placement of urea a reality in Myanmar. This will involve not only the manufacturer of quality briquettes and their distribution at a competitive price but education and training of farmers and extension workers and the development of systems of mechanization that reduce the labor requirement. Deep placement can be adapted to both regular puddled soils as well as to no-till rice fields. Work in China (Liu et al., 2015) suggests that a 10-centimeter (cm) depth is optimum (as compared to 5 cm or 20 cm) for both nitrogen uptake by plants and reduction in

N_2O and NH_3 emissions. Special techniques may need to be developed to avoid increased leaching losses when deep placement is used on coarse-textured soils that have high permeability and low cation exchange capacity.

Key suggestion: Most detrimental effects from fertilizers stem from their overuse or poor management. This fortunate fact means that efficient fertilizer use (including placement) can both enhance profitable production and protect environmental quality.

4. Fertilizer Quality Assessment

Fertilizer quality is an old problem that has been with us since the dawn of the fertilizer industry. Concerns over quality were behind the original legislation in the United States and other countries that required certain information to be carried as a guarantee on the fertilizer label. In fact, that's how the familiar NPK percentages arose. Many states in the USA have an office of the state chemist whose job originally was focused on analyzing fertilizers to be sure that the guaranteed nutrient content was accurate. In many developing countries with informal fertilizer markets, high levels of adulteration still take place or fertilizers are stored in ways that cause them to be degraded. Adulteration can usually be detected by some simple chemical tests. For instance, adulteration of urea and other major fertilizers can easily be tested with an inexpensive and simple combination meter that measures pH and electrical conductivity (EC) (Figure 3). Such a meter or combination of meters can be purchased for U.S. $50-$60 with almost no cost for each test. Pure urea is rapidly soluble but with a very low EC and with a near neutral pH. It would be difficult to adulterate urea and maintain this combination of easily measurable properties.

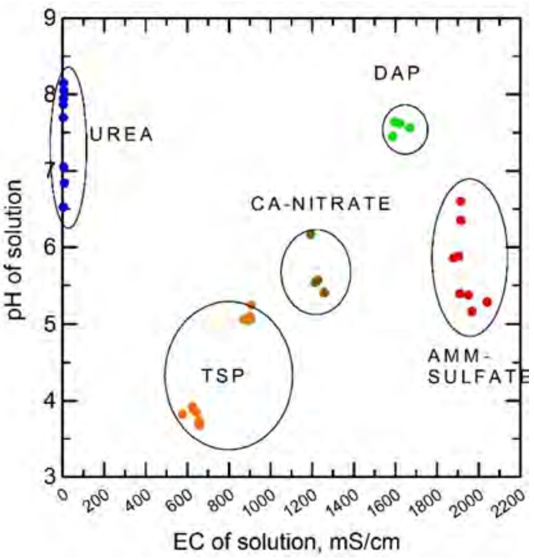

Figure 3. Identification of major fertilizer materials by characteristic combination of EC and pH properties (Unpublished data of R. Weil using SoilDoc kit).

A recent study by IFDC in the Dry Zone of Myanmar suggests that fertilizer adulteration, physical deterioration, and below-guaranteed nutrient content are not major problems within the commercial compound granular fertilizer markets. However quality inspections should continue, especially in the informal or black market sector, in markets directed toward smallholder farmers, and with fertilizers that claim to contain micronutrients.

For total nitrogen content, few tests are readily available as the nitrogen is usually in the ammonium form period, but for total P, K, S, and most micronutrients, portable XRF offers the possibility of rapid, non-destructive, inexpensive field determination of fertilizer nutrient content. Near- and mid-infrared (MIR) spectral scanners can determine fertilizer N, P, K, and S content with sufficient accuracy to flag questionable lots of material. In fact, I would recommend that the Ministry of Agriculture (or a fertilizer industry association) seriously consider purchasing handheld MIR or portable XRF instruments that could be deployed at the border entry (Muse) and ports (Yangon) and even for random on-the-spot checks in the marketplace and warehouses. Once the instruments are calibrated, readings of P, K, S, Ca, Mg, Zn, Cu, N, and Fe can all be made simultaneously in about one minute with no chemical sample preparation. This technology can work with both inorganic and organic fertilizers. Note that XRF cannot detect nitrogen and will require a vacuum pump to determine P and S.

Education of farmers and their advisors (extensionists and dealers) is an important part of fertilizer quality control policy. Unfortunately in Myanmar, as in much of Asia, small-scale farmers are often quite uneducated in the most basic aspects of fertilizer science. For example, it is common for farmers to choose the fertilizer that is most inexpensive per bag, regardless of the actual nutrient content of the various materials on offer. Such lack of understanding probably has a greater potential than adulteration to cheat farmers of the value they deserve for their money.

Key suggestions: Inexpensive, simple pH and EC tests can detect many of the worst fertilizer adulteration and quality problems. A few portable MIR scanning and/or XRF instruments distributed at major entry points and markets and deployed by properly trained personnel could efficiently determine in real-time whether fertilizers contain the claimed amounts of nutrients or are contaminated with toxic elements. To facilitate rational farmer purchasing decisions, fertilizer labels that state the nutrient contents (N, P, S, K, as well as total nutrients) in kg per bag should be considered.

Conclusion

This conference takes place at an auspicious time for Myanmar and its agricultural development. With suitable attention to the lessons learned by other countries making similar transitions, Myanmar can hope to avoid making the past mistakes of others. The four Rs do hold lessons for Myanmar, but only if interpreted in the light of integrated ecologically sensitive agricultural systems thinking. Fertilizers must not be seen as the engine that can "push" yields higher but rather as the resource that can fulfill the higher productivity potentials of improved genetics, agronomy, economic incentives, and whole-farm integration. Deep placement can help with the "Right Place" in rice systems, while linear-plateau models can help with the "Right Rate" of fertilizer application. Balanced nutrition, especially including sulfur, can help with the "Right Source," and split applications based on foliar color or measurements can help with the "Right Time." Mechanization with an eye to no-till planting more than tractor plowing, rotations that include a diversity of crops including legumes, and integration of animal production to conserve crop residues and provide for efficient grazing, and site-specific fertilizer use based on soil types, land characteristics, and soil tests can all contribute to the possibility that Myanmar will be able to "tunnel through" from low-input, low-yield agriculture to high-yield, high-efficiency agriculture without having to traverse the downward spiral into excessive fertilizer use and environmental degradation experienced in most developing countries (Figure 4).

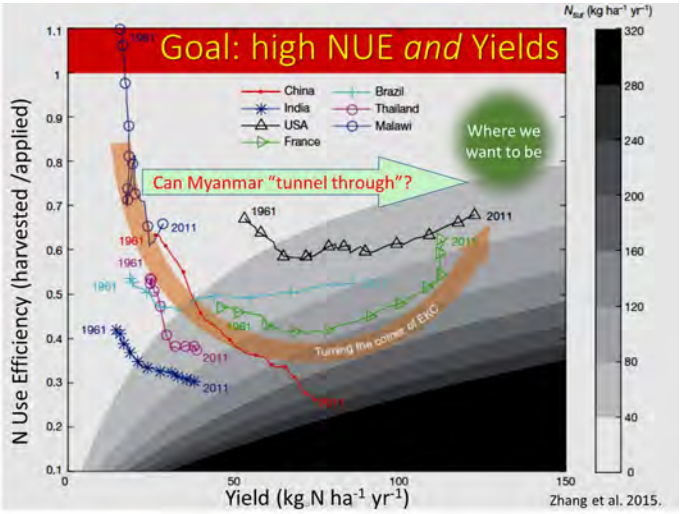

Figure 4. ***With the benefit of lessons learned by other countries, can Myanmar "tunnel through" from low-input, low-yield agriculture to high-yield, high-efficiency systems without going through the downward spiral of excessive, inefficient fertilizer use? Diagram modified from Zhang et al. (2015).***

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Session 1.
Soil Fertility and Crop Nutrient Management

Role of Yield Potential and Yield-Gap Analyses on Resource-Use Efficiency Improvement

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Abstract

A systems approach is used to show the effect of genotypic, environmental, and management factors on the potential yield of rice and maize and the role yield potential and yield-gap analyses play in fertilizer recommendations. Examples from Myanmar are presented for determining yield potential, conducting yield-gap analyses, and identifying appropriate management strategies taking into consideration climatic, soil, and management inputs. CERES-Rice and CERES-Maize models were used to simulate yield potential and N response using site-specific weather and soil data from 18 locations in Myanmar. Planting dates typical for the wet and dry seasons were used for each of the locations. To capture the effect of weather variations, 18 weather years (1997-2015) for each location were used in the simulation study. The wet season rainfed potential production yield, which was the same as the potential production yield, varied from 6.5-7.3 tons per hectare (t/ha) in the Delta Region to 9.4-10.3 t/ha in the Central Dry Zone and Shan State for high-yielding hybrid rice. Similar differences for maize were also observed with the wet season rainfed maize potential production yield of 4.0-4.9 t/ha in the Delta Region and 6.8-7.2 t/ha in the Central Dry Zone and Shan State for the improved maize variety. The potential production yield for irrigated dry season rice was an average of 11.1 t/ha for the 18 locations. The irrigated maize yield potential for the dry season ranged from 6.9-7.6 t/ha in the Delta Region to 7.0-8.6 t/ha in the Central Dry Zone and Shan State. The lower yields in the Delta Region compared to others, particularly during the wet season, were attributed to lower solar radiation. Nitrogen (N) response varied with season, yield potential, and indigenous N supply. Due to these differences, optimum N rates varied from 40 to 120 kilograms (kg) N per ha for rice during the wet season. The optimum agronomic N rates during the dry season were much higher at 120-180 kg N/ha for irrigated hybrid rice. The effects of varieties, indigenous N supply, and method of N application on N recommendations were also simulated.

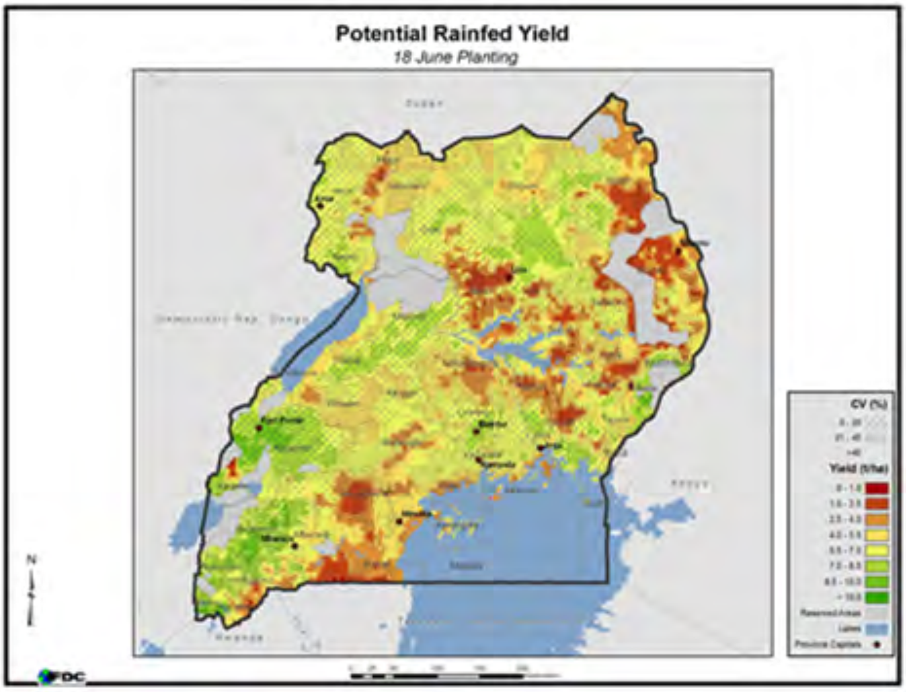
Introduction

Sustainable intensification is needed for Myanmar's agriculture to meet the challenge of increased demand, improved environmental sustainability, and economic efficiency while operating under increased climatic risks. The agriculture sector contributes 24% to gross domestic product (GDP) and 24.6% to export earnings and employs 61.2% of the labor force (MGI, 2013). A key component of sustainable intensification is achieving more agricultural production on the existing agricultural land. Most Asian countries have experienced significant advancements in agricultural production through intensification. In Myanmar, agricultural production is driven by both the changes in cultivated area and yield per unit area. Low nutrient application, especially of inorganic fertilizer, estimated at a national average of 5-20 kg/ha compared with the world average of about 100 kg/ha, is among the major factors contributing to low and declining agricultural productivity (Lwin et al., 2013). The low rate of fertilizer application is a major contributing factor to low rice yield (Naing et al., 2008). The low productivity of the agriculture sector is reflected in output of only $1,300 per year per worker compared to $2,500 in Thailand and Indonesia (MGI, 2013).

Although low rates of fertilizer application may explain the low rice yields at 3.3 t/ha in Myanmar, rice yields vary across Asia from 2 to 15 t/ha due to variety and location (Jing et al., 2008; Ying et al., 1998). Yield for any given crop is the outcome of the effect and interactions of genotype (cultivar characteristics), environment (climatic and soil), and management. Also, yield variances for major food crops in important agricultural areas, such as maize in the USA and Eastern Africa or wheat in Europe and North America, are on the rise (Xu et al., 2016; Ilzumi and Ramankutty, 2016; Trnka et al., 2014). In Myanmar, 15% of the arable land under rice cultivation is challenged by weather-related environmental factors including flooding, drought, and salinity (MOALI, 2015). Hence, insights into the relative importance of genotype, environment, and management are critical for improved yields, increased resource use efficiency, and reduced losses. Myint et al. (2017) reported rice yields ranging from 3.1 t/ha to 6.4 t/ha in the Delta Region of Myanmar, without any N fertilizer application, indicating yields were affected by indigenous soil N supply. This further highlights that yield potential, yield gap, and fertilizer recommendations are site-specific. Myanmar's wide range of agro-environments (soils and climatic conditions) also reinforces the need for site-specific recommendations.

Yield gap is defined as the difference between potential or target yield under optimum conditions and the current farmer's yield. For example, based on current yield of 3.78 and 3.61 t/ha and target yield of 5.16 and 4.93 t/ha, a yield gap of 1.38 and 1.32 t/ha for rice and maize, respectively, was reported by the Japan International Cooperation Agency (JICA, 2013). Another approach is to use simulation models to obtain the potential production yield as the upper ceiling for reference yield. The potential production approach allows one to determine areas with low and high yield ceilings and provides opportunities for improved returns on investment (Singh et al., 2002). As shown in Figure 1, rainfed potential yield for maize changed with planting dates for northeastern Uganda while yield was unaffected in southern Uganda. The fertilizer demand and the returns on fertilizer applications on maize during the September planting will be greater in southern Uganda.

In this paper, we present reducing the yield gap approach to increased agricultural production on the existing agricultural land. A simulation approach using CERES-Rice and CERES-Maize in the Decision Support System for Agrotechnology Transfer (DSSAT) program (Jones et al., 2003) is used for obtaining potential production for rice and maize in three areas of Myanmar: the Delta Region, Shan State, and the Central Dry Zone. The models were also used to determine nitrogen response for rice and maize for the various locations during both the wet and dry season. The findings of the paper highlight the multitude of factors that affect crop production, yield and yield potential, and N management.



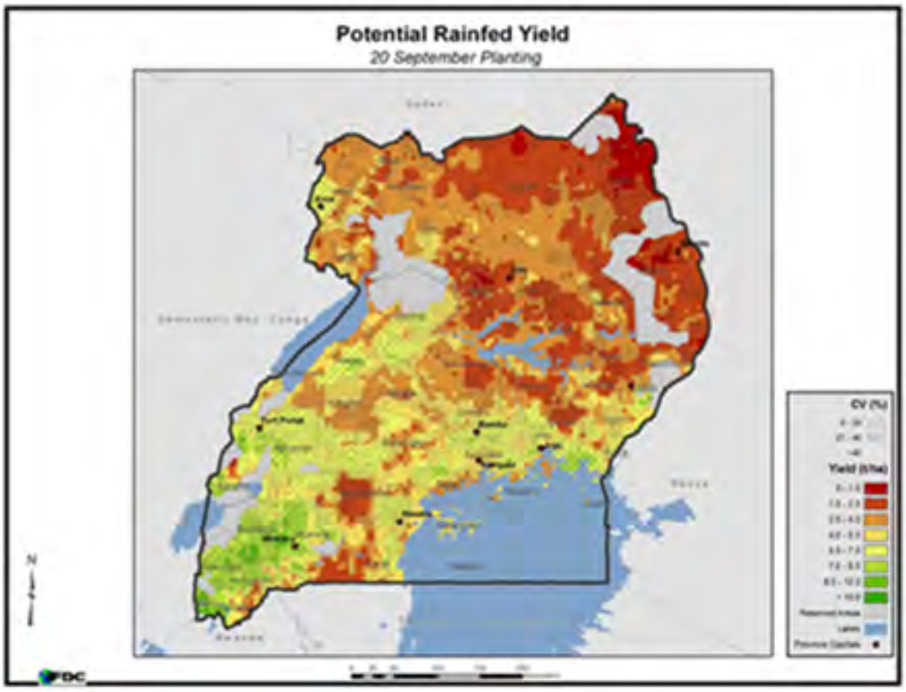


Figure 1. **Effect of planting date on rainfed-limited potential production yield for maize in Uganda.**

Methods

Model and Data Requirements

The potential yield and the yield responses were derived using the CERES-Rice and CERES-Maize models available through the DSSAT program (Tsuji et al., 1994). The crop models require daily weather data for rainfall, maximum and minimum temperature, and solar radiation. The rainfall, maximum temperature, and minimum temperature were obtained from Myanmar Meteorology Department, and the solar radiation was based on NASA Prediction of Worldwide Energy Resources (POWER) data (https://power.larc.nasa.gov/new/). Soils data were based on the Harmonized World Soil Database (HWSD). HWSD is a global soil database established jointly by the International Institute for Applied Soil Analysis (IIASA) and the Food and Agriculture Organization (FAO) of the United Nations in partnership with ISRIC-World Soil Information, the European Soil Bureau Network, and the Institute of Soil Science, Chinese Academy of Sciences.

The following 18 locations, representing the Fertilizer Sector Improvement (FSI) project and Livelihoods and Food Security Trust (LIFT) Fund field sites, were selected: Aungban, Ayeyarwady, Daik U, HeHo, Kalaw, Kungyangon, Kyaiklat, Letpadan, Ma Gyi Gone, Mandalay, Myaungmya, Naypyitaw, Pakokku, Pindaya, Taik Kyi, Thanatpin, Twantay, and Yangon. To capture the effect of weather variation, 18 years of weather data (1997-2015) were used to determine the mean and standard deviation on yield potential and N response.

Wet and Dry Season Simulations

Although in reality maize may not be grown during the wet season in the Delta Region or rice in the Central Dry Zone during the dry season, simulations for both rice and maize were done for all 18 locations during both the wet and dry season planting. The planting dates were 15 June and 15 December for the Delta Region and 30 June and 30 January for the Central Dry Zone and Shan State, respectively, for wet and dry season rice. The corresponding dates for maize were 15 June and 1 November for the Delta Region and 30 June and 21 December for the Central Dry Zone and 1 June and 1 December for Shan State, respectively, for wet and dry seasons. For the N response simulation, urea was applied using the conventional broadcast application method. Genetic coefficients representative of hybrid rice and improved maize varieties were used for both seasons. Although both the CERES-Rice and the CERES-Maize models have been evaluated in similar environments (Jones et al., 2003; Timsina and Humphreys, 2006; Basso et al., 2016), they were used for the first time in Myanmar in this study. Additional treatments highlighting the effects of soil fertility, cultivars, and urea deep placement (UDP) on yield and N response were simulated.

Yield Potentials

Potential production yield is defined as the yield obtained when crop production is not limited by water, nutrients, or any other biological stress (production situation 1 in Figure 2), hence the effects of soil properties, rainfall, and pests and diseases were not simulated. However, the effects of temperature, radiation, planting date, planting density, and variety were simulated. Rainfed potential yield took into account the effect of water limitation as influenced by rainfall and soil properties (water holding capacity, percolation rate, and runoff) as shown in production situation 2 of Figure 2. This will be the equivalent of an experiment conducted under rainfed conditions in which all nutrients were applied and complete care was taken to control pest and disease incidences. The N response simulations captured the effect of weather and soils, including N limitations; however, other nutrients were assumed to be non-limiting.

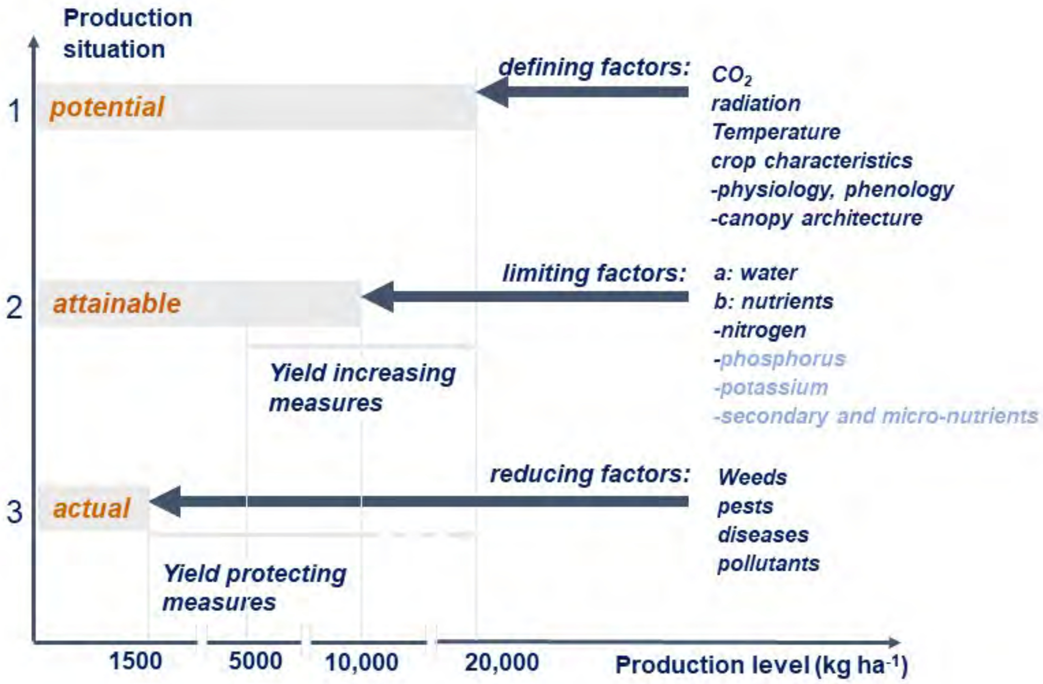


Figure 2. Simulating potential and attainable yield using CERES-Rice and CERES-Maize models.

Results

Yield Potential and Nitrogen Response for Wet Season Rice

The potential yield and the rainfed potential production yield for wet season rice were the same for all locations, indicating that water was not the limiting factor (Figure 5). The average rainfall during the growing season ranged from 845 millimeters (mm) in the Central Dry Zone and Shan Sate to 1,590 mm in the Delta Region. The mean rainfed potential yield ranged from 6.5-7.3 t/ha in the Delta Region (shaded section) to 9.4-10.3 t/ha in the Central Dry Zone and Shan State (Table 1). As evident from the low variance (standard deviation of 0.5 t/ha), the effect of weather variation over the past 18 weather years (1997-2015) was minimal on the rainfed potential production yield.

The response to N fertilizer application was influenced both by the yield potential and the initial N status (Figure 3). The relatively high simulated yields without N application (0 N) compared to average reported yield of rice shows the dependence of yield and fertilizer recommendation on soil properties and the need for reliable soil data. Soil organic matter content was generally high because it were based on soil samples from at least 10 years ago. In the high-yielding environments (Shan State and the Central Dry Zone), N rates of more than 120 kg N/ha was needed to approach the potential yield. In Daik U, a relatively low-yielding environment, additional application of N beyond 100 kg N/ha gave little incremental yield increase to achieve the potential yield. As shown in Figure 3, the agronomic optimal N recommendation varies with locations (soil properties and weather). The average daily solar radiation during the rice wet season ranged from 12.5 megajoules per square meter a day ($MJ/m^2/day$) in Twantay and Kyaiklat to 17.2 $MJ/m^2/day$ in Pakokku and, on average, the solar radiation was 13.1 $MJ/m^2/day$ in the Delta Region compared with 16.5 $MJ/m^2/day$ in the Central Dry Zone and Shan State. This explains the significantly higher yield potential in the Central Dry Zone and Shan State than in the Delta Region.

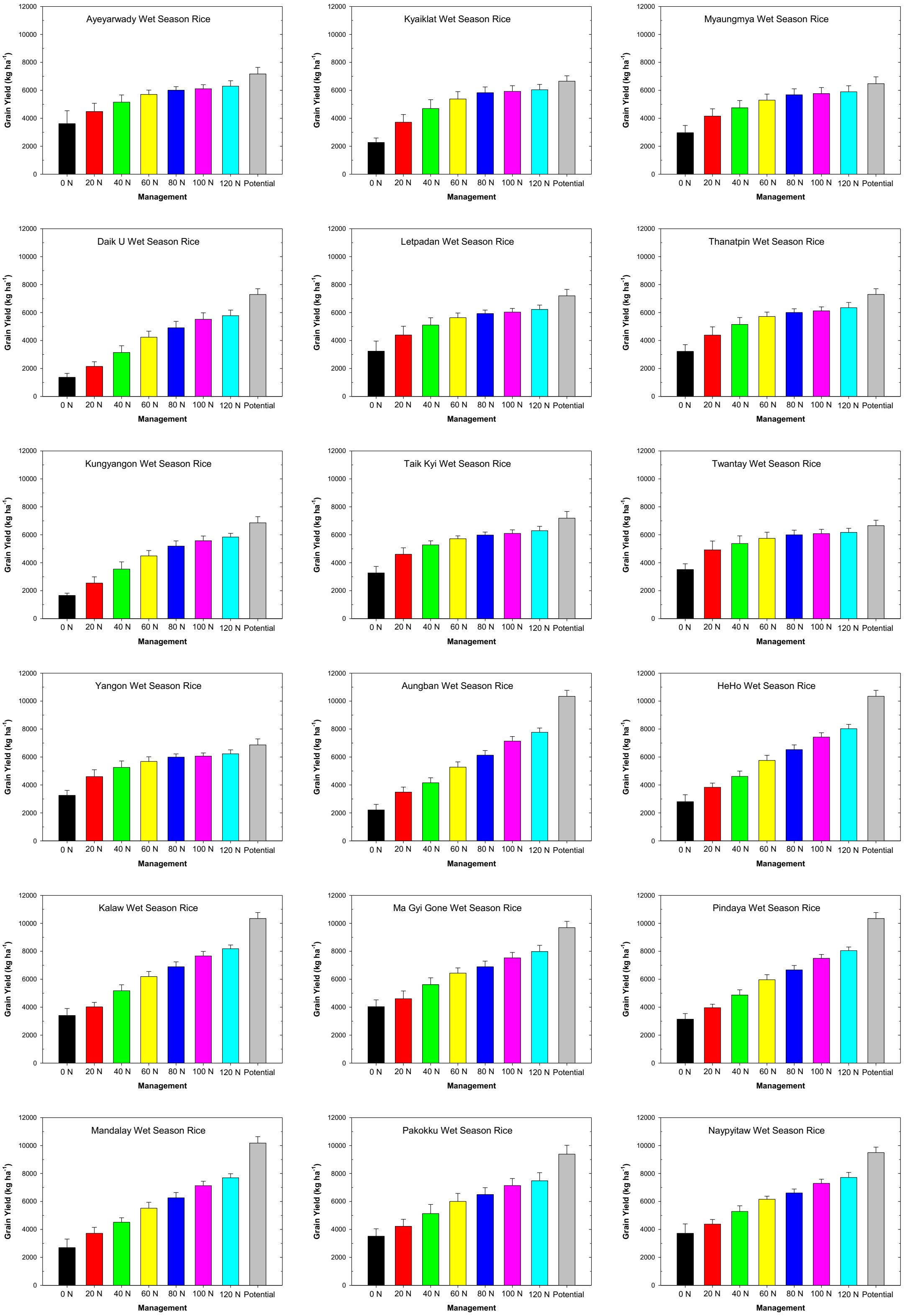


Figure 3. Simulating potential and attainable yield for wet season rice.

Yield Potential and Nitrogen Response for Dry Season Rice

The mean dry season potential production yield for rice ranged from 9.8 to 13.5 t/ha with the average of 11.1 t/ha for the 18 locations (Table 1). The differences in potential yield among the different zones were not as dramatic as in the wet season rice. However, the variation in the potential yield at any given location was much higher compared to the wet season. The same rice variety was used for both seasons. The rainfed potential production yield for dry season rice, on residual soil moisture (no cropping during the wet season) and late rainfall, ranged from 1.5 t/ha to 6.1 t/ha. The simulated yield was higher than expected because drought stress during vegetative stress prolonged the growing season, on average, by 56 days, allowing the rice crop to capture the early monsoon rain (Table 1). However, as evident from ongoing cultural practice, rainfed dry season rice is not practical for most places in Myanmar.

Table 1. Potential yield and duration to anthesis for rice.

	Potential Yield (t/ha)				Duration to Anthesis (days after planting)		
Location	Wet Season-Rainfed		Dry Season-Irrigated		Wet Season	Dry Season	
	Mean	Std Dev	Mean	Std Dev	Rainfed	Irrigated	Rainfed
Ayeyarwady	7.18	0.47	11.21	1.25	64	72	136
Kyaiklat	6.65	0.39	10.58	1.45	63	68	124
Myaungmya	6.48	0.49	11.28	1.27	62	69	115
Daik U	7.29	0.43	10.67	1.14	65	70	123
Letpadan	7.2	0.46	11.21	1.25	64	72	129
Thanatpin	7.3	0.41	10.67	1.14	65	70	128
Kungyangon	6.86	0.44	10.25	0.75	63	66	119
Taik Kyi	7.19	0.48	11.21	1.25	64	72	128
Twantay	6.65	0.39	10.58	1.45	63	68	131
Yangon	6.87	0.43	10.25	0.75	63	66	119
Aungban	10.34	0.43	11.74	0.55	74	74	128
HeHo	10.34	0.43	11.74	0.55	74	74	128
Kalaw	10.34	0.43	11.74	0.55	74	74	126
Ma Gyi Gone	9.69	0.45	9.77	0.92	67	66	129
Pindaya	10.34	0.43	11.74	0.55	74	74	129
Mandalay	10.18	0.46	11.60	0.63	73	74	126
Pakokku	9.39	0.64	9.81	0.92	66	66	129
Naypyitaw	9.49	0.39	13.49	0.74	72	86	138

There was a near-linear increase in rice grain yield with increasing N fertilizer rates of up to 180 kg N/ha at all locations (Figure 4). The N response in the Delta Region during the wet and dry season differed as dictated by the yield potential (Figure 5A and 5B). Such large differences are generally not reported in field trials, perhaps due to inadequate irrigation and other nutrient limitations during the dry season. The rice production in Shan State and the Central Dry Zone are similar between the wet season rainfed rice and the dry season irrigated rice (Figure 5C and 5D).

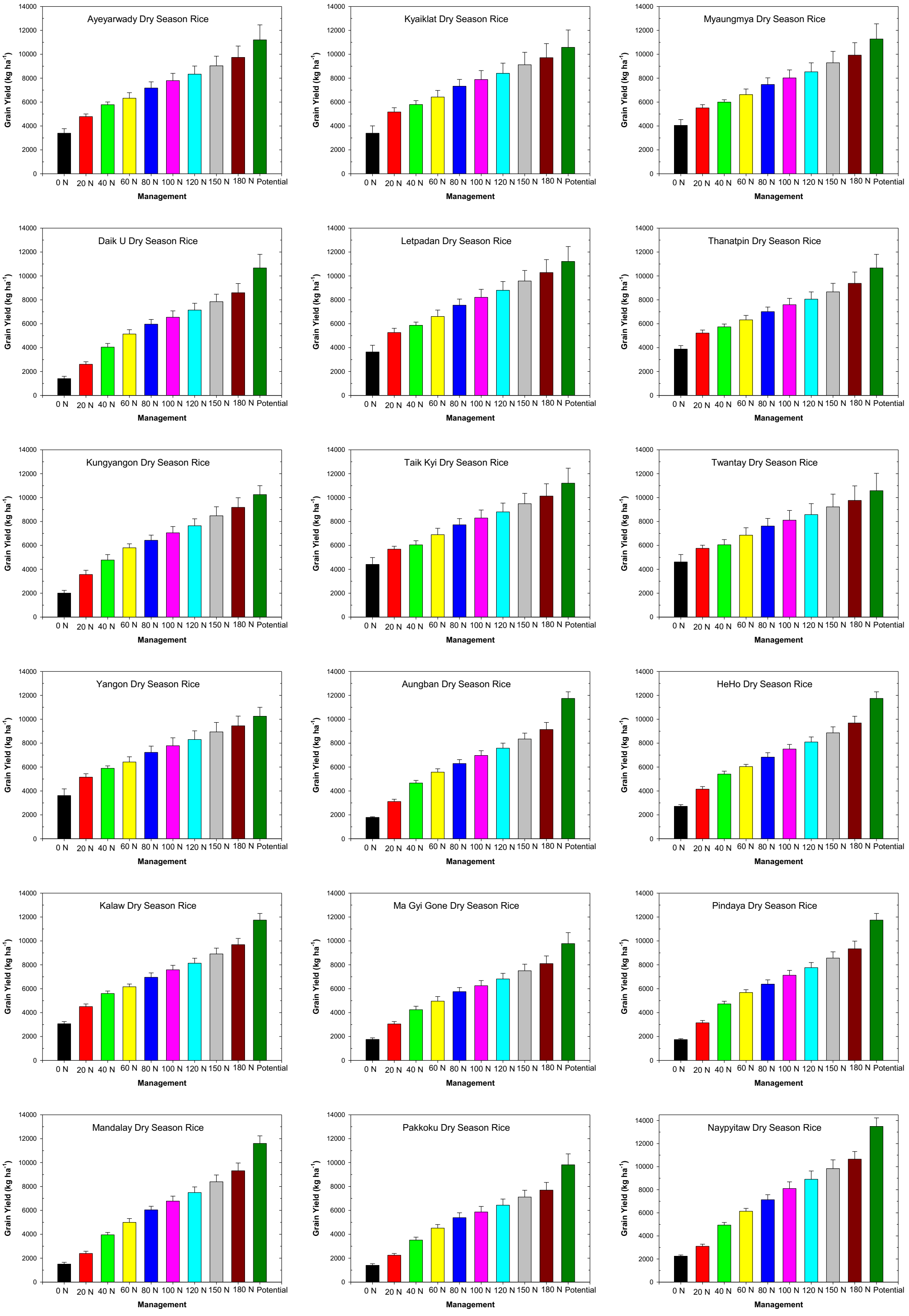


Figure 4. Simulating potential and attainable yield for dry season rice.

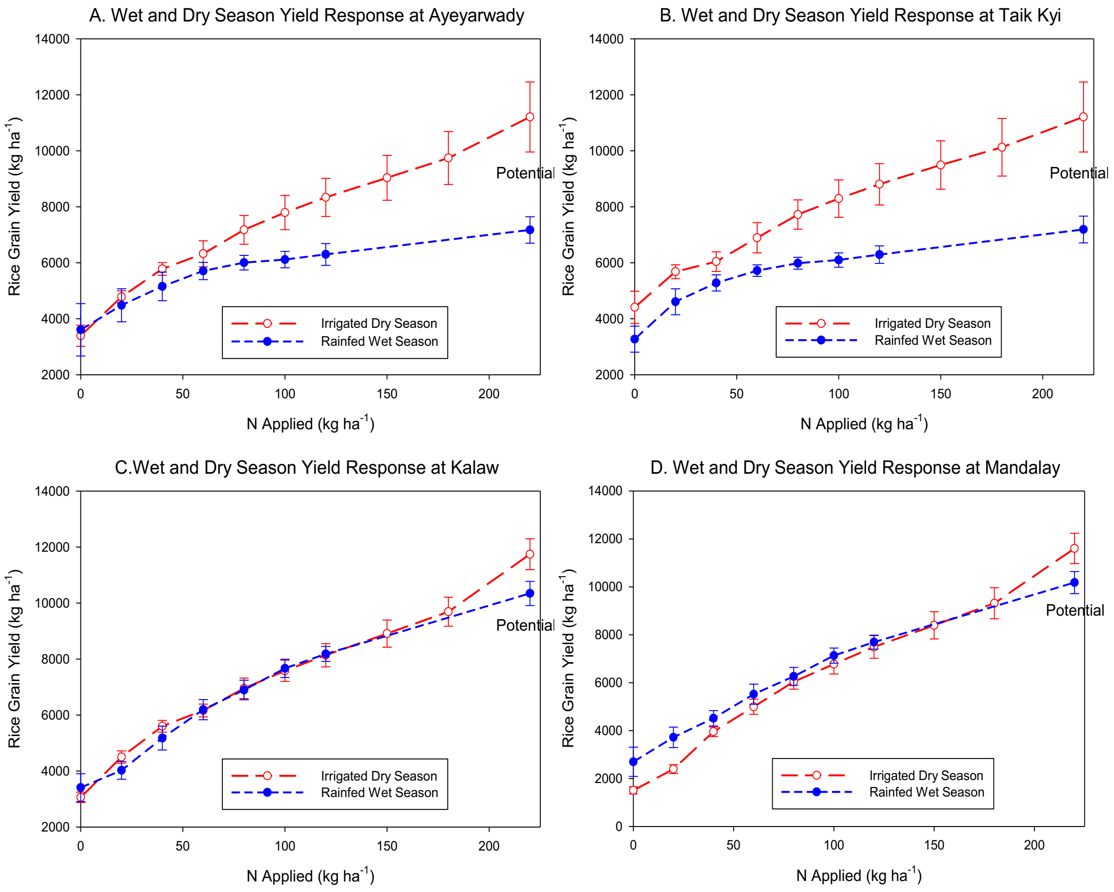


Figure 5. Comparison of N response on wet and dry season rice.

The dry season rainfed rice, even with the extended duration, was risky, with high variations from year-to-year and no response to N application (Figure 6). The irrigated dry season rice, in contrast, was high yielding, low in variance, and highly N responsive across all locations (Figures 4-6). The amount of N fertilizer required to minimize the yield gap to less than 1 t/ha was 180-200 kg N/ha. However, the N rate can be substantially reduced with urea deep placement as evident from Figure 7. In the high-yielding Aungban site, 150 kg N/ha deep-placed gave 17% higher yield compared to broadcast application of 180 kg N/ha. Similar increases in yield with savings of N have been reported in field trials in Myanmar and elsewhere (Myint et al., 2017; Miah et al., 2016). In a simulated N response to achieve a similar yield of 9.4 t/ha for irrigated dry season rice at Yangon, N fertilizer requirements ranged from 180 kg N/ha for broadcast application to 100 kg N/ha for UDP (Figure 7).

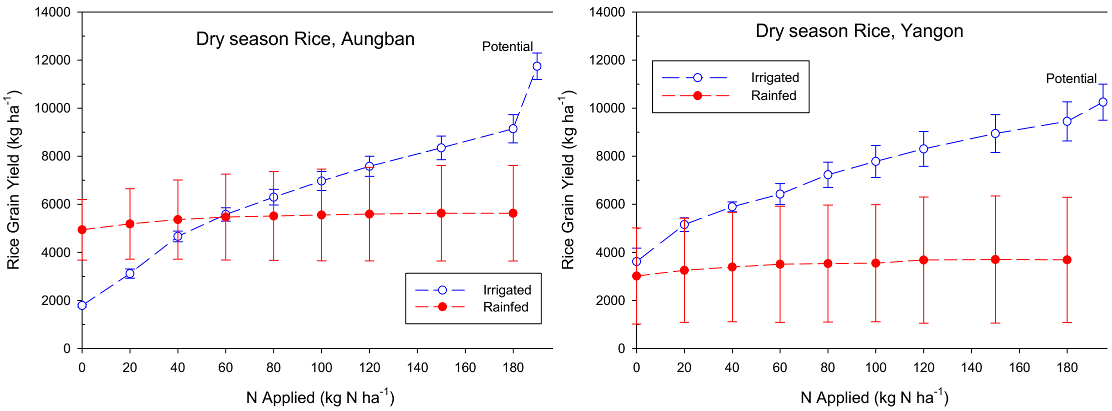


Figure 6. ***Comparison of N response on irrigated and rainfed dry season rice.***

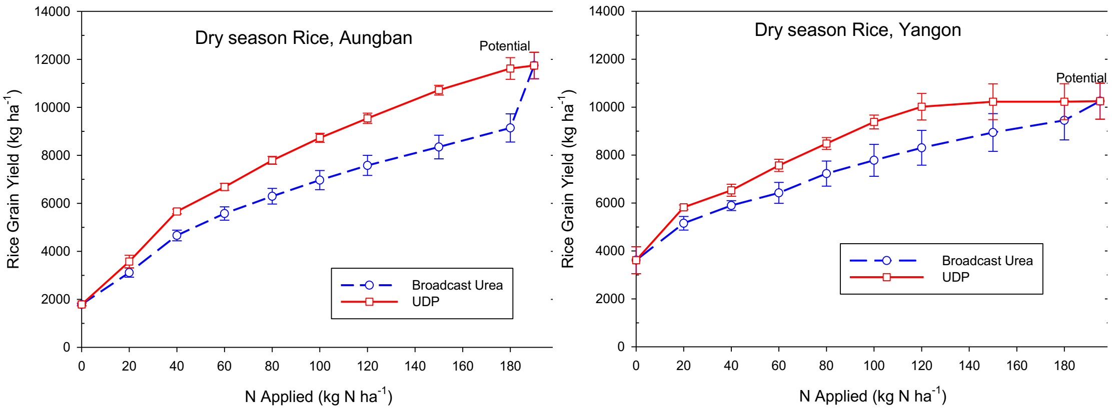


Figure 7. ***Comparison of N response with broadcast urea and UDP.***

Yield Potential and Nitrogen Response for Maize

Simulated rainfed maize potential production during the wet season, as with rice, was lower in the Delta Region with a mean yield of 4.5 t/ha compared to 7.0 t/ha in the Central Dry Zone and Shan State (Table 2). Since the simulated yields do not take into account the effect of pests and diseases, the actual maize yields in the Delta Region would likely be severely depressed during the wet season with high pest and disease incidences. While the CERES-Maize model simulates the effect of flooding and saturated water content on maize crop, it does not simulate the lateral movement of water, a common occurrence during the wet season in the Delta Region. This additional water in the fields would have correctly resulted in the model predicting lower maize yields.

Table 2. Potential yield for maize.

Location	Maize Potential Yield (t/ha)					
	Wet Season-Rainfed		Dry Season-Irrigated		Dry Season-Rainfed	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Ayeyarwady	4.60	0.78	7.64	0.86	1.89	0.77
Kyaiklat	4.14	0.55	7.06	1.19	3.46	1.10
Myaungmya	3.95	0.87	7.42	0.91	4.48	1.35
Daik U	4.86	0.63	7.22	0.91	2.88	0.69
Letpadan	4.61	0.78	7.64	0.86	4.53	0.89
Thanatpin	4.88	0.62	7.22	0.91	4.00	0.74
Kungyangon	4.42	0.54	6.90	0.69	2.74	1.11
Taik Kyi	4.61	0.78	7.64	0.87	4.35	0.89
Twantay	4.14	0.55	7.06	1.19	4.04	1.23
Yangon	4.42	0.54	6.90	0.69	4.97	1.21
Aungban	6.95	0.74	8.64	0.51	0.42	0.55
HeHo	6.95	0.74	8.64	0.51	0.74	0.55
Kalaw	6.95	0.74	8.64	0.51	0.65	0.52
Ma Gyi Gone	7.01	0.87	6.78	0.86	1.50	0.50
Pindaya	6.95	0.74	8.64	0.51	0.63	0.51
Mandalay	7.19	0.48	7.69	0.98	0.70	0.38
Pakokku	6.96	0.52	7.11	1.19	0.78	0.29
Naypyitaw	6.74	0.74	8.76	0.76	3.76	0.78

The dry season irrigated maize potential production was 7.3 t/ha in the Delta Region and 7.9 t/ha in the other locations. On the other hand, simulated yield potential under rainfed conditions for the dry season maize, even with the build-up of residual moisture, was unsustainable in the Central Dry Zone and Shan State with mean yield of 0.8 t/ha and standard deviation of 0.5 t/ha (Table 2). In the Delta Region, the yields ranged from 1.9 to 5.0 t/ha. The soils data with higher organic matter content than reality could have influenced both the soil fertility and water-holding capacity, particularly for deep-rooting crops such as maize, resulting in crop growth and reasonable yield on residual moisture with limited rainfall.

The variation in N response across the locations both during the wet season for rainfed maize (Figure 8) and during the dry season for irrigated maize (Figure 9) highlighted the effect of indigenous N supply (soil property) and yield potential (weather and variety). The yield variation from less than 1.0 to 6.9 t/ha without N application clearly indicates the need for up-to-date and reliable soil data. The seasonal and soil fertility effects on N response and N fertilizer recommendations are presented in Figure 10. Thus, fertilizer recommendations must consider both site and seasonal effects. The choice of maize variety will also influence N response and N recommendations. As simulated results in Figure 11 showed, higher N rates would be more lucrative for hybrid maize with higher yield potential than the improved maize variety used in this study.

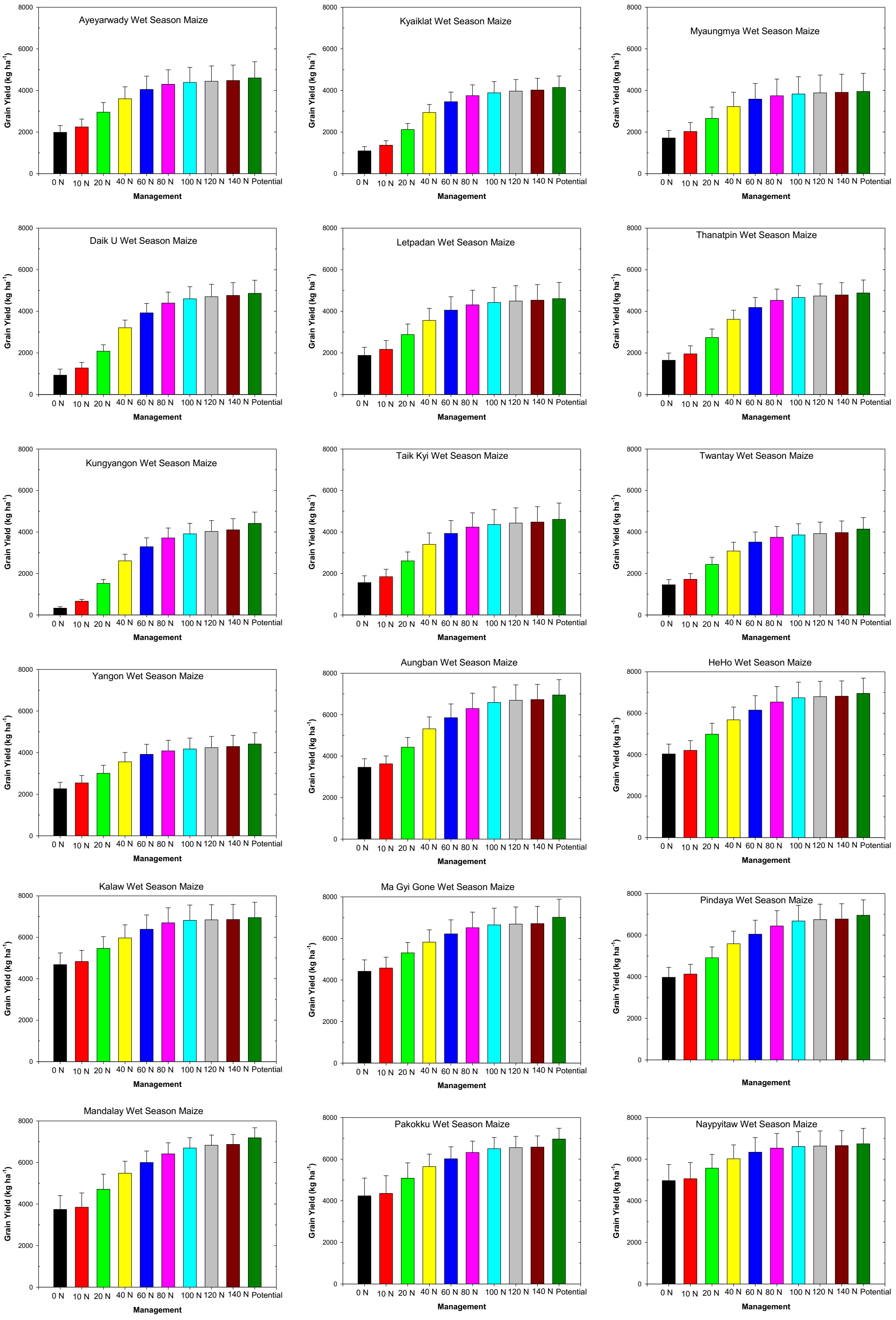


Figure 8. ***Simulating potential and attainable yield for wet season maize.***

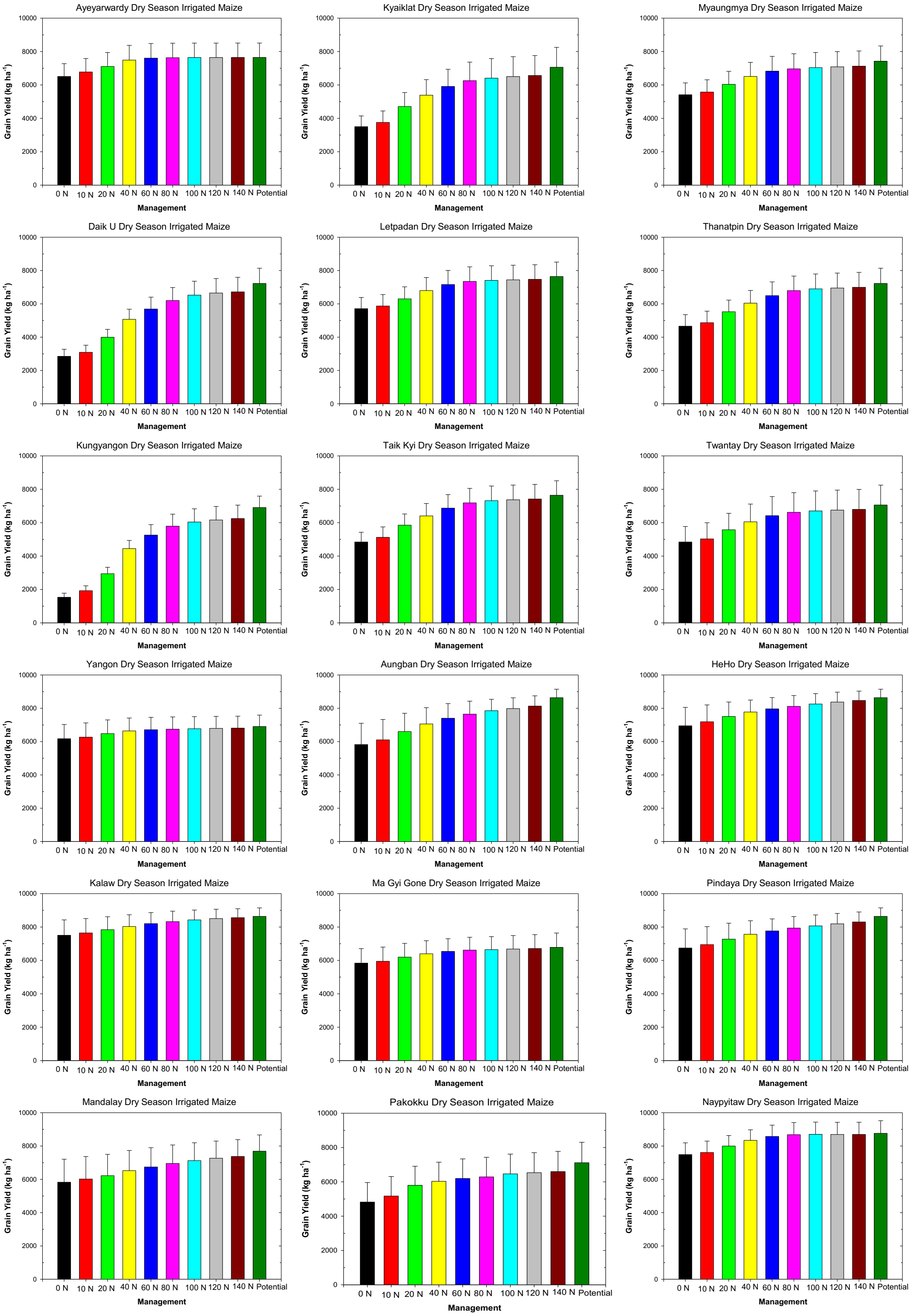


Figure 9. Simulating potential and attainable yield for dry season irrigated maize.

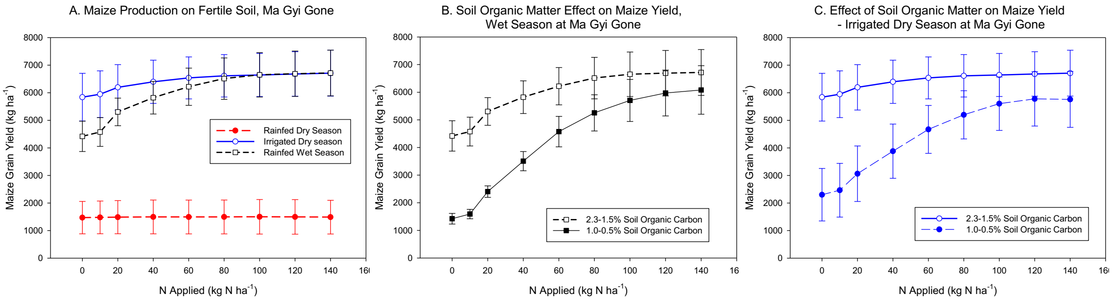


Figure 10. ***Comparing effect of season, irrigation, and soil fertility on maize yield.***

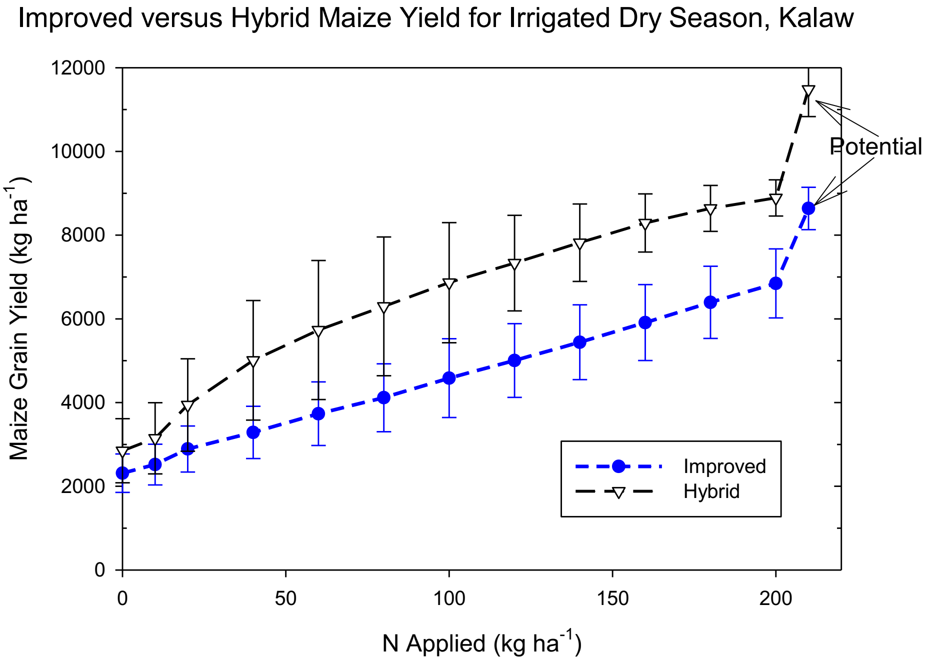


Figure 11. ***Comparing effect of maize variety on N response and yield potential.***

Conclusion

Potential yield determination provides the opportunities and constraints for growing a crop in a given environment. The constraints may be overcome with changes in management such as investment in irrigation or simply identifying appropriate varieties and planting dates. Other conditions may require a more drastic change, such as growing a different crop or switching from annual to perennial crop or even agroforestry. The yield gap between the potential yield and attainable yield and more so between the potential and farmer yield provides opportunities for intensification and identifying likely yield-limiting constraints.

The large differences in yield potential for wet season rainfed rice and irrigated dry season rice in the Delta Region than those reported provide opportunities to identify limiting factors and reduce the yield gap for dry season rice. The differences in maize and rice yield potential due to seasons and locations highlight the importance of weather conditions and planting dates as major potential yield-determining factors. For example, 3.4 MJ/m^2/day higher solar radiation in the Central Dry Zone than that in the Delta Region over 100+ days of active crop growth can significantly increase the yield potential.

The changes in N response function was dictated by both the yield potential and the indigenous N supply. N application as UDP was shown to be more efficient than broadcast application. The importance of soil testing for providing current and reliable soil data for fertilizer recommendations is amply evident. Effective agricultural intensification therefore requires a concerted effort to incorporate site-specific soils and weather data. Decision support tools can improve the efficiency of agricultural research and technology transfer; however, as with any other tools, they need to be evaluated under Myanmar conditions.

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Evaluation of Low-N Tolerant Rice Varieties through the Use of ^{15}N Isotope Dilution Technique

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Abstract

The lowland rice-based cropping system is a major cropping system and fertilizer responsive, high-yielding rice varieties (HYVs) are used by the majority of farmers in Myanmar. Farmers' affordable amount of fertilizers applied to the rice fields never meets the N requirement of rice crops, resulting in low rice yields. The national average yield of rice in the country was 2.84 t/ha in 2015-2016, although the Ministry of Agriculture has set a target of 5 t/ha. Among the HYVs, responsive-efficient varieties with better grain yield efficiency index (GYEI) were screened at the Soil Science Research Section in Department of Agricultural Research (DAR) from 2007 to 2009. As a result of screening during the study, six varieties (MR-230, MR-9, IRAT-191, Innmayebaw, Yaenalo-1, and Shwemanaw) were identified as low-N tolerant rice varieties. In 2014, the Technical Cooperation (TC) project (MYA 5023) between the Soil and Water Management and Crop Nutrition Section of International Atomic Energy Agency (IAEA) and Soil Science Section of DAR was initiated to evaluate the nitrogen use efficiency (NUE) of these varieties using the nitrogen-15 (^{15}N) isotopic dilution method. The experiment was established at Yezin, Nay Pyi Taw, Myanmar, during the 2015 and 2016 wet season (WS). In 2015 WS, MR-9, IRAT-191, Innmayebaw, and Yaenalo-1 were tested. All six varieties, including Yezin Lonethwe and Yadanartoe as check varieties, were evaluated in 2016 WS. Three rates of N fertilizer were N0 (without N fertilizer), N1 (58 kg N/ha as per DAR recommendation), and N2 (116 kg N/ha, which is twice the DAR recommendation). Fertilizer nitrogen use efficiency (FNUE) was calculated after the application of ^{15}N-labeled urea (5.16 atom %) to micro-plots of 8.9 square meter (m^2). The results showed that N application of 58 kg N/ha gave the highest yield and highest FNUE of 17%. Among the tested low-N tolerant rice varieties, Innmayebaw and IRAT-191 in 2015 WS gave the highest grain yield (5 t/ha) and straw yield (6 t/ha). In 2016 WS, Innmayebaw, IRAT-191, MR-230, and check variety Yezin Lonethwe gave the highest grain yield of 5-6 t/ha and straw yield of 5-7 t/ha. The highest FNUE was recorded by Inmayebaw in 2015 WS and in Shwemanaw in 2016 WS. The research outcome suggested to rice farmers in Myanmar that the judicious application of 58 kg N/ha led to 30% fertilizer saving with 20% fertilizer loss to the environment with optimum yield.

Introduction

In Myanmar, the lowland rice-based cropping system is a major cropping system covering a total area of 7.21 million hectares in 2015-2016 (MOALI, 2016a). Land utilization in 2015-2016 was 7.8% as cultivable waste land, 0.7% as fallow land, 17.7% as net sown area, 21.8% as other forest, 27.5% as reserved forest, and 24.6% as other land out of total land utilization (MOALI, 2016b).The varieties used by the majority of farmers are fertilizer-responsive high-yielding varieties (HYVs but farmers' affordable amount of fertilizers applied to the field is not enough to meet the crop requirements, resulting in low recorded rice yields. The national average yield of rice in 2015-2016 was 2.84 t/ha compared to 4 t/ha in Malaysia and Philippines and 6 t/ha in Vietnam (USDA, 2015).

Low yields attributed to low fertilizer inputs account for the yield gap between potential yield of HYVs and actual yield observed in the farmers' fields in Myanmar. Low-N tolerant rice varieties were evaluated from 2007 to 2009 wet and dry seasons at the Soil Science Section in Yezin for their tolerance to low N application using the Grain Yield Efficiency Index (GYEI>1) and the responsive-efficient rice varieties based on internal efficiency of nitrogen (Su Su Win et al., 2015).

As nitrogen is the most limiting nutrient in rice production, nitrogen use efficiency (NUE) of rice plays a key role especially under low soil N conditions. The varieties with better NUE are much appreciated to maximize crop N uptake with optimum yield and to reduce N losses to the environment.

Before releasing these low-N tolerant rice varieties to the farmers' fields, it is vital to validate their NUE using the nitrogen-15 (^{15}N) isotope dilution method.

The use of the ^{15}N tracer technique is essential because it is not only the most powerful technique to distinguish N uptake of the rice from added fertilizer and the indigenous soil N supply but it is also environmentally friendly being a stable isotope. After validating their NUE, those varieties will be grown through farmers' participatory appraisal to show the effectiveness of using these varieties in resource-scarce environments. Furthermore, getting acceptable yield under resource-scarce environments with farmers' affordable N supply through using low-N tolerant rice varieties with no fertilizer or a very low fertilizer rate will also mitigate the emission of greenhouse gases from the rice fields.

Materials and Methods

Rice Varieties

Low-N tolerant rice varieties were screened at Soil Science Research Section (SSRS) in the Department of Agricultural Research (DAR) from 2007 to 2012. Among the 106 rice varieties tested, six varieties, Yaeanaelo-1 (Yezinyar 9), IRAT-191, Inmayebaw, Shwemanaw, MR 230 (Malaytun), and MR-9, were selected as low-N tolerant rice varieties (DAR, 2012 and Su Su Win et al., 2015). These rice varieties were evaluated for their nitrogen use efficiency using the ^{15}N isotope dilution method.

Experimental Site

The experimental plot was established at C0 Block in 2015 wet season (WS) and at F2 Block in 2016 WS in the research field of SSRS, DAR (19.8°N, 96.1° E, 112 alt.). Wet season in DAR is from May to October. Annual rainfall in 2015 was 827 mm and 1,359 mm in 2016. During the wet season, mean maximum temperature was 34°C and minimum temperature was 24°C. The weather data were recorded from a weather station located within 800 m of the experimental site.

Soil samples were collected before sowing and after harvest and analyzed at the Soil and Plant Analysis Laboratory (SPAL) in DAR. Composite soil samples were taken from 0-20 cm depth and analyzed for pH (H_2O) by total N (Kjeldahl's method), available N (potassium permanganate method), available P (Olsen’s method), available K (1N ammonium acetate extraction), soil textural class (mechanical analysis), and soil organic matter (SOM, Tyurin’s method, Rayment and Lyons, 2011; Kononova, 1966).

The soil in C0 Block was sandy loam (68% sand, 17% silt, and 15% clay) and slightly acidic (pH 6.2). Total N content was 0.18% and SOM was low (1.2%). Available N, P, and K were medium (69 mg/kg, 19 mg/kg, and 150 mg/kg, respectively). According to the initial soil analysis data of F2 Block, soil could be categorized as sandy loam (77% sand, 5% silt, and 18% clay) and slightly acidic (pH 6.1). Total N content was 0.23% and SOM was medium (2.9%). Available K was rated as low (91 mg/kg), and available N and P were classified as medium (78 mg/kg and 20 mg/kg, respectively).

Experimental Design

The experiment was set up in split plot design with three replications. Each main plot received three levels of urea fertilizer (46% N) as a source of N fertilizer. Three rates of nitrogen fertilizer, 0 kg N/ha (N0), 58 kg N/ha (N1), and 116 kg N/ha (N2), were applied. MR-9, IRAT-191, Innmayebaw, and Yaenalo-1 were randomized into a subplot in 2015 WS. For the 2016 WS, six low-N tolerant rice varieties (MR-9, IRAT-191, Innmayebaw, Yaenalo-1, MR-230, and Shwemanaw) and two check varieties (Yezin Lonethwe and Yadanartoe) were randomly assigned to the subplots.

A micro-plot size of 8.9 m^2 was demarcated in each experimental unit assigned as the main plot with different levels of nitrogen fertilizer. ^{15}N-labeled urea (5.16 atom % enrichment) was applied as a source of labeled N fertilizer where all the tested low-N tolerant rice varieties were transplanted. The micro-plot received ^{15}N-labeled urea fertilizer as much as an equivalent amount of unlabeled urea fertilizer applied outside the micro-plots.

Fertilizer and Crop Management

Split application of urea at 30 days after seeding (DAS), 50 DAS, and 65 DAS was practiced. All plots received 12 kg P/ha, 31 kg K/ha, and 8 kg S/ha. Triple superphosphate and gypsum were added at basal and muriate of potash was applied at 30 DAS and 50 DAS. Basal fertilizer application (without N) was applied after land preparation and 20-day-old seedlings were transplanted at 20 cm between rows and 15 cm inter-hill spacing.

Plant samples were taken at 65 DAS and grain and straw samples were taken at harvest. At two rows on each side of the experimental unit, one hill at the middle of each row on all four sides of a plot was selected as the plant sample for the determination of dry matter yield (DMY) and N uptake. Four hills (two hills x two hills) at the corner of the sampling area were selected for yield component data at physiological maturity. At harvest, 14% moisture adjusted grain yield was measured from the inner harvested area of each plot. Plant samples were dried at 70°C for 72 hours. ^{15}N-labeled samples were analyzed using the isotope ratio mass spectrometry at the Agrotechnology and Biosciences Division of the Malaysian Nuclear Agency in 2015 and at the Soil and Water Management and Crop Nutrition Laboratory of the Joint FAO/IAEA Division of Nuclear Techniques in Seibersdorf, Austria, in 2016.

Calculation and Data Analysis

Nitrogen derived from unlabeled soil (Ndfs) and nitrogen from ^{15}N-labeled fertilizer (Ndff) were two sources from which rice crops derived their N by the following expression:

Ndff + Ndfs = N crop [or] % Ndff + % Ndfs = 100

Percentage of Ndff was calculated using the following equation:

$$\%\text{Ndff} = \frac{\text{atom \% } ^{15}\text{N excess}_{\text{Crop}}}{\text{atom \% } ^{15}\text{N excess}_{\text{fertilizer}}} \times 100$$

The amount of N in the crop derived from fertilizer was calculated as follows:

$$\text{Amount of N in crop derived from fertilizer} = \frac{\%\text{ Ndff}}{100} \times \text{Total N in crop}$$

Then, fertilizer use efficiency was calculated as:

$$\text{Fertilizer Use Efficiency (FUE)} = \frac{\text{Amount of N in crop derived from fertilizer}}{\text{Amount of N added as fertilizer}} \times 100$$

Remarks: The atom % of ^{15}N excess was calculated as the difference between the ^{15}N atom % and fixed value of natural abundance (0.366%). The total N concentration in tissue was multiplied by the dry matter yield to obtain and monitor nitrogen uptake (Adu-Gyamfi, October 2015).

Data from each year were analyzed separately. Analysis of variance was performed by CropStat Version 7.2.2007.2, and treatment means were compared using Fisher's protected Least Significant Difference (LSD) test at the 5% probability level. Where varieties x fertilizer interactions were observed as significant, LSDs were calculated separately.

Results and Discussion

There was an interaction between low-N tolerant rice varieties and N levels as expected except for the dry matter yield at the first sampling. The mean yield of different low-N tolerant rice varieties at different levels of N is shown in Table 1. The highest grain yield of the low-N varieties was recorded by the Innmayebaw variety followed by IRAT-191 in 2015 WS and MR-230 in 2016 WS. Although an occurrence of lodging was noted due to the heavy rainfall at harvested time in 2016 WS, the increased grain yield was realized with increasing rate of N fertilizer in 2016 WS; however, the highest grain yield was recorded at N1 level (58 kg N/ha) in 2015 WS. On average, the highest grain yield was observed in 2016 WS compared to 2015 WS for Yaenalo-1, MR-9, IRAT-191, and Innmayebaw. It was observed that the initial soil N at F2 block enhanced the rice grain yield in 2016 WS even with the extreme weather conditions (Table 1).

In 2015 WS, further increases in N fertilizer did not affect the rice grain yield. Irrespective of the seasons, the highest average grain yield was observed in N1 with 58 kg N/ha (Figure 1). The grain yield that responded to the N1 application was IRAT-191 (5,744.9 kg/ha) and Innmayebaw rice varieties (5,820.5 kg/ha). In 2016 WS, the yield trend significantly increased with increasing rate of N fertilizer, except for MR-9, Yaenalo-1, and Shwemanaw rice varieties. Among the tested low-N tolerant rice varieties, including two check varieties, Innmayebaw produced the highest grain yield (6,454.7 kg/ha) in 2016 WS, and the same trend was observed in 2015 WS (Table 1 and Figure 1). It could be concluded that Innmayebaw was more locally adapted than the other rice varieties in Yezin.

The percentage of FNUE of different rice varieties for 2015 WS and 2016 WS is presented in Figure 2. It can be clearly seen that % FNUE in 2015 WS was higher than that in 2016 WS with the same rice varieties. This could be due to loss of nitrogen through leaching from added fertilizer under sandy loam soil with unpredicted rainfall in 2016 WS. Generally, the % FNUE was low because of the high indigenous nitrogen in the soil, as indicated from the results of N derived from soil (Ndfs) rather than from fertilizer (Ndff). Nevertheless, FNUE was highest in Innmayebaw (17%) followed by MR-9 (13%), and IRAT-191 (10.4%); the lowest was in Yaenaelo-1 (9.4%). Although the highest FNUE was found with check varieties in 2016 WS, Shwemanaw gave higher FNUE (7.3%) than the other varieties; subsequently, MR 9 and MR 230 gave the second highest FNUE (6.6%), followed by Innmayebaw (6.5%) in 2016 WS (Figure 2). Yaenaelo-1 recorded the lowest FNUE (6.1%), and IRAT-191 FNUE was 6.3%. Pham Quang Ha and Vu Dinh Tuan (2004) reported that the % FNUE of BaoThai Lin rice variety in Vietnam ranged from 11.3% to 46.5% based on the nitrogen fertilizer application rate of 89 kg N/ha to 160 kg N/ha in summer rice. The authors explained that % Ndff was affected by inorganic fertilizer applied during the rice-growing summer and spring seasons in Vietnam.

Table 1. ***Results of the ANOVA for the effect of different levels of nitrogen fertilizer on the yield of low-N tolerant varieties in 2015 WS and 2016 WS conducted at Yezin, Myanmar.***

Variety	Level of N	Dry Matter Yield of 1st Sampling kg/ha		Straw Yield kg/ha at Harvest		Grain Yield kg/ha at Harvest	
		2015 WS	2016 WS	2015 WS	2016 WS	2015 WS	2016 WS
Yaenalo-1	N0	1779.6	430.5	3988.7	4479.8	4670.8	4468.5
Yaenalo-1	N1	1766.9	1210.9	3562.3	5452.7	3404.8	4716.4
Yaenalo-1	N2	1182.9	1036.0	4393.4	5102.7	5214.0	4946.9
MR-9	N0	1677.8	786.1	5536.6	3472.6	4009.2	2897.6
MR-9	N1	2406.4	1937.5	4237.3	5782.8	4114.0	5343.8
MR-9	N2	2531.9	1369.7	3814.2	6181.1	3840.0	5195.1
IRAT-191	N0	1632.4	1119.4	3168.9	4935.8	4060.5	4519.2
IRAT-191	N1	1531.4	850.3	4249.6	5195.7	5744.9	5286.3
IRAT-191	N2	1271.8	1410.0	6531.5	5876.5	4711.5	6158.2
Innmayebaw	N0	3320.4	1323.9	5932.2	5762.3	5173.1	6028.7
Innmayebaw	N1	5836.5	1539.2	5295.8	7479.6	5820.5	6698.5
Innmayebaw	N2	4116.7	2214.6	6941.8	6925.8	4901.7	6636.8
MR-230	N0	-	1358.9	-	5985.2	-	5031.7
MR-230	N1	-	1563.4	-	5350.4	-	5630.9
MR-230	N2	-	2330.3	-	7733.8	-	5463.3
Shwemanaw	N0	-	1504.2	-	5542.3	-	4441.9
Shwemanaw	N1	-	917.6	-	4826.6	-	4364.2
Shwemanaw	N2	-	1945.5	-	4642.6	-	4388.5
Yezinlonethwe	N0	-	1773.3	-	5209.4	-	4381.7
Yezinlonethwe	N1	-	2335.7	-	5272.8	-	5259.5
Yezinlonethwe	N2	-	1471.9	-	5571.6	-	6170.5
Yadanartoe	N0	-	1644.2	-	4922.3	-	3488.6
Yadanartoe	N1	-	834.2	-	5914.6	-	4245.6
Yadanartoe	N2	-	842.3	-	6332.0	-	5652.4
Mean effect_Variety							
Yaenalo-1		1576.4	892.5	3981.5	5011.7	4429.8	4710.6
MR-9		2205.4	1363.4	4529.3	5145.5	3987.7	4478.9
IRAT-191		1478.5	1126.6	4650.0	5336.0	4839.0	5321.2
Innmayebaw		4424.5	1692.6	6056.6	6692.5	5298.5	6454.7
MR-230		-	1750.9	-	6356.5	-	5375.3
Shwemanaw		-	1455.8	-	5003.9	-	4398.2
Yezinlonethwe		-	1860.3	-	5351.3	-	5303.9
Yadanartoe		-	1106.9	-	5722.9	-	4462.2
Mean effect_N application							
No		2102.5	1242.2	4656.6	5027.5	4478.4	4407.2
N1		2885.3	1398.6	4336.3	5659.4	4771.0	5193.2
N2		2275.8	1577.6	5420.2	6045.7	4666.8	5539.0
N levels (N)		*0.176*	*0.321*	*0.03*	*0.028*	*0.655*	*0.005*
Varieties (V)		*<0.001*	*<0.001*	*0.01*	*<0.001*	*0.004*	*<0.001*
N × V		*0.655*	*0.001*	*0.004*	*<0.001*	*0.010*	*<0.001*
LSD$_{0.05}$ (N × V)		***1309.3***	***730.2***	***1934.9***	***867.4***	***1133.9***	***659.1***
CV%		*31.5*	*31.5*	*23.5*	*9.4*	*14.2*	*7.9*

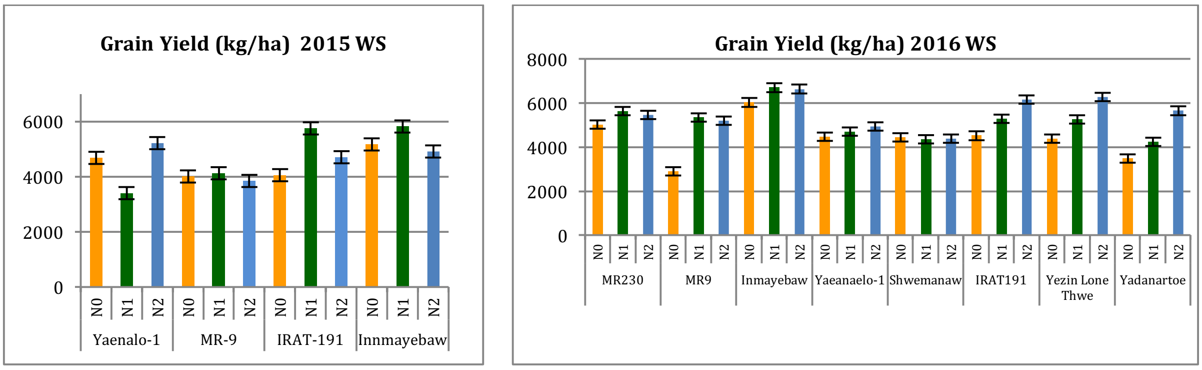

Figure 1. ***Rice grain yield kg/ha of low-N tolerant rice varieties at three different levels of N fertilizer observed in 2015 WS and 2016 WS at Yezin in Myanmar.***

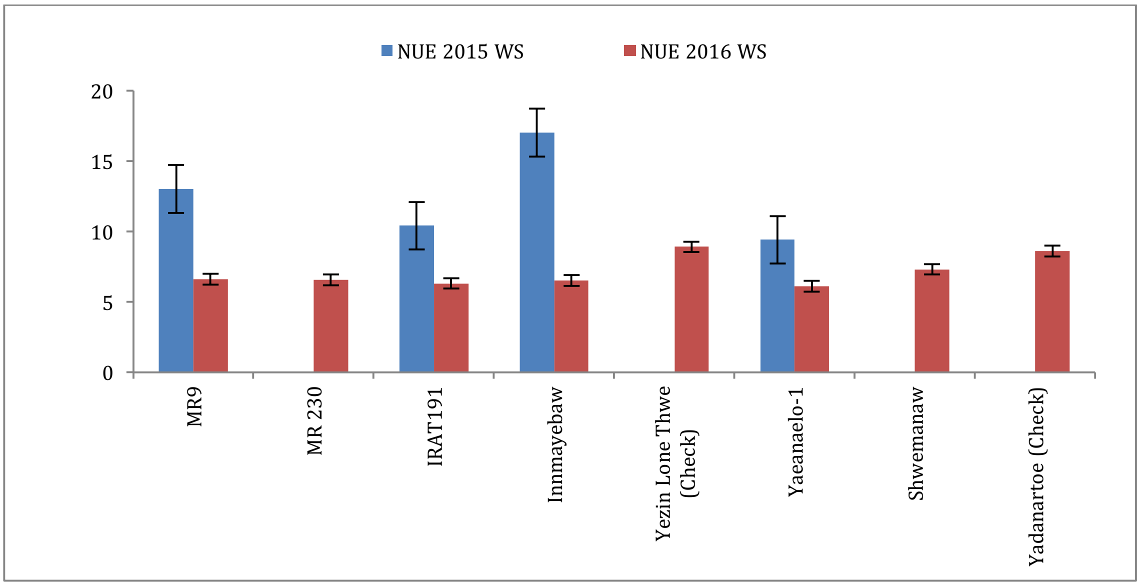

Figure 2. ***Fertilizer nitrogen use efficiency (% FNUE) of low-N tolerant rice varieties tested in 2015 WS and 2016 WS at Yezin in Myanmar.***

Conclusion

The application of N fertilizer above 58 kg N/ha did not result in a significant yield increase of low N-tolerant rice varieties. Our results suggest that the judicious application of 58 kg N/ha by rice farmers in Myanmar would optimize rice yield with 30% fertilizer saving and 20% fertilizer loss to the environment.

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Photo 1. Implementation of the experiment "MYA/5023: Evaluating Nitrogen Use Efficiency Using Low-N Tolerant Rice Varieties" at Soil Science Research Section in DAR, Myanmar during 2015 WS and 2016 WS.

Comparison of Yield Response and Nutrient Use Efficiency between Urea Deep Placement Technology and Farmers' Practice of Surface Broadcasting Urea on Transplanted Lowland Rice in Myanmar

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Abstract

Urea deep placement (UDP) adaptation trials in randomized complete block design with four treatments and three replications were conducted in two wet seasons (2014 and 2015) and two dry seasons (2105 and 2016) at selected sites in the Delta Region of Myanmar to study yield comparison and nutrient use efficiency between UDP and surface broadcasting urea on transplanted lowland rice. The four treatments were: (1) control (0 N), (2) farmers' practice of urea application with farmers' rate (FP), (3) urea broadcasting (UB) with the same rate as UDP, and (4) UDP. A Generalized Linear Mixed Model was used to analyze variances among treatments, locations, and interaction of location by treatment for each year/season. Yield superiority of UDP over other treatments and nutrient use efficiency (NUE) for each urea applied treatment were calculated. Significant differences at $P_{(0.01)}$ were observed among treatments and locations in every year/season. Significant differences of interaction of treatments by locations at $P_{(0.05)}$ were found in wet season trials only. UDP gave the highest yield at all times. It was significantly higher than FP treatment and often higher than UB treatment. Yield superiority of UDP over UB and FP was 16-18% in the wet season and 24-28% in the dry season. Nutrient use efficiency with UDP was double the NUE with other N-applied treatments. UDP produced 30 kg of rice grain for every kg of N applied while other treatments produced 14-17 kg of rice grain per kg of N applied. UDP is therefore the more effective technology to apply N fertilizer on transplanted lowland rice, and dry season results indicated that yield with UDP could be expected more with best management practices under favorable water conditions and proper water management.

Key Words

Transplanted lowland rice, urea deep placement, nutrient use efficiency, yield superiority

Introduction

Urea is widely used as a source of a nitrogen fertilizer in lowland rice cultivation around the world. In Asia, where rice is mainly grown under lowland conditions, most farmers are surface broadcasting to apply urea in rice fields with more or less standing water. Surface broadcasting urea onto lowland rice fields with standing water is a very wasteful practice (Dong et al., 2012). To reduce nitrogen losses, farmers need to apply urea two to three times during the growing season. The crop gets only onethird of the applied urea, and two-thirds is lost through various ways, such as ammonia volatilization, surface runoff, leaching, and denitrification processes (Dong et al., 2012; Watanabe et al., 2009; Zhao et al., 2009). In addition to nutrient losses, this practice can also harm the environment by contamination of river/stream water through runoff and emission of nitrogenous oxides into the atmosphere through nitrification-denitrification.

Urea deep placement (UDP) is a proven climate-smart technology, which involves point placement of urea briquettes of 1.8 g or 2.7 g at 7-10 cm depth below the soil surface where no oxygen is present and close to the root zone of the crop (IFDC, 2017). By a process of hydrolysis, the nitrogen in urea transforms to ammonium cations (NH_4^+). The N remains as ammonium in the soil because no nitrification process takes place due to lack of oxygen in the anaerobic zone. Plants can gradually absorb readily available ammonium nitrogen from the soil. Single application of UDP is enough for a rice crop of early to medium-maturing varieties. With this technology, plants can better utilize the nitrogen applied and produce more yield with less impact on the environment (Kapoor et al., 2008; Gaihre et al., 2015, 2016).

Therefore, it can be said that Myanmar rice farmers are wasting urea by practicing surface broadcasting. Compared to other Asian countries, such as Bangladesh, Indonesia, and Malaysia, the amount of fertilizer used in Myanmar rice cultivation is low (FAO, 2015). Less urea is applied in the wet season in the Delta Region, when water levels are deep, than in the dry season. More urea is applied in the dry season rice crop, and higher yields can be obtained than in wet season rice. However, the amount and type of fertilizer used vary among farmers. Urea fertilizer is a very common fertilizer applied by most rice farmers due to its visible response (IFDC, 2016). All is broadcast onto the soil surface. UDP technology can increase rice yield with less urea applied. Coupled with a balanced application of phosphorus, potassium, and secondary and micronutrients as required by soil, UDP would be the best practice for rice growing in Myanmar. This paper presents the results of UDP adaptation trials in farmer fields that measure yield and nitrogen use efficiency of UDP technology when compared with farmers' practice of broadcasting urea.

Materials and Methods

On-farm UDP adaptation trials were conducted at selected locations in four continuous seasons, two wet seasons and two dry seasons starting from the wet season of 2014 and ending after the dry season of 2016. Trial locations were from Yangon, Bago, and Ayeyarwady regions, where rice is the main crop. The trial sites in farmer fields and villages changed from season to season. There were three trials in each wet season and four trials in each dry season. Trial locations, villages, townships, and regions for each year and season are given in Table 1. The farmers' preferred variety was used in each trial. These were mostly high-yielding medium-maturing varieties in the wet season and early maturing varieties in the dry season. Varieties included Sin

Thu Kha, Manaw Thu Kha 2, Thee Dat Yin, Shwe Pyi Htay, and Yadanar Toe as improved varieties. Hybrid rice varieties, Pale Thwe and GW 1, were also used for some trials. See Table 1.

Table 1. Locations, test varieties, and farmers' practice N rates for each year and season.

Year/ Season	Village	Township	Variety	N Rate with FP (kg/ha)	Basal in FP
2014 WS	Sat Ka Lay	Htandabin	Sin Thu Kha	57	No
	Sar Ma Lauk	Nyaungdon	Pale Thwe hybrid	57	No
	Ohn Hnae Gone	Hlegu	Manaw Thu Kha 2	28	No
2015 DS	Ein Lay Lone	Htandabin	Shwe Pyi Htay	57	Compound
	Nga Pa	Thanlyin	Thee Dat Yin	114	Compound
	Ohn Hnae Gone	Hlegu	Pale Thwe hybrid	57	Compound
	U To	Taikkyi	Yadanar Toe	114	Compound
2015 WS	Too Chaung	Nyaungdon	Sin Thu Kha	57	No
	Wagon Gayet	Maubin	Sin Thu Kha	28	No
	Gyoe Phyu	Taikkyi	GW 1 hybrid	57	No
2016 DS	Ein Gyi	Twantay	Thee Dat Yin	57	TSP only
	Inglone	Kunchangone	Thee Dat Yin	85	TSP + MOP
	Pyin Ma Lwin	Daik-U	Thai Manaw	57	TSP only
	Zay Bine	Thanatpin	Sin Thu Kha	85	TSP + MOP

Four fertilizer treatments, namely Zero N (control), farmers' practice of fertilizer application (FP), urea surface broadcasting practice (UB), and UDP were tested in a randomized complete block design with three replications. For the UDP treatment, the size of the urea briquette was 1.8 g in the wet season trials and 2.7 g in the dry season trials. One briquette was deep-placed one time only at the center of four alternate rice hills with a spacing of 20 cm x 20 cm, seven days after transplanting. This produced a nitrogen rate of 52 kg N/ha in the wet season and 78 kg N/ha in the dry season. To get precise place and depth of application, UDP was applied by hand. With the UB treatment, the same N rate as UDP was applied. But it was applied as three split doses in equal amounts. The first application was at the same time as UDP, the second application was at the panicle initiation stage, and the last application was just before flowering. In the FP treatment, N rates varied from one farmer to another, year to year, and season to season. Normally, the N rate was lower in the wet season and higher in the dry season. N rates of FP ranged from 28 kg N/ha to 57 kg N/ha in the wet season and 57 kg N/ha to 114 kg N/ha in the dry season. It was also applied in three split applications as for the UB treatment for all N rates except the lowest N rate. With the lowest N rate (28 kg N/ha), it was applied as two split applications in equal amount. With the lowest N rate, no nitrogen was applied at the flowering stage.

A basal fertilizer of triple super phosphate (TSP) 80 kg/ha (36 kg P_2O_5/ha), muriate of potash (MOP) 40 kg/ha (24 kg K_2O/ha), and gypsum 25 kg/ha (4.5 kg S/ha) were applied on all treatments except the FP treatment. Basal fertilizer application for the FP treatment differed from season to season. No basal fertilizer was applied on the FP treatment in the wet season trials. In the dry season of 2015, compound fertilizer with a nutrient ratio of 15:15:15 ($N:P_2O_5:K_2O$) was applied at the rate of 25 kg/acre (or 61.8 kg/ha). In the dry season of 2016, TSP 25 kg/acre, or 61.8 kg/ha, was applied on all trials. And MOP 12.5 kg/acre, or 31 kg/ha, was applied on the trials with higher FP N rates (Table 1).

Raising the nursery, management, and field land preparation was done by farmers. Plots were pegged one day before transplanting. Each experimental plot with a size of 24 feet x 28 feet was separated by bunds about 12 inches high and 12 inches wide. Basal fertilizer was applied to each plot after bunding and incorporated with soil, and the plot was re-leveled. Transplanting was done the following day using 25-day-old seedlings at two to three per hill. Crop management, such as weed, pest, and water management, was carried out by the farmers.

At maturity, a crop cut was taken from 100 square feet (10 feet x 10 feet) inside each plot, leaving at least six border rows. Moisture content (%) was measured at harvest. Crop cut wet yield was recorded as kilograms. Paddy yield (t/ha) was adjusted to 14% moisture content using the formula:

$$\text{Yield (t/ha)} = \frac{\text{Crop cut yield (kg)} \times (100 - \text{MC\%}) \times 43{,}560 \times 2.471}{1{,}000 \times 100 \times 86}$$

Where:

Crop cut yield = actual grain weight (kg) from crop cut area at harvest
MC% = Moisture content (%) at harvest
43,560 = square feet of 1 acre
2.471 = Conversion from acre to hectare
1,000 = Conversion from kg to ton
100 = Crop cut area (sq. ft.)
86 = Adjustment of moisture content to 14%

Analysis of variance was conducted by each year/season. Within each of the four years/seasons, the effect of treatments, locations, and interaction of location by treatment were used as the sources of variation in the analysis of variance. A Generalized Linear Mixed Model was used for the analysis of variance. Treatment and location were handled as fixed effects and the error Rep (Treatment*Location) as random effect. When the interaction location by treatment was significant in the analysis of variance, treatment means were compared within each location. When the interaction location by treatment was not significant, average treatment means across locations were compared. Least Significant Difference (LSD) was run to compare treatment means.

Superiority of UDP over other fertilizer application practices (FP and UB) was also calculated as a percentage to express what yield increase could be obtained using UDP compared with other N application practices. Nutrient use efficiency (NUE) of each application practice was also calculated to see how many kilograms of grain were produced by applying a kilogram of nitrogen by the practice. Both calculations were done for wet and dry season separately using average yield across locations and years. The following formulas were used to calculate the above parameters.

$$\text{\% superiority of UDP over other practice} = \frac{(\text{Yield with UDP} - \text{Yield with other practice})}{\text{Yield with other practice}} \times 100$$

$$\text{NUE (kg)} = \frac{(\text{Yield with treatment, kg} - \text{Yield with Zero N, kg})}{\text{kg of N applied with treatment}}$$

Results and Discussion

There was some variability in yields from year/season to year/season and from location to location. Analysis of variance showed highly significant difference at $P_{(0.01)}$ among both treatments and locations. Interaction of location by treatment showed significant difference at the $P_{(0.05)}$ level in the wet season trials. It was not significant in the dry season trials. A significant effect of interaction in the wet season indicates that the yield responses to treatments, especially urea broadcast treatments (FP and UB), are not consistent among locations. This is explained by the poor water control and heavy rain in lower parts of Myanmar. In the dry season, water management is better than in the wet season; hence, the yield responses to treatments are similar at all locations and show no significant interaction of locations by treatments (Table 2).

Table 2. Significance tests of sources of variation for each year and season.

Effect	2014 Wet Season		2015 Dry Season		2015 Wet Season		2016 Dry Season	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Treatment	22.19	< .0001	30.92	< .0001	14.90	< .0001	17.58	< .0001
Location	154.51	< .0001	23.14	< .0001	19.67	< .0001	8.34	< .0003
Location*Treatment	3.59	0.0111	0.39	0.9303	2.97	0.0261	0.89	0.5423

UDP consistently produced the highest yield at all locations in every year and season. The treatment that gave the second highest yield differed from year to year, season to season, and location to location. Sometimes, it was the FP treatment and sometimes it was the UB treatment, regardless of N rates for both treatments. The zero N treatment gave the lowest yield in most locations in every year/season. Comparing treatment means in 2014 wet season trials, two of the three locations showed the UDP treatment was significantly better than other fertilizer application practices. UDP yields ranged from 4.59 t/ha to 6.86 t/ha (Table 3). UDP yield at Sar Ma Lauk was the highest with 6.86 t/ha. But yields with other treatments were also high at Sar Ma Lauk, and there was no significant difference between treatments. The high yield may be attributed to the use of the high-yielding hybrid variety Pale Thwe. Since hybrid varieties require high amounts of nitrogen, the high yield of 6.38 t/ha from the control plot with zero N suggests that either the soil N supply was very high or additional urea might have been applied.

In the 2015 wet season trials, UDP treatment produced the highest yield (5.93-6.53 t/ha) at all three locations, and it was significantly higher than FP and control (Table 3). However, it was statistically higher from the UB treatment only at Too

Chaung. As evident from the yields of the control plots (Table 3), soil N supply at Too Chaung (3.13 t/ha) was lower than Wayon Gayet (4.65 t/ha) and Gyoe Phyu (5.54 t/ha). The soil of Too Chaung is more sandy and classified as sandy loam. (Land Use Map, 2017).

Table 3. Comparison of treatment means of each location for wet season.

2014 Wet Season			2015 Wet Season		
Location Treatment	Mean Yield (t/ha)	Comparison using LSD	*Location* Treatment	Mean Yield (t/ha)	Comparison using LSD
Sat Ka Lay			*Too Chaung*		
Control (0 N)	3.97	c	Control (0 N)	3.13	c
FP (57 kg N)	5.49	b	FP (57 kg N)	4.99	b
UB (52 kg N)	4.87	b	UB (52 kg N)	4.04	c
UDP (52 kg N)	6.38	a	UDP (52 kg N)	5.93	a
Sar Ma Lauk			*Wayon Gayet*		
Control (0 N)	6.38	ns	Control (0 N)	4.65	c
FP (57 kg N)	6.58	ns	FP (28 kg N)	5.35	bc
UB (52 kg N)	6.28	ns	UB (52 kg N)	5.92	ab
UDP (52 kg N)	6.86	ns	UDP (52 kg N)	6.12	a
Ohn Hnae Gone			*Gyoe Phyu*		
Control (0 N)	3.06	b	Control (0 N)	5.54	b
FP (28 kg N)	3.55	b	FP (57 kg N)	5.44	b
UB (52 kg N)	3.67	b	UB (52 kg N)	6.13	ab
UDP (52 kg N)	4.59	a	UDP (52 kg N)	6.53	a

Since there was no significant interaction of location by treatment in dry season trials, a comparison of treatment means was made using average values across all locations. Both dry seasons (2015 and 2016) showed UDP treatment produced the highest yield, and it was significantly higher than all other treatments. The yield with the FP treatment, which used a little higher N rate in 2015 and slightly lower in 2016, was not significantly different from the UB treatment (Table 4).

Table 4. Comparison of average treatment means across locations and years for the dry season.

Treatment	2015 Dry Season		Treatment	2016 Dry Season	
	Mean Yield (t/ha)	$LSD_{(0.05)}$ Comparison		Mean Yield (t/ha)	$LSD_{(0.05)}$ Comparison
Control (0 N)	3.29	c	Control (0 N)	3.30	c
FP (95 kg N)	4.85	b	FP (71 kg N)	4.23	b
UB (78 kg N)	4.53	b	UB (78 kg N)	4.26	b
UDP (78 kg N)	5.93	a	UDP (78 kg N)	5.31	a

The results clearly indicate that UDP technology is better than surface-broadcasting urea and can increase the yield of transplanted lowland rice in Myanmar. This is consistent with findings in other countries (Bandaogo et al., 2014; Miah et al., 2016). Percent yield increase of UDP over broadcast fertilizer practices were calculated by using overall average yield of the wet and dry season as given in Table 5. The data showed UDP can increase yield by 16-18% over FP and UB in the wet season and 24% to 28% over FP and UB in the dry season. This indicates UDP is more responsive on dry season rice than on wet season rice. Overall, the increase in yield of 16-28% on application of UDP is similar to results from Bangladesh and Africa (Miah et al., 2016). Nutrient use efficiency (NUE) is not much different between the wet and dry season. With urea surface-broadcasting practices, 13-16 kg of rice grain are produced by applying one kilogram of nitrogen (Table 5). But with UDP practice, NUE is twice as high as other practices (30-31 kg rice grain per kg N applied). The effect of N application on yield increase is twice as high in the dry season compared to the wet season, validating why farmers apply more in the dry season.

Table 5. Percent yield superiority of UDP over other practices and NUE of fertilizer practices.

Treat.	Wet Season				Dry Season			
	N Rate (ave) (kg/ha)	Yield (t/ha)	% of UDP Over	NUE kg/kg N	N Rate (ave) (kg/ha)	Yield (t/ha)	% of UDP Over	NUE kg/kg N
Zero N	0	4.46	36	-	0	3.30	70	-
FP	47	5.23	16	16	83	4.54	24	15
UB	52	5.15	18	13	78	4.39	28	14
UDP	52	6.07	-	31	78	5.62	-	30

Conclusion

These rice trials were conducted on transplanted rainfed lowland rice in the lower part of Myanmar and run for both the wet and dry season. Although there were variations in rice yield from year to year, season to season, and location to location, UDP treatment produced the highest yield at all times among all other treatments. It was often significantly higher than other urea application practices. With UDP technology, rice yield can be improved by at least 18% in the wet season and 28% in the dry season compared with broadcasting urea at the same N rate. Yield increase with UDP is due to an increase in nutrient use efficiency. UDP can double the NUE over urea surface-broadcasting practices. It is concluded that UDP technology is a highly effective method of urea application on rainfed lowland rice. The best result from UDP can be obtained in lowland rice cultivation under favorable water condition or good irrigation and best management practices.

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Economics of Fertilizer Use Efficiency for Selected Crops in Tatkone Township

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Abstract

Myanmar has been probing for the right drive of policy for vertical expansion of agricultural production for a long time. Technology and investment in agriculture are generally recommended. Among agricultural technologies, fertilizer technology is highly recommended to obtain potential yield for crops. The term "*Fertilizer Jump*" has been cited as one of the policy drives during the last government. Fertilizer is obviously the most expensive input for agriculture. The ultimate goal for farmers is to reap maximum profit with minimum cost. Therefore, the costly inputs must be efficiently and optimally utilized. Too much fertilizer use is harmful to the environment, but the level of fertilizer use in the crop production sector of Myanmar is far below the dangerous level. Overall, fertilizer consumption in Myanmar was just 20.5 kg/ha of arable land in 2014, the lowest among neighboring economies (WB, 2014).

Tatkone Township has been selected as a study area, because it is one of the ACIAR project (ACIAR/SMCN/2014/044) areas and well-known for high crop diversification. Rice, maize, and green gram were selected to investigate the economics of fertilizer use, especially nitrogen fertilizer. There were 117 respondents from three sample villages: Chone Gyi, Yway Su, and Newl Yit. Simple random sampling was employed, and the primary data were collected by using a set of structured questionnaires. The study was conducted to measure economic efficiency (benefit-cost ratio, BCR), to investigate partial factor productivity of nitrogen fertilizer (PFP_N), to estimate nitrogen use efficiency, and to find the factors affecting the yields of different crops, which are economically important for farmers in the region and for the nation as well.

Rice, maize, and green gram were chosen to study for their economic and strategic importance. The results showed maize with the highest BCR of 1.91, followed by green gram (1.66) and rice (1.48). Partial factor productivity of nitrogen was the highest in green gram with 66.06 kg/kg, followed by 39.47 kg/kg in maize and 37.84 kg/kg in rice. Fertilizer use efficiency was also the highest in green gram production with 63,655 Myanmar kyats (MMK)/kg, followed by maize (12,919 MMK/kg) and rice (7,919 MMK/kg). Accordingly, the fertilizer cost share was the lowest in green gram (only 7.12%), followed by 17.1% in maize and 18.9% in rice production. The seed rate and nitrogen fertilizer were found to be significant factors for yield in rice production at 5% significant level. Therefore, the productivity of pulse crops can be boosted by increasing the rate of fertilizer utilization. As Tatkone is becoming known as a special maize zone, it is recommended to continue maize production, because maize reaped the highest BCR among selected crops.

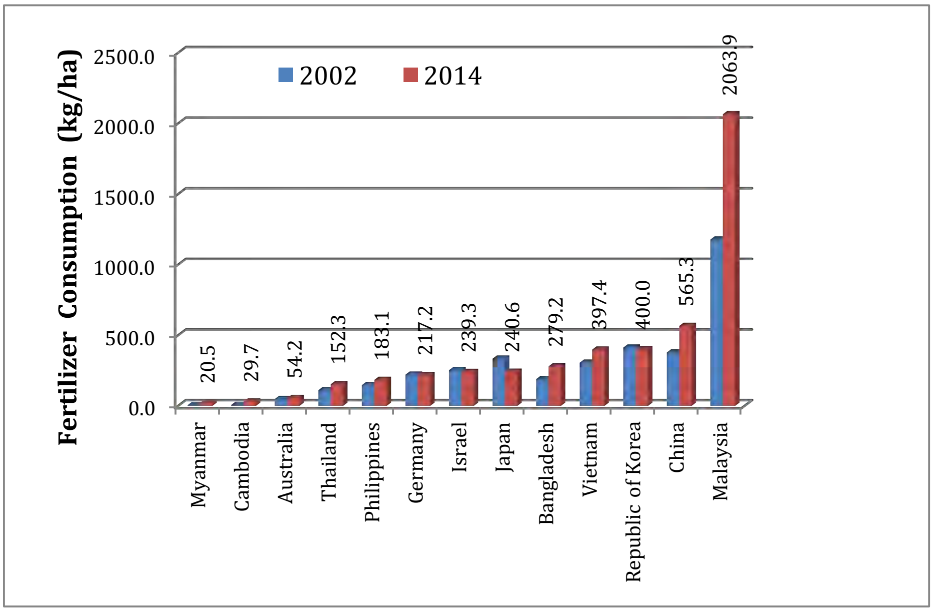
Key Words

Fertilizer use efficiency, partial factor productivity, cost share, economic efficiency

1. Introduction

Myanmar has been probing for the right drive of policy for vertical expansion of agricultural production for a long time. Technology and investment in agriculture are generally recommended. Among agricultural technologies, fertilizer technology is highly recommended to obtain potential yield for crops. The term "*Fertilizer Jump*" has been cited as one of the policy drives during the last government. Fertilizer is obviously the most expensive input for agriculture. The ultimate goal for farmers is to reap maximum profit with minimum cost. Therefore, the costly inputs must be efficiently and optimally utilized. Research workers in agronomy and agricultural economics, recognizing the importance of economics of fertilizer use for crop production, began cooperating on research projects designed to estimate the most profitable rates of plant nutrients for different soils (Munson and Doll, 1959).

Too much fertilizer use is harmful to the environment, but the level of fertilizer use in the crop production sector of Myanmar is far below the dangerous level. Overall, fertilizer consumption is the lowest among selected countries in Figure 1.



Source: http://data.worldbank.org/indicator/AG.CON.FERT.ZS.

Figure 1. Fertilizer consumption per hectare of arable land for selected countries (kg/ha).

According to the data, the rate of fertilizer consumption for Myanmar in 2014 was as low as 20.5 kg/ha of arable land, while Thailand consumed 152.3 kg/ha, the Philippines consumed 183.1 kg/ha, Bangladesh consumed 279 kg/ha, Vietnam consumed 397.4 kg/ha, and Korea (Republic of), China, and Malaysia consumed 400, 563, and 2,063.9 kg/ha, respectively (www.worldbank.org).

Fertilizer use efficiency depends on physical and chemical properties of soil and fertilizer characteristics. To get the maximum benefit from using fertilizers, the correct choice of fertilizer from a wide selection of different brands, different chemical composition, and different chemical composition is needed. Stewart (2002) referred to long-term studies covering 157 years of crop production. Variability in crop productivity depends on several factors, such as crop species and varieties, soil and climate conditions, and use of agro-chemicals and management practices. However, some have estimated that nutrient inputs are responsible for between 30% and 50% of crop yield.

1.2 Background

Successive governments of Myanmar have favored rice for food security, for export promotion, and for agricultural development. And, as rice is our main staple food, its role will remain important in the future as well. However, pulses came into the picture as an important and lead agricultural export crop in 1989 after the government adopted an open-door economic policy in 1988. Maize also has an export market and the private sector is well-developed for the maize supply chain and related industries. For example, CP companies and its subsidiaries have been deeply rooted for decades. In addition, these three crops are among the top strategic crops set up by MOALI for agriculture sector development.

There are many studies and research on fertilizer use and crop production. But very few studies were observed from an economic point of view regarding fertilizer use and its efficiency in Myanmar. As mentioned above, rice stood as a policy crop for so long that most agricultural development policies are rice-based. Extension workers paid more attention to rice production, resulting in farmers using a good amount of fertilizer for rice production. But the successive crops, pulses, are grown by nutrient residues left by rice and have to grow with its ability of nitrogen fixation. Literature recommends 25-50-50-20 kg/ha of N-P-K-S in irrigated condition and half that amount in rainfed condition for pulse cultivation. Department of Agriculture, MOALI, recommended 17-68-34-70 of N-P-K-S per hectare, which is equivalent to urea 15 kg, triple superphosphate (TSP) 60 kg, muriate of potash (MOP) 30 kg, and gypsum 150 kg per acre in green gram production. In reality, almost 80% of pulse growers put no additional fertilizer in pulse production. They are just enjoying reaping at the intercept yield of production function. This study tried to point out the high potential for jump-increases in pulse production by managing fertilizer utilization in an efficient way.

1.3 Objectives of the Study

The study generally aims to determine the fertilizer use efficiency of economically important crops, which were selected as rice, maize, and green gram in the Tatkone area. The specific objectives were:

- To study socio-economic conditions of the sample farmers in the study area.
- To evaluate net economic return from economically important crops in the study area.
- To measure the economics of nitrogen use efficiency and total fertilizer use efficiency for economically important crops.
- To find out the factors affecting the yield of monsoon rice.

2.1 Study Area Selection

The study was partly funded by the ACIAR project ACIAR/SMCN/2014/044 “Management of nutrients for improved profitability and sustainability of crop production in central Myanmar.” Therefore, one of the project sites has been chosen to conduct this study. Furthermore, Tatkone is well-known its rich crop diversity. In addition, it is close to Yezin and the logistics for the field survey were fundable.

Tatkone is one of the eight townships in Nay Pyi Taw territory area. Based on 2014 data, Nay Pyi Taw has a population of 1.16 million. Chone Gyi, Nwel Yit, and Yway Su village tracts in Tatkone Township were chosen for the study.

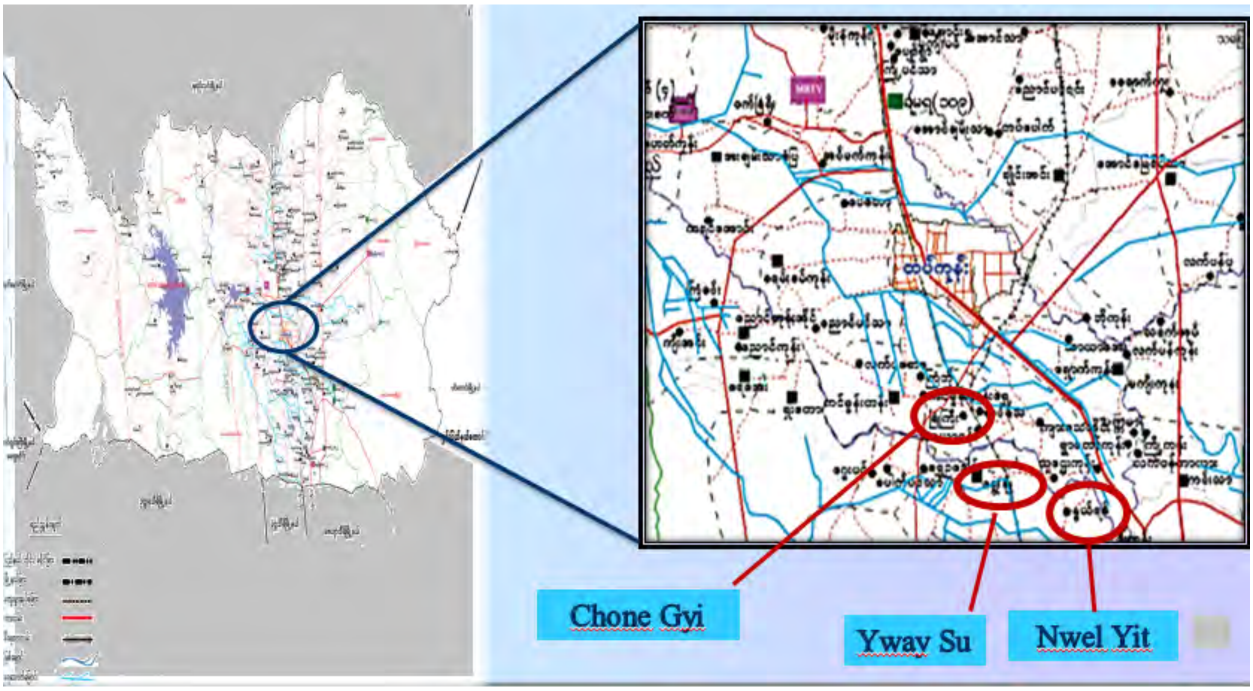


Figure 1. Map of study area.

2.2 General Description of Study Village Tracts

In the study area, both types of land – lowland and upland – were observed. The largest lowland area was in Yway Su with 266.96 ha, 65.59 ha in Nwel Yit, and 38.06 ha in Chone Gyi village. The largest upland area was in Nwel Yit with 323.38 ha, and the lowest upland area was in Chone Gyi (50.61 ha). Yway Su has 190.28 ha of upland. In terms of the number of households, Nwel Yit was the largest among three village tracts, and in terms of population, Yway Su was the largest with a population size of 3,800. By the distance from the nearest town, Chone Gyi was the closest at 3.2 km from the town, and Nwel Yit was the farthest at 7.2 km.

Table 1. General description of study village tracts in Tatkone Township (2016).

Village Tract	Lowland (ha)	Upland (ha)	Total HHs (No.)	Population (No.)	Farm HHs (No.)	Distance from Town (km)
Chone Gyi	38.06	50.61	200	1,210	105	3.2
Yway Su	266.96	190.28	450	3,800	717	5.6
Nwel Yit	65.59	323.48	684	3,030	239	7.2

3. Research Methodology

Simple random sampling method was used to select respondent farmers. The structured questionnaire was designed to interview farmers personally. The data collected were farmer's age, education level, family members, farm size, seed rate, yield of crops, product price, cost of crop production per acre, rate of fertilizer application and the difficulties they were facing with crop production.

The research methodologies were descriptive analysis, cost and return analysis, measures of fertilizer use efficiency, and multiple regression analysis. For enterprise budgeting, the following parameters were estimated.

Parameters	Unit	How Calculated
Gross benefit (GB)	MMK/ha	Py*Y
Return above variable cost (RAVC)	MMK/ha	GB–TVC
Return per unit of capital (BCR)	MMK	GB/TVC
Break-even yield	kg/ha	TVC/Average price per kg
Break-even price	MMK/kg	TVC/Average yield per ha

For fertilizer use efficiencies, the following formulas were used. Fertilizer cost share indicated the portion of fertilizer cost in the total production cost, which usually takes a tiger portion in production cost. Partial factor productivity of N fertilizer indicated the productivity of one kilogram of nitrogen for a particular crop, and N fertilizer use efficiency measures the value of total production for using one kilogram of mitrogen. For computing N fertilizer use, we calculated the contents of nitrogen from any fertilizer the farmers used.

$$\text{Fertilizer cost share (\%)} = \frac{Total\ Cost\ of\ Fertilizer\ Used}{Total\ Cost\ of\ Production} \times 100$$

$$\text{Partial factor productivity of N fertilizer} = \frac{Total\ Production\ per\ Acre\ (kg)}{Total\ Nitrogen\ Used\ per\ Acre\ (kg)}$$

$$\text{N fertilizer use efficiency (MMK/kg N)} = \frac{Value\ of\ Total\ Production}{Total\ N\ Fertilizer\ Use}$$

The following model was used to estimate the production function of rice.

$$Y_i = \beta_0 + \beta_i X_{1i} + \beta_i X_{2i} + \beta_i X_{3i} + \ldots + \beta i\ X_{8i} + \mu_i$$

Where, dependent variable was yield (kg/ha), and independent variables were age of household head (yr), education level of household head (yr), farm size (ha), seed rate (kg), total no. of labor (labor days/ha), amount of N fertilizer (kg/ha), amount of P fertilizer (kg/ha), and amount of K fertilizer (kg/ha). μ_i is the error term in the model.

4. Results and Discussions

4.1 Demographic Characteristics

There were a total of 117 respondents from three village tracts, and the average age was 49 years, ranging from 22 to 78 years. Their education level was six years of schooling, ranging from two to 14 years in school. Average farm experience was 24 years; minimum experience was two years and maximum experience was 59 years. Average family size was five, ranging from one to nine family members. Every sample household has farm family laborers of three family members, on average, ranging from one to seven. Average farm size was 2.02 ha, and minimum land holding was 0.81 ha; maximum land size of the sample household was 10.12 ha.

Table 2. Demographic characteristics of sample households in Tatkone Township (2015).

Item	Unit	Average	Minimum	Maximum	S.D.
Age	Year	49	22	78	11.71
Schooling year	Year	6	2	14	2.76
Farming experience	Year	24	2	59	12.22
Family size	No.	5	1	9	1.63
Farm family labor	No.	3	1	7	1.21
Farm size	ha	2.02	0.81	10.12	1.25

S.D. is standard deviation.

4.2 Sown Area of Selected Crops

Green gram, monsoon paddy, and maize were selected to study in this research because they were grown by most of the respondents and they were strategically and nationally important crops as well. Green gram was grown by 79 respondents, or 68 percent of total respondents, and followed by monsoon paddy and maize. The average area of green gram was 2.49 ha per farmer. Paddy in the monsoon season was grown by 62 percent of farmers, and the average area for paddy was 2.65 ha per farmer. Maize was grown by 22 respondents only, and they grew 1.44 ha on average.

Table 3. Sown area of green gram, monsoon paddy, and maize in Tatkone Township (2015).

Crop	No. of Farmers	Percent	Sown Area (ha)		
			Average	Minimum	Maximum
Green gram	79	67.52	2.49	0.25	10
Monsoon paddy	73	62.39	2.65	0.25	10
Maize	22	18.80	1.44	0.10	3

4.3 Profitability of Selected Crops

The economic analysis was conducted for profitability of crop production. An enterprise budget was used to estimate the profitability of selected crop production. Gross benefit was gained by multiplying yield and price of the product. Average yields were 4.431 t/ha for maize, 878.06 kg/ha for green gram, and 4.06 t/ha for paddy. The price per kilogram was the highest for green gram with 964 Myanmar kyats (MMK), followed by 327 MMK for maize, and paddy received the lowest price per kilogram at 292 MMK.

Total variable cost (TVC) was calculated by adding all variable costs, such as seed cost, fertilizer cost, other agro-chemical cost, labor cost, and fuel and machinery cost. Interest expenses were the opportunity cost of invested capital.

Table 4. Result of profitability analysis for maize, green gram, and paddy in Tatkone Township (2015)

Item	Maize N=22	Green Gram N=79	Paddy N=73
Yield (kg/ha)	4,431.45	878.06	4,058.7
Price (MMK/kg)	327	964	292
Gross benefits (Y*Py)	1,449,084	836,809	1,185,140
Total variable cost (MMK/ha)	731,610	496,828	772,855
Material cost (MMK/ha)	233,325	140,739	317,010
Total labor cost (MMK/ha)	471,637	337,738	419,043
Interest cost	26,648	18,351	30,731
Return above variable cost (GB–TVC)	717,475	339,981	418,356
Break-even yield (kg/ha)	2,237.34	515.38	2,626.97
Break-even price (MMK/kg)	165	572	189
Benefit-cost ratio	1.96	1.68	1.55

Total cost of production was the highest for rice at more than 772,000 MMK, which made rice the least profitable with a benefit-cost ratio (BCR) of 1.55 only. The lowest production cost was for green gram at less than 497,000, giving it a higher BCR than that of monsoon paddy. For maize production, TVC was as high as 730,000 MMK but yielded the highest BCR of 1.96. Therefore, maize was found to be the most profitable crop in Tatkon Township, and monsoon rice production was the least profitable. Therefore, the policymaker should encourage maize production in Tatkon area and look for the causes of low profitability in rice production. The farmers and the nation will keep producing rice as a strategically important crop or as a staple crop and will not ignore rice production. Green gram could be grown with much less investment than other crops and give enough return on investment to enourage farmers to keep growing. However, the access to sustainable markets is very important to get a stable price. Otherwise, price fluctuation will make the farmers suffer.

4.4 Cost-Share Analysis

As Myanmar's agriculture is still labor-intensive, the cost of labor for any crop shares the tiger portion in crop production cost. Sixty-five percent of labor cost can be seen in green gram production (Figure 2). Labor cost-share in maize was also as high as 64% and in paddy it was 54%. The second highest production cost was for chemical fertilizer and other agro-chemicals. Cost-share for fertilizer in paddy and maize production was as high as 18% of total production cost, but it was only 7% in green gram production.

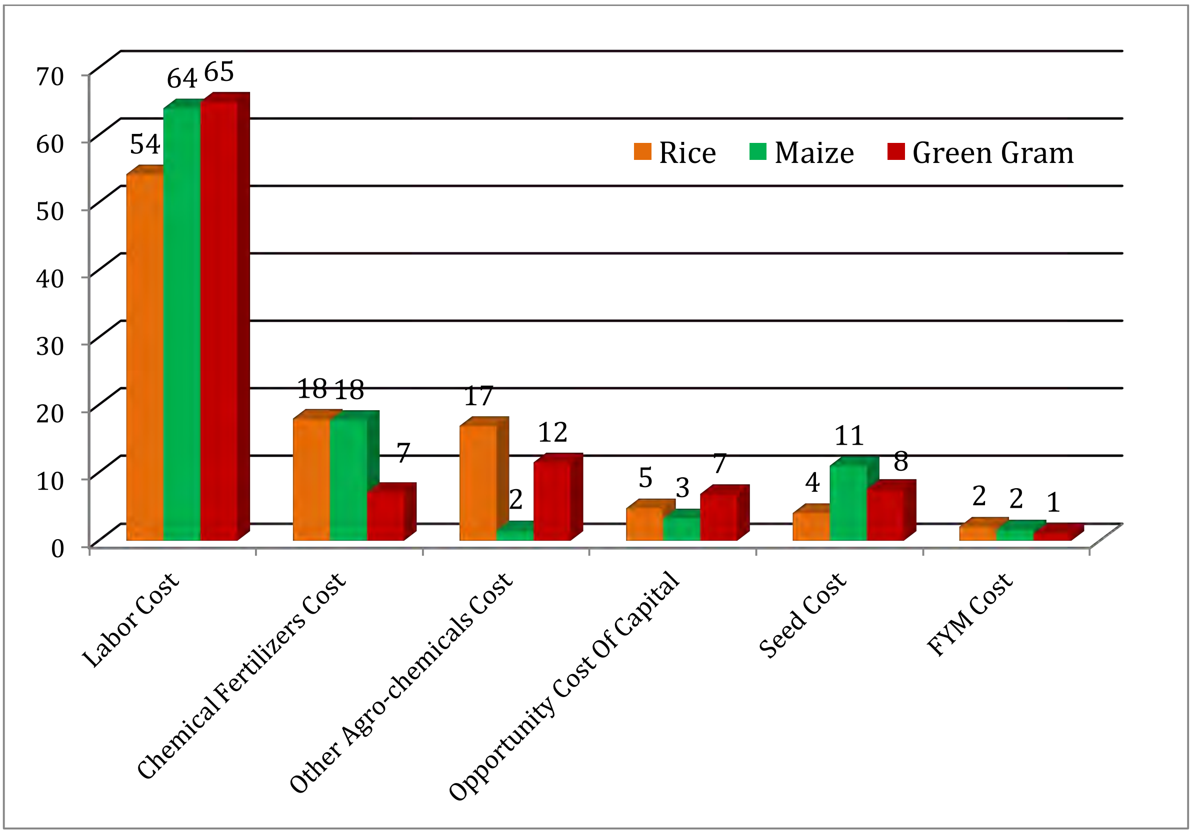


Figure 2. ***Cost-share in rice, maize, and green gram crop production in Tatkon Township (2015-16).***

Farmers use a very small amount of fertilizer in green gram or other pulse production in Myanmar. Peas and beans have nitrogen fixation effects, but they still need a starter dose of nitrogen to grow well in the very early stages of growth. It was observed that more than 60% of green gram growers were at intercept yield (Figure 3). They did not apply any amount of nitrogen fertilizer for green gram production. The marginal amount of nitrogen fertilizer will boost the yield significantly following the quadratic production function.

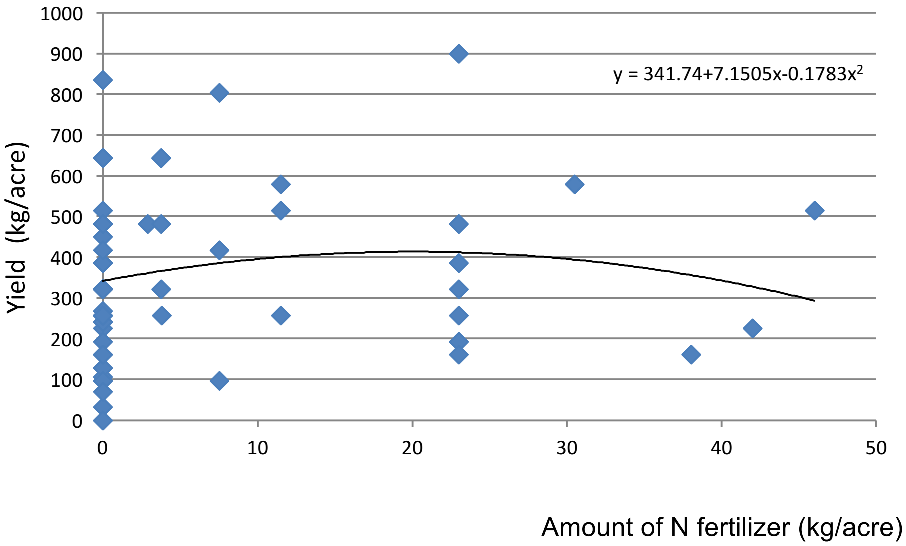


Figure 3. ***Quadratic production of green gram***

4.5 Partial factor productivity of nitrogen (PFP_N) and N fertilizer use efficiency (FNUE)

Nitrogen plays a very important role in crop productivity (Ahmad, 2000) and its deficiency is one of the major yield-limiting factors for cereal production (Shah et al., 2003). Decline in partial productivity for N has been reported in cereal-based systems, leading to higher investment in N to maintain higher yields. Decline in partial factor productivity for N may be attributed to nutrient imbalance, decline in indigenous soil N supply, subsoil compaction, reduced root volume, and increased incidence of pests and diseases (Karim and Ramasamy, 2000). Since higher fertilizer use efficiency is always associated with a low fertilizer rate, cultural practices meant for promoting integrated nutrient management will help to bring about saving in the amount of fertilizer applied to the crops and, therefore, improve fertilizer use efficiency (Karim and Ramasamy, 2000).

Best management practices (BMPs) focus on the effectiveness of fertilizers and keeping them in the field for use by the intended crop in adapting cropping systems to the economic and environmental challenges. Effectiveness is maximized when the most appropriate nutrient sources are applied at the right rate. Partial factor productivity (PFP) of nutrients due to factor fertilization answers the question what is the productivity of the system compared to nutrient inputs. This index is the simplest form for the yield efficiency. The amount of N fertilizer used in green gram production is very low so that PFP_N was very high with 66.06 kg of product per kg of N fertilizer (kg/kg), while maize received 39.47 kg/kg and rice received 37.87 kg/kg. N fertilizer use efficiency (FNUE) was also the highest is green gram with 63,628 MMK per 1 kg use of N fertilizer, which was more than five times greater than that of other crops.

Efficiency gains in the short term may sometimes be at the expense of those in the long term. Short-term reductions in application rates increase nutrient use efficiencies, even when yields decline. However, in the long term, lower yields reduce production of crop residues, leading to increased erosion risks, decreased soil organic matter, and diminished soil productivity.

Table 5. Nitrogen partial factor productivity and fertilizer use efficiency of selected crops in Tatkone Township.

Crops	Yield (kg/ha)	Price per Yield (MMK/kg)	Total Amount of N (kg/ha)	Partial Factor Productivity of Nitrogen	FNUE (MMK/kg)
Green gram	876.18	964	13.26	66.06	63,682
Maize	4,431.70	327	112.29	39.47	12,906
Rice	4,152.34	292	109.64	37.87	11,058

4.6 Factors Influencing Monsoon Rice Production

Lowland rice, or monsoon rice, is the major crop produced in Myanmar. It is also the main food production not only for Myanmar but also for the world's rice consumers. The production, processing, and marketing of monsoon rice gives many job opportunities for agricultural labor. To increase productivity as well as profitability for this major crop is also very important for income increases of the rural majority. As mentioned previously, the profitability is the lowest among three selected crops: rice, green gram, and maize. It is very important to know the factors affecting monsoon rice production. There are a wide range of factors that influence rice yield: geographic factors, climatic factors, biological factors, and socioeconomic factors. In this study, only socioeconomic factors, such as farmer's age, education, farm size, number of family laborers, and rates of seed and N, P, K fertilizer application, are analyzed.

Table 6. Factors influencing monsoon rice production of sample farmers in Tatkon Township (N=73).

Independent Variables	Unit	Unstandardized Coefficients		t	Sig.
		B	Std. Error		
(Constant)		77.478***	13.156	5.889	.000
Education	Yrs	.143	.716	.200	.842
Farm size	ha	-.027	.599	-.045	.964
Seed rate	kg	-3.867**	1.791	-2.159	.035
Age	Yrs	-.066	.165	-.399	.691
Total labor	Labor days	-.062	.137	-.452	.653
N fertilizer	kg	.348**	.137	2.544	.013
P fertilizer	kg	1.462	1.254	1.166	.248
K fertilizer	kg	-.864	.980	-.882	.381
R^2	0.219				

Among the considered factor in multiple regression analysis, only seed rate and amount of N fertilizer were significantly influencing factors on rice production in Tatkone Township at 5% significant level. As farmers use a high rate of seed, the negative sign explains that the reduction in seed rate could reduce the yield of the rice crop, and an increase in N fertilizer application can increase the rice yield.

5. Conclusion and Policy Recommendations

The majority of famers in Myanmar are small-scale farmers, and this study emphasized small-scale farmers. Their average land size was only 2.02 ha, average age was 49 years, and education level was six years in secondary school. Maize was the most profitable crop with a BCR of 1.96, and rice was the least profitable with a BCR of 1.55. N partial factor productivity was the highest in green gram production, followed by maize and rice. Nitrogen use efficiency was also the highest in green gram production and the lowest in rice. Fertilizer cost-share for rice production was the highest, because most of the farmer apply chemical fertilizer in rice production. But farmers usually grow pulses using the rest of the nutrients left by rice, which is why the fertilizer cost-share in green gram was found to be the lowest with only 7%. Maize is known to be a heavy eater, so the fertilizer cost share for maize production was also found to be as high as that of rice. According to the results of multiple regression analysis, rice yield was negatively and significantly affected by seed rate at 5% level. So, farmers should use quality seeds to get higher yield. However, it was positively and significantly influenced by nitrogen fertilizer at 5% level. The farmers are encouraged to use more nitrogen fertilizer in rice production, because higher yield can be obtained by using a higher amount of N fertilizer. The results suggested that farmers should apply a greater amount of N fertilizer in green gram production because nitrogen use efficiency for green gram was very high and the majority of farmers are still at the intercept yield level. Likewise, nitrogen fertilizer should be used efficiently and effectively in rice and maize production.

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Nutrient Management for Maximizing Yield in Rice-Rice and Rice-Pulse Cropping Systems in Lower Myanmar

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Abstract

On-farm adaptive research on improving nutrient management was implemented during the 2014 wet season (WS) and 2014-15 dry season (DS) in Maubin Township, Ayeyarwady region, and in Daik Oo Township, Bago region, Myanmar. The study demonstrated the importance of improving nutrition for rice, in rice-rice and rice-pulse cropping systems, and for pulses, in rice-pulse cropping systems. Because of difficulties in fertilizer application under flooded conditions, it is hypothesized that, in comparison with the farmers' practice, adding improved nutrients at the nursery (seedbed) stage and after transplanting will have positive effects on rice growth and grain yield. Four combinations of seedbed and fertilizer management after transplanting served as treatments in three to four farmers' fields per township during the 2014 WS and 2014-15 DS, as follows: Treatment 1 = farmer seedbed management + farmer practice of nutrient management in the field after transplanting; Treatment 2 = farmer seedbed management + improved nutrient management in the field after transplanting; Treatment 3 = improved seedbed management + farmer practice of nutrient management in the field after transplanting; and Treatment 4 = improved seedbed management + improved nutrient management in the field after transplanting (Department of Agricultural Research [DAR] recommendation). In Maubin Township, T4 compared with T1 in the rice-rice system resulted in 50% higher yield and 53% higher income but had 41% higher production cost during the 2014 WS, whereas T2 versus T1 showed 53% higher yield and 61% higher income but incurred 23% higher production cost. For summer rice during the 2014-15 DS, T4 versus T1 showed 11% higher yield and 14% higher income but incurred a 1.0% higher production cost, whereas T2 versus T1 resulted in 4.0% higher yield, 1.0% higher production cost, and 4.0% higher income. In Daik Oo Township, for rice in the rice-rice system, a 10% higher yield, 10% higher income, and 30% higher production cost were observed when T4 was compared with T1, whereas T2 versus T1 showed 4.0% higher yield and 4.0% higher income but had 15% higher production cost. For monsoon rice in the rice-pulse system in Maubin Township, T4 versus T1 showed 5.0% higher yield, 3.0% higher income, and 40% higher production cost, whereas T2 versus T1 showed 3.0% higher yield, 2.0% higher income, and 13% higher production cost. Further, in Daik Oo Township, comparing T4 versus T1 for monsoon rice in the rice-pulse system showed a 10% higher yield and 8.0% higher income but incurred 40% higher production cost; T2 versus T1 showed no increase in yield, lower income by 1.0%, and 17% higher production cost. This comparison shows that additional production cost did not result in an increase in yield and income. For black gram grown after rice, the DAR fertilizer recommendation of 12.5 kg N, 25 kg P_2O_5, 12.5 kg K_2O, and 10 kg S per ha applied as basal fertilizer gave a 15% increase in yield and 17% increase in income across five locations. The additional fertilizer requirement resulted in a 9.0% increase in production cost compared with the farmers' practice of basal application of triple superphosphate fertilizer at the rate of 61.75 kg/ha.

Key Words

Improved nutrient management, improved seedbed management, on-farm adaptive research, benefit-cost ratio, rice-based systems

Introduction

Rice is the most important staple food and commodity in Myanmar with more than 52 million people dependent on it. In 2014-15, rice was grown on about 7.2 million ha, occupying 64% of the arable land. Of this total rice area, only 20% is irrigated but the water supply is ample during the monsoon season. Recent data show that Myanmar's per capita consumption of rice is 154 kg per year (Myint, 2016), and rice provides 71% of the daily calorie intake. From 2001 to 2011, mean rice yield increased about 20% from 3.42 t/ha to 4.07 t/ha, whereas a decline to about 3.2% from 4.07 t/ha to 3.94 t/ha was observed in 2011-15. The area of land under rice increased by about 33% from 2001 to 2011, whereas a decrease of about 14% occurred from 2011 to 2015 (MOALI, 2015).

The Delta Region, composed of Ayeyarwady, Yangon, and Bago divisions, accounts for about 48% of the annual rice production in Myanmar. It is followed by the Central Dry Zone (Sagaing, Magway, and Mandalay divisions), contributing 22% of the total rice production (MOALI, 2015). National average rice productivity is 3.8 t/ha and 4.7 t/ha in the wet and dry seasons, respectively, while the average productivity in the delta is 3.7 t/ha and 4.5 t/ha during the wet and dry seasons (MOALI, 2015; Rahman et al., 2015; Singleton et al., 2015b). The wet season rice starts in May-June and ends in October-November, while the dry season begins in November-December and continues until April-May. During the wet season, average rainfall in the Delta Region ranges from 3,062 mm to 4,310 mm, with a peak during July (7,981 mm) and August (6,045 mm). This is sufficient for growing rice without supplemental irrigation from dams, river and stream diversions, or groundwater. With limited drainage structures, instability of production and risks of flooding and stagnant water are common constraints that limit rice productivity (Denning et al., 2013; FAO, 2014; Naing et al., 2012; Thant et al., 2010). However, during the dry season, rice growing is not possible in the Central Dry Zone because of the lack of sufficient rainfall, but rice is grown in the Delta and Coastal regions with great challenges of high salinity due to brackish water intrusion and limited irrigation facilities. From 2000 to 2013, only 16% of the net sown area to different crops was serviced by an irrigation system, and the majority of the rice fields were left fallow or grown to short-duration upland crops, such as pulses and oilseed crops, immediately after the rice harvest to maximize use of the remaining soil moisture (FAO, 2001; MOALI, 2014).

Farmers obtain poor income from mono-cropping of rice. They need to realize that crop removal of nutrients from the soil from two or more crops in a year can result in nutrient mining. In diversified and intensive rice-based cropping systems, the adoption of improved nutrient management for rice-rice and rice-pulses needs to be encouraged. The usual farmers' practice with imbalanced fertilization or application of urea alone to rice crops and no application of fertilizer in pulses resulted in a yield decline in both rice and pulses (ACIAR, 2014; Singleton et al., 2015a).

Improved nutrient management in nursery plots and after transplanting should be recommended for some flooded rice areas in lower Myanmar (Singleton et al., 2015a). In addition, the importance of phosphorus for pulses should be introduced and explained to farmers (Lwin et al., 2005).

Materials and Methods

Site Selection and Description of the Study Area

This study focused on lower Myanmar in Maubin Township, Ayeyarwady region (latitude16°3′48.00″ N; longitude 95°39′0.00″ E), and Daik Oo Township, Bago region (latitude 17°55′51″ N; longitude 96°50′59″ E), where rice and pulses are commonly grown. The project focused on rice-based systems in the Ayeyarwady Delta because big opportunities exist to improve the diversification and productivity of lowland rice-based systems for smallholder farmers. The adoption of new rice varieties and alternative crop management options, particularly nutrient management, advanced the rice harvest and provided options for post-rice crops and greater diversification.

The project team assessed the sites and consulted with key leaders and farmers in the community before the start of the project to determine the agronomic and other production constraints and needs to overcome low productivity in the rice areas. In the implementation stage, meetings were conducted with farmers at the start of each cropping season to review the results of field trials, gather feedback, and plan activities for the coming season with the farmers.

Baseline Soil Analysis of the Study Area

Soil samples were collected on the farms of farmer cooperators and analyzed in the soil analytical laboratory of the Department of Agricultural Research (DAR) in Yezin to describe the soil characteristics in the study area. The sampling areas in Maubin Township were located in A Lann, Nga Gyi Gayat, and Tar Pat West villages, while in Daik Oo Township, these were located in Kadote Phayar Gyi and Pha Aung Wei villages for the rice-rice system. For the rice-pulse system, sampling areas were located in Papinsu Village, Maubin Township, and in Oak Shit Kone Village, Daik Oo Township (Tables 1 to 3).

Using the soil analysis results and interpretation from the soil laboratory of the DAR, the soils of the rice-rice system at Maubin and Daik Oo project sites are characterized as generally acidic (Tables 1 and 2), while they are characterized as neutral in the rice-pulse system in Daik Oo Township (Table 3) and moderately acidic in Maubin Township. Soil organic matter (SOM) content in the rice-rice system in Maubin is low to high, and it is low in Daik Oo. In the rice-pulse system in Maubin, SOM is medium, while in Daik Oo, SOM is low. Soils with low organic matter are generally recommended for higher application rates of nitrogen fertilizer.

Soil available N in the rice-rice system is low to medium in Maubin while it is low to high in Daik Oo. Soil available N in the rice-pulse system is high in Maubin and medium to high in Daik Oo. Available phosphorus and potassium in the rice-rice system are low to medium in Maubin and low in Daik Oo. Available phosphorus for the rice-pulse system is medium in Maubin and low in Daik Oo. Available potassium for the rice-pulse system is low in Maubin and low to medium in Daik Oo. Application of NPK fertilizers is recommended for these farms to increase and maintain rice yields.

Table 1. Soil characteristics in the rice-rice system in Maubin Township (May 2014).

Soil Characteristics	Farmer 1 (A Lann)	Farmer 2 (Nga Gyi Gayat)	Farmer 3 (Tar Pat West)
Soil pH (reaction)	5.7	6.4	4.7
Soil pH (rating)	Moderately acidic	Slightly acidic	Strongly acidic
Organic matter (%)	3.1	1.8	4.0
Available N (mg/kg)	43	83	57
Available P (mg/kg)	16	11	5
Available K (mg/kg)	233	115	155
Soil texture	Sandy clay loam	Silt loam	Sandy loam

Table 2. Soil characteristics in the rice-rice system in Daik Oo Township (May 2014).

Soil Characteristics	Farmer 1 (Kadote Phayar Gyi)	Farmer 2* (Kadote Phayar Gyi)	Farmer 3 (Pha Aung Wei)
Soil pH (reaction)	6.0	5.7	6.2
Soil pH (rating)	Moderately acidic	Moderately acidic	Slightly acidic
Organic matter (%)	0.7	1.3	1.5
Available N (mg/kg)	47	105	61
Available P (mg/kg)	3	3	14
Available K (mg/kg)	69	67	136
Soil texture	Sandy loam	Loamy sand	Loamy sand

*Kadote Agricultural Extension Camp

Table 3. Soil characteristics in the rice-pulse system in Maubin and Daik Oo townships (May 2014).

Soil Characteristics	Farmer 1 (Papinsu*)	Farmer 2 (Oak Shit Kone**)	Farmer 3 (Oak Shit Kone)	Farmer 4 (Oak Shit Kone)
Soil pH (reaction)	5.9	6.8	6.6	6.6
Soil pH (rating)	Moderately acidic	Neutral	Neutral	Neutral
Organic matter (%)	2.6	1.5	1.2	1.0
Available N (mg/kg)	97	93	78	83
Available P (mg/kg)	14	7	6	7
Available K (mg/kg)	124	94	189	119
Soil texture	Silt loam	Silt loam	Silt loam	Silt loam

*Maubin; **Daik Oo.

Nutrient Management for Rice in Rice-Rice and Rice-Pulse Systems

Farmers at the project sites establish their rice crops by transplanting and broadcasting methods. In this study, improved seedbed management was compared with the farmers' practice of seedbed management and the succeeding nutrient management after transplanting.

Improved Seedbed Management (ISM)

A non-flooded area was selected to prepare the seedbed. For a 1-ha field, a 400-m^2 seedbed area was established. The size of the raised seedbed was 1 m (width) x 20 m (length) x 15 cm (height). Twenty seedbeds were prepared. The length of the seedbeds varied depending on the length of the field. About 100 g of seeds were sown per m^2 or 2.0 kg of seeds per 20-m^2 seedbed. The seed rate was 40 kg/ha. Seeds were pre-germinated first (24-hour soaking; 24-36-hour incubation or until the radicle emerges).

The recommended rate for improved seedbed management was 52 kg N, 40 kg P_2O_5, and 5 kg $ZnSO_4$ per ha. Before seeding, 10 g $ZnSO_4$ per 20 m^2 were applied. Compost was applied on the beds immediately after seeding to cover the germinating seedlings and to prevent splashing of seeds when heavy rains occur as well as to avoid damage by birds and rodents. At seven days after seeding, 540 g of 15-1-5-15 per 20 m^2 were applied in each of the raised beds. At 7-10 days before uprooting, 50 g of urea (46-0-0) per 20 m^2 were applied to jumpstart the growth of the seedlings. For medium-maturing varieties, seedlings were uprooted 30 days after seeding. Two to three seedlings per hill were transplanted, and the spacing was 15 cm x 20 cm or 20 cm x 20 cm.

Farmer Seedbed Management (FSM)

For a 1-ha field, a 1,000-m^2 seedbed area was established and divided into four or five smaller beds using a wooden log or banana stem. The seeding rate was 103 kg/ha. Urea (21 kg/ha) was applied at 7-10 days after sowing (DAS) and at 24 DAS.

Improved Nutrient Management Before and After Transplanting

During the wet season, the recommended rate was 58 kg N, 28 kg P_2O_5, 20 kg K_2O, and 8 kg S/ha. P_2O_5 and S were applied as basal, N was applied in three splits (7 DAT, maximum tillering, and early panicle initiation), and K_2O was applied in two splits (7 DAT, maximum tillering). The sources of fertilizer are urea, triple superphosphate, muriate of potash, and gypsum.

During the dry season, the recommended rate was 87 kg N, 28 kg P_2O_5, 38 kg K_2O, and 8 kg S/ha. P_2O_5 and S were applied as basal, N was applied in three splits (7 DAT, maximum tillering, and early panicle initiation), and K_2O was applied in two splits (7 DAT, maximum tillering). The sources of fertilizer are urea, triple superphosphate, muriate of potash, and gypsum.

Farmer Nutrient Management After Transplanting

For the rice-rice system, the farmers' practice of fertilizer application after transplanting was 34 kg N, 6.2 kg P_2O_5, and 3 kg K_2O/ha. All fertilizers are mixed and applied only once at 15 DAT.

For the rice-pulse system, the farmers' practice of fertilizer application after transplanting was 15 kg N, 22 kg P_2O_5, 9 kg K_2O, and 6 kg S/ha. One-half of the urea fertilizer was applied at 10 DAT and at 25 DAT. One-third of the TSP was applied at 10 DAT and two-thirds at 45 DAT (panicle initiation stage). Potash was applied once at 45 DAT. Sulfur was applied at 10 DAT.

Nutrient Management for Black Gram in the Rice-Pulse System

Before sowing, seeds were treated with fungicide (e.g., Homai at 2.5 g/kg of seed), followed by inoculation of *Rhizobium* culture. One packet of 200 g of *Rhizobium* culture is sufficient to treat seeds for 4,000 m^2. The DAR recommendation for black gram is 12.5 kg N, 25 kg P_2O_5, 12.5 kg K_2O, and 10 kg S/ha applied as basal and incorporated before sowing seed.

Experimental Design and Treatments

Rice-Rice System

Four combinations of nursery and fertilizer management served as treatments during the 2014 wet season (WS) and 2014-15 dry season (DS). Each treatment combination has 1,000 m^2 plot size, with a total of 4,000 m^2 experimental plot size. Three to four farmers were selected, and each farmer served as one replication. The treatment combinations were as follows:

Treatment 1 = farmer seedbed management + farmer practice of nutrient management in the field	Treatment 2 = farmer seedbed management + improved nutrient management in the field (DAR recommendation)
Treatment 3 = improved seedbed management + farmer practice of nutrient management in the field	Treatment 4 = improved seedbed management + improved nutrient management in the field (DAR recommendation)

Rice-Pulse System

For the 2014 WS, the same treatment combinations as in the wet season rice-rice system were followed in Maubin and Daik Oo townships. For pulses in Maubin during the 2014-15 DS, the layout and previous plots used for the four treatments during the wet season were followed, and in each plot two phosphate rates were applied: T1 = 61.75 kg/ha triple superphosphate (farmer practice applied as basal); T2 = 12.5 kg N, 25 kg P_2O_5, 12.5 kg K_2O, and 10 kg S/ha (DAR recommendation applied as basal).

T1 = wet season rice		T2 = wet season rice	
T1 = dry season pulse	T2 = dry season pulse	T1 = dry season pulse	T2 = dry season pulse

T3 = wet season rice		T4 = wet season rice	
T1 = dry season pulse	T2 = dry season pulse	T1 = dry season pulse	T2 = dry season pulse

Results and Discussion

Nutrient Management for Rice in the Rice-Rice System

During the 2014 WS in Maubin Township, T4 showed 50% higher yield than T1 (2.8 vs. 1.9 t/ha ± 0.23 SE) and resulted in 53% higher income. With the improved system, 41% higher production cost was incurred compared with the farmers' practice (Figure 1a). By improving nutrient management after transplanting using farmer seedbed management (FP+INM), 53% higher yield (2.9 vs. 1.9 t/ha ± 0.23 SE) was observed compared with the farmers' practice. This also resulted in a 23% higher production cost but gave 61% higher income (Figure 1a).

For summer rice in the rice-rice system in Maubin Township, T4 showed 11% higher yield than T1 (5.3 vs. 4.8 t/ha ± 0.17 SE) and 14% higher income. With the improved system, a small increase in production cost (1%) was incurred compared with the farmers' practice (Figure 1b). By comparing T2 and T1, a 4.0% increase in yield with T2 (5.0 vs. 4.8 t/ha ± 0.17 SE) was observed. It also resulted in a 1.3% higher production cost but with 4.2% higher income (Figure 1b).

In Daik Oo Township, T4 compared with T1 showed 10% higher yield (4.6 vs. 4.1 t/ha ± 0.20 SE) and 10% higher income. With the improved system, a 30% higher production cost was incurred compared with the farmers' practice (Figure 2). A 4.0% higher yield (4.3 vs. 4.1 t/ha ± 0.20 SE) was observed when T2 was compared with T1. It also resulted in a 15% increase in production cost and gave 4.0% higher income (Figure 2).

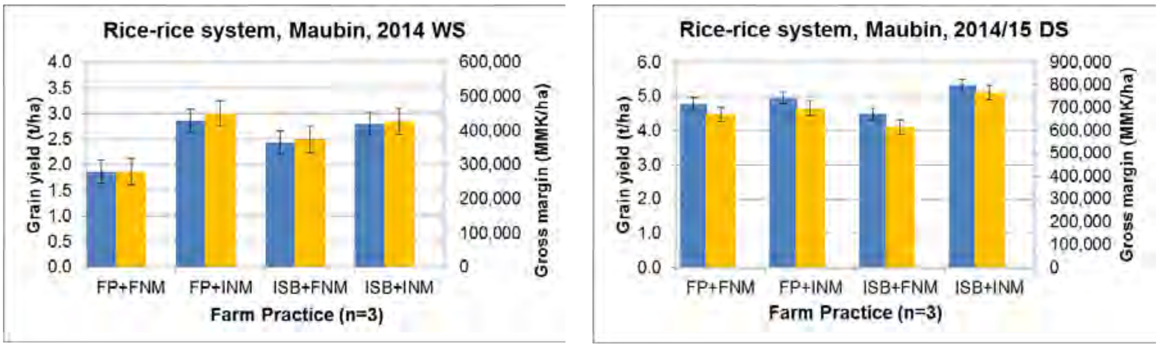

Figure 1. Grain yield and gross income with rice in the rice-rice system in Maubin Township during (a) 2014 WS (left) and (b) 2014-15 DS (right).

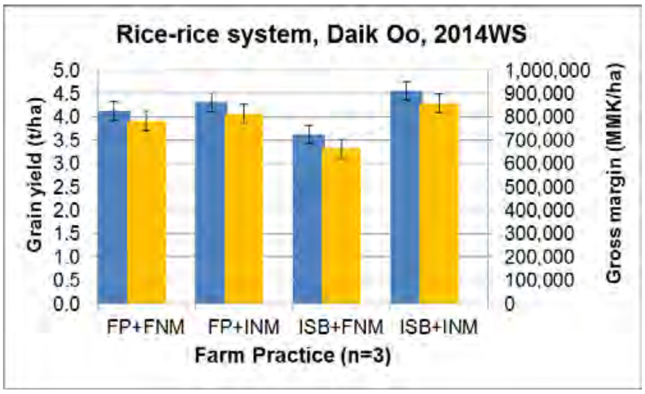

Figure 2. Grain yield and gross income with rice in the rice-rice system in Daik Oo Township during 2014 WS.

Across two townships with an average of six locations, 23% higher yield (3.7 vs. 3.0 t/ha ± 0.18 SE) and 21% higher income but with 36% higher production cost were observed with T4 compared with T1 (Figure 3).

By improving nutrient management after transplanting using the farmers' seedbed method (FP+INM), 19% higher yield (3.6 vs. 3.0 t/ha ± 0.18 SE) was observed compared with FP+FNM. This also resulted in 20% higher production cost but 19% higher income (Figure 3).

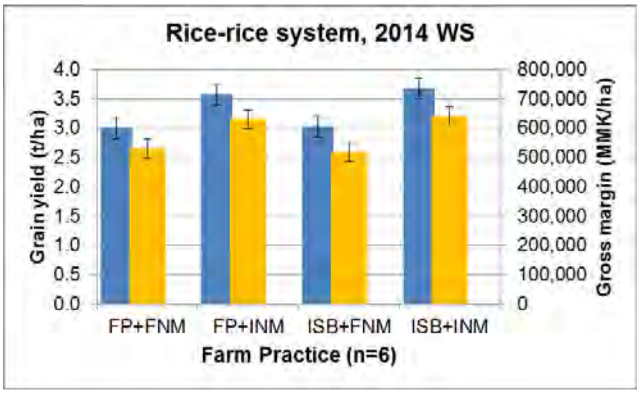

Figure 3. Grain yield and gross income with rice in the rice-rice system in Maubin and Daik Oo townships during 2014 WS.

Nutrient Management for Rice and Black Gram in the Rice-Pulse System

For monsoon rice in Maubin Township, T4 showed 5.0% higher yield (5.0 vs. 4.7 t/ha ± 0.05 SE) and 3.0% higher income than T1. With the improved system, 40% higher production cost was incurred compared with the farmers' practice (Figure 4). By improving nutrient management after transplanting but using farmer seedbed management (FP+INM), a 3.0% higher yield (4.9 vs. 4.7 t/ha ± 0.05 SE) was observed compared with FP+FNM. This also resulted in a 13% higher production cost and only 2.0% higher income (Figure 4).

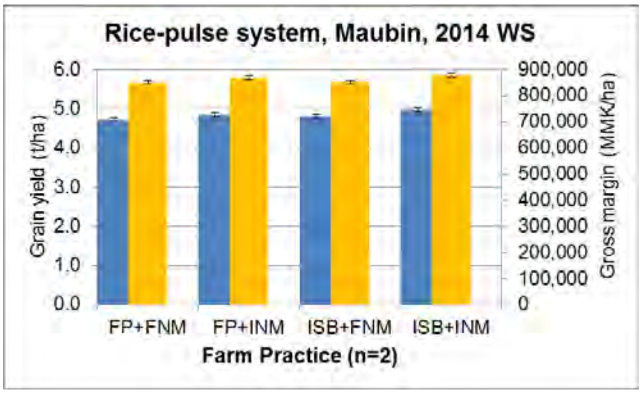

Figure 4. Grain yield and gross income with rice in the rice-pulse system in Maubin Township during 2014 WS.

For black gram grown after rice, the DAR fertilizer recommendation of 12.5 kg N, 25 kg P_2O_5, 12.5 kg K_2O, and 10 kg S/ha when applied as a basal application gave 15% higher yield and 17% higher income across five locations. The additional fertilizer application resulted in 9.0% higher production cost than the farmers' practice of basal application of TSP at the rate of 61.75 kg/ha (Table 4).

Table 4. Summary of cost and return analysis of improved nutrient management in pulses compared with the farmers' practice in the rice-pulse system, Maubin Township, 2014-15 DS.

Parameters	Rice-pulse, 2014-15 DS (n=5)									
	FPSB+FNM (WS)		FPSB+INM (WS)		ISB+FNM (WS)		ISB+INM (WS)		Mean	
	FP	DAR	FP	DAR	FP	DAR	FP	DAR	FP	DAR
Grain yield (t/ha)	1.20	1.24	1.28	1.27	1.02	1.33	1.05	1.42	1.14	1.31
Gross return (MMK/ha)	1,092,975	1,127,479	1,172,870	1,157,594	925,546	1,216,888	955,226	1,301,841	1,036,654	1,200,950
Total cost (MMK/ha)	112,275	119,811	113,475	120,411	109,275	121,011	109,875	122,811	111,225	121,011
Gross margin (MMK/ha)	980,700	1,007,668	1,059,395	1,037,183	816,271	1,095,877	845,351	117,9030	925,429	1,079,939
BCR	1.13	1.13	1.11	1.12	1.21	1.14	1.15	1.11	1.15	1.12

In Daik Oo Township for monsoon rice in the rice-pulse system, T4 showed 10% higher yield (3.9 vs. 3.5 t/ha ± 0.10 SE), an 8.0% increase in income, and a 40% increase in production cost compared with T1 (Figure 5). By improving nutrient management after transplanting while using farmer seedbed management (FP+INM), there was no increase in yield (3.5 vs. 3.5 t/ha ± 0.10 SE) compared with FP+FNM. This also resulted in a 17% higher production cost and lower income by 1.4% (Figure 5). This means that the additional production cost did not provide a considerable increase in yield and income.

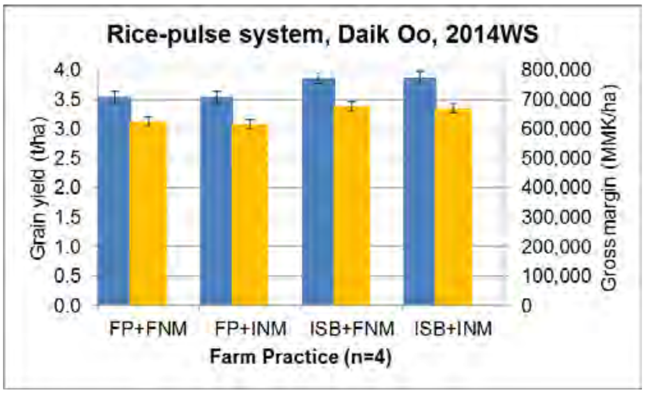

Figure 5. Grain yield and gross income of rice in the rice-pulse system in Daik Oo Township during the 2014 WS.

Across two townships, 7.0% higher yield (4.4 vs. 4.1 t/ha ± 0.07 SE) and 5.0% higher income but with 38% higher production cost were observed in T4 compared with T1 (Figure 6). By improving nutrient management after transplanting while using farmer seedbed management (FP+INM), there was a small (1.0%) increase in yield (4.2 vs. 4.1 t/ha ± 0.07 SE) compared with FP+FNM. This also resulted in a 1.5% higher production cost and gave a 0.1% increase in income (Figure 6).

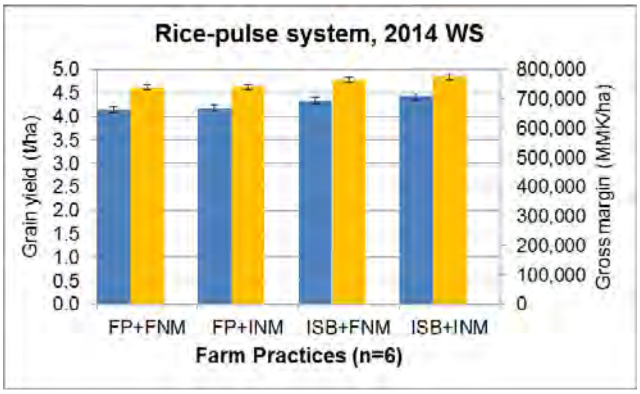

Figure 6. Grain yield and gross income with rice in the rice-pulse system in Maubin and Daik Oo townships, 2014 WS.

Conclusions

In both the rice-rice and rice-pulse cropping systems, partial cost-benefit analyses showed positive results, indicating that improving seedbed and nutrient management during the nursery stage and after transplanting resulted in higher yield and income in both townships. According to the project objectives, the importance of healthy seedlings through improved seedbed and nutrient management can be demonstrated to the farmers. Moreover, balanced nutrition with improved nutrient management is also imperative in rice-based cropping systems.

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Dry Season Rice Yield Responses to Nitrogen Fertilizer in Central Myanmar

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Abstract

Rice crop yields in central Myanmar are considered to be relatively low due to inadequate applications of fertilizer, particularly nitrogen (N). In this study, replicated field experiments were conducted at two sites, Taungoo and Yezin, in central Myanmar to determine the crop yield responses to N fertilizer for dry season irrigated rice in 2017. The two field experiments were identical in design and conducted at the same time. The experiments had a randomized complete block design with three replicates of eight treatments. The eight treatments included six rates of N fertilizer (0, 30, 77.6, 100, 130, and 160 kg N/ha), applied as two split surface-broadcast applications at 10 days after transplanting (10 DAT) and at crop panicle initiation (PI) in accordance with local farmers' practice. In addition, a urea deep placement (UDP) treatment with placement of 2.7-gram urea briquettes at IFDC-recommended spacing and soil depth at a N rate of 77.6 kg N/ha was included, as well as a nil input control. All treatments, except for the nil input control, received basal applications of phosphorus (P), potassium (K), sulfur (S), and zinc (Zn). Mean grain yields at Taungoo ranged from 3.54 t/ha (0 kg N/ha) to 5.24 t/ha (160 kg N/ha), while at Yezin they ranged from 6.78 t/ha (0 kg N/ha) to 8.15 t/ha (130 kg N/ha). The Taungoo site may represent a typical low-fertility farm site, whereas the Yezin site had a more fertile soil. The 77.6 kg N/ha application rate was found to result in a 33% increase (i.e., +1.18 t/ha) in grain yield ($P<0.05$) at the Taungoo site and a 12% increase (i.e., +0.84 t/ha) at the Yezin site ($P<0.05$), indicating benefits from this N fertilizer rate, depending on economic analysis. At the Taungoo site, the UDP treatment (77.6 kg N/ha) produced yields consistently higher than the comparable 77.6 kg N/ha surface-broadcast treatment, with a UDP mean yield of 5.23 versus 4.72 t/ha for surface broadcast. However, analysis of variance (ANOVA) found this not to be significant at P=0.05, with a t-test estimating P=0.054 for this comparison. This is sufficient to encourage further research on UDP in this environment. Yield response curves were derived for N fertilizer applications from the experimental data from the two experiment sites. The Taungoo site yield response curve for N was thought to be more applicable to the general soil fertility levels of rice farms in central Myanmar. This paper presents the first results from these experiments, which will be expanded on as the full dataset, including soil and plant analysis, is obtained.

Key Words

Rice yields, nitrogen fertilizer, urea deep placement

Introduction

Rice crop yields in central Myanmar have been found to be low relative to comparable countries, and this is thought to be due to inadequate fertilizer application (Denning et al., 2013; Hnin et al., 2013; Hla Myo Thwe et al., 2014). Min Thiha et al. (2010) reported yields of irrigated rice near Nay Pyi Taw in the range of 2.8-4.3 t/ha, with a mean of 3.3 t/ha when no fertilizer was applied, which increased to 3.7 t/ha when a modest rate of basal NPK was applied. At a national level, the use of N fertilizer is notably smaller than other comparable countries in Southeast Asia (IRRI, 2014), and is thought to be a principal cause of the low yields of rice (Denning et al., 2013; Hnin et al., 2013; Hla Myo Thwe et al., 2014).

The most common farmers' practice for N fertilizer applications in the Yezin area of central Myanmar is to surface broadcast a total of just 28-57 kg/ha of N as urea (i.e., one-half to one 50-kg bag per acre) to the paddy as two equal split applications (i.e., 50/50); one at 10 days after transplanting (10 DAT) and then another at the panicle initiation (PI) stage of the crop. The International Rice Research Institute (IRRI) recommends applying N as surface applications in three splits: 14 days after transplanting (14 DAT), at mid-tillering (20-35 DAT), and at PI (40-50 DAT) (IRRI, 2017). But research indicates that as much as half of the urea surface broadcast to paddy can be lost to the atmosphere by ammonia volatilization (Vlek and Craswell, 1979; Humphreys et al., 1987; Dong et al., 2012; Rochette et al., 2013). Recent research has reported nitrogen fertilizer use efficiency and yield benefits in paddy rice crops from the deep placement of urea briquettes in Bangladesh (Miah et al., 2016; Huda et al., 2016; Datta et al., 2017) and granular urea in China (Liu et al., 2016; Liu et al., 2017).

The objective of this study was to determine the crop N requirement and optimal N fertilizer rate for dry season rice at two sites in central Myanmar. The study is a first step toward acquiring the necessary data to inform and validate the development of a fertilizer decision support tool for farmers in central Myanmar. A UDP treatment was included in this study to extend work currently being conducted by IFDC in other rice-growing regions of Myanmar.

Materials and Methods

Replicated field experiments of identical design were established at two locations in central Myanmar to determine nitrogen fertilizer response curves for irrigated dry season rice. The two sites were at Yezin Agricultural University, near Nay Pyi Taw, and a farmer's field near Taungoo, Upper Bago. The topsoil of the Yezin site was a sandy medium-textured soil (sandy clay loam to clay loam – sandy). The topsoil at the Taungoo site was a light silty clay. The experiments had a randomized complete block design with eight treatments and three replications. The plots were 5 m × 5 m delineated by double bund walls 40 cm wide and 30 cm high. There was a 1-m spacing between plots in each block and a 3-m spacing between blocks. There were eight treatments, which included a nil input control (T1), six rates of N fertilizer applied as granulated urea by surface broadcasting [0 (T2), 30 (T3), 77.6 (T4), 100 (T5), 130 (T6) and 160 kg N/ha (T7)], and a deep placement (75 mm) treatment of 2.7-g urea briquettes according to the IFDC recommended spacing pattern at a rate of 77.6 kg N/ha (T8). The six surface-broadcast granulated urea treatments (T2, T3, T4, T5, T6, T7) were applied to the plots in accordance with the dominant local farmer practice in the region, which is to apply the urea N fertilizer as two equal split applications (i.e., 50/50): one at 10 DAT and the second at the PI phase in the crop. The deep-placed urea briquettes were also applied to the plots 10 DAT so that a direct comparison could be made between surface broadcast (T4) and deep placement (T8) for the 77.6 kg N/ha N application rate.

The plots of all treatments, except for the nil control (T1), received basal applications of P as triple superphosphate at 40 kg of P/ha, S as gypsum at 25 kg S/ha, K as muriate of potash (KCl) at 25 kg K/ha (+ two later applications = total of 75 kg K/ha for each trial). The roots of the rice transplant seedlings, with the exception of T1, were dipped in a 2% Zn solution (as $ZnSO_4$) prior to transplanting in order to eliminate Zn deficiency. Rice seedlings were transplanted at a 20-cm plant hill spacing commencing 10 cm in from the edge of the plot with three to four individual seedlings planted on each hill on average. The *Yadanar Toe* rice variety was selected for these field experiments on the basis that it was a common dry season variety grown by local farmers. The plots were irrigated with bore water at the Yezin site and channel irrigation water at Taungoo. Initially, the fields were flushed with irrigation water and the areas between the bunded plots were filled with fresh irrigation water, which was then bucketed by hand into the bunded plots until a water depth of about 15 cm was achieved. This water level within the bunded plots was then allowed to drop over time until it was only a few centimeters deep over any one plot, at which point the irrigation procedure would be repeated. The plots were irrigated on a regular basis to keep the water level within the plots between 5 cm and 20 cm deep at all times.

The central 1.8 m × 1.8 m of each treatment plot was harvested by hand with sickles by cutting the plant just above the soil surface. The harvested rice was then threshed with a foot-pedal operated threshing machine, and the threshed material was then sieved and winnowed to separate the grain from other plant matter. The total grain weight was weighed, and the moisture content of the grain was measured at harvest using a grain moisture meter. The total fresh weight of the biomass of the rice crop plants from the harvested area was measured on a field balance following threshing, and a representative 1-kg subsample of the fresh biomass was then taken and placed in a paper sample bag and weighed on an accurate lab balance, dried to constant mass at 65°C in an oven, and reweighed to then calculate the dry matter biomass weight for the harvested crop plant (minus the grain). The harvested rice grain weight from the harvested area of each plot was then adjusted to the standard 14% moisture content used for rice research. These figures for dry matter crop biomass and grain yield (adjusted to 14% moisture content) were then converted to t/ha for data analysis. The full range of rice crop yield parameters (i.e., number of panicles, filled and unfilled spikelets, tillers per area, and 1,000-grain weight) were also determined from a subsample of six plant hills within the harvest area using the standard methodologies outlined in Dobermann and Fairhurst (2000).

This paper presents only the first results from Taungoo (established on 26 February 2017 and harvested on 13 June 2017) and Yezin (established on 5 March 2017 and harvested on 20 June 2017) field experiments.

The data were analyzed using a one-way ANOVA with blocking by Genstat® (18th ed.). Least significant difference (LSD) at 5% level was used to compare differences between treatment means when the F-test was significant ($P<0.05$). A student t-test was also carried out between harvest data of treatments T4 and T8 for the Taungoo site data to further evaluate if these treatment means were significantly different at $P=0.05$, and interpreted cautiously given Genstat® rated less than five replicates (three in this case) as insufficiently robust. The Taungoo site harvest data were log transformed prior to the ANOVA and t-test analyses to meet normal distribution assumptions. The N response curves were fitted to the harvested grain yield data of the sites by fitting an exponential (or asymptotic regression) Mitscherlich curve function to the data using the FITCURVE function of Genstat®.

Results and Discussion

Treatment Effects at the Taungoo Site

The ANOVA results for the Taungoo site rice harvest data are shown in Table 1. The mean grain yield of the nil control (T1) treatment was found to be not significantly different to the 0 kg N/ha (T2) treatments, indicating basal nutrients (P, K, S, and Zn) were not limiting at the zero N rate at this site. The mean grain yield for T3 (30 kg N/ha) was found to be not significantly different (*P=0.05)* to the T1 (0 kg N / ha) mean grain yield. This finding is important as it indicates that the T3 treatment (30 kg N/ha), which represents the most common N application rate used by local poor farmers for summer rice (dry season rice), was not sufficient to significantly increase the grain yield at this location.

Table 1. Treatment mean grain yield (adjusted to 14% moisture) and dry biomass at harvest for the 2017 irrigated dry season rice crop at Taungoo.

Treatment	Grain Yield (14% M) (t/ha)	S.D.	Dry Biomass (t/ha)	S.D.
T1 – nil Control	3.74 (0.57) c	0.11	6.78 (0.82) cd	1.54
T2 – 0 kg N/ha	3.54 (0.55) c	0.31	5.86 (0.77) d	0.28
T3 – 30 kg N/ha	3.86 (0.59) c	0.42	6.91 (0.83) cd	1.62
T4 – 77.6 kg N/ha	4.72 (0.67) a	0.21	7.45 (0.87) bcd	1.63
T5 – 100 kg N/ha	4.34 (0.64) b	0.40	6.47 (0.81) cd	0.57
T6 – 130 kg N/ha	4.37 (0.64) b	0.25	8.68 (0.93) abc	1.81
T7 – 160 kg N/ha	5.24 (0.72) a	0.28	9.95 (1.00) a	1.26
T8 – UDP – 77.6 kg N/ha	5.23 (0.72) a	0.25	9.38 (0.97) ab	1.25
LSD (P=0.05)	(0.05)		(0.12)	

Values in parenthesis are the means of the $\log_{10}$ transformed data used in the ANOVA. Treatments with the same letter within each column indicate no significant difference between the treatment mean values at P=0.05. S.D. is standard deviation.

However, the mean grain yield of T4 (77.6 kg N/ha) was found to be significantly higher than all of the other surface-broadcast (farmer practice) rate treatments except for T7 (160 kg N/ha), the largest urea application rate, where no significant difference was found for mean grain yield. This suggests that the T4 treatment resulted in a significant increase in grain yield at the site and that no significant increase in mean grain yield was achieved by increasing the urea application above this at this site on this occasion.

These results for the surface-broadcast urea application treatments show that the application of urea at a rate of 77.6 kg N/ha increased the yield, on average, by 1.18 t/ha from 3.54 t/ha to 4.72 t/ha at the Taungoo site (Table 1). In contrast, an application of urea at a rate of 160 kg N/ha increased the yield, on average, by 1.70 t/ha. Thus, increasing the N fertilizer from 0 kg N/ha to 77.6 kg N/ha resulted in a yield increase of 15.2 kg of rice for every kg of N applied per hectare, while the increase in yield for the additional urea to bring the application rate from 77.6 kg to 170 kg N/ha represented a yield increase of only 6.3 kg of rice for every additional kg of N applied as urea per hectare.

A comparison of the grain yield results for treatments T4 and T8 represents a comparison of the farmers' practice of surface-broadcast application with the deep placement of urea briquettes (UDP) at a common urea application rate of 77.6 kg N/ha. At the Taungoo site, no significant difference at $P=0.05$ level was found between the mean grain yields of T4 (77.6 kg N/ha – surface-broadcast farmer practice) and T8 (77.6 kg N/ha – deep placement of urea briquettes). Further comparison of the yield results for these treatments in Table 2 using a student t test found that the probability that the difference between the means was due to chance was only $P=0.054$ (noting the replicate number was sub-optimal, n<5). Likewise, the range of values for each treatment (i.e., the minimum to maximum values for the replicates), Table 3, did not overlap, providing a case supporting the need for further UDP research trials.

Table 2. Comparison of the grain yield results for treatments T4 and T8 (both 77.6 kg N/ha) for the irrigated dry season rice crop at the Taungoo site.

Treatment	Sample Size (n)	Min. Value	Max. Value	S.D.	Mean Grain Yield (14% M) (t/ha)
T4	3†	4.50	4.93	0.21	4.72 (0.67)‡
T8 – UDP	3	5.01	5.50	0.25	5.23 (0.72)
*Probability (P)** (d.f = 4; t = -2.70)					0.054

† *Note: Genstat 18th edition recommends n>5 to ensure t-test results are robust.*

* *Probability that apparent difference in means is due to chance.*

‡ *$\log_{10}$ of mean is in parentheses. Note: t test was carried out on $\log_{10}$ transformed data.*

Table 3. Comparison of the dry biomass results for treatments T4 and T8 (both 77.6 kg N/ha) for the irrigated dry season rice crop at the Taungoo site.

Treatment	Sample Size (n)	Min. Value	Max. Value	S.D.	Mean Dry Biomass (t/ha)
T4	3†	5.78	9.04	1.63	7.45 (0.86) ‡
T8 – UDP	3	8.28	10.73	1.25	9.38 (0.97)
*Probability (P)** (d.f = 4; t=1.60)					0.184

† *Note: Genstat 18th edition recommends n>5 to ensure t-test results are robust.*

* *Probability that apparent difference in means is due to chance.*

‡ *$\log_{10}$ of mean in parentheses. Note: t test was carried out on $\log_{10}$ transformed data.*

Crop dry biomass (excluding grain) results presented in Table 1 show that only treatments T6 (130 kg N/ha), T7 (160 kg N/ha), and T8 (UDP – 77.6 kg N/ha) had mean dry biomass values significantly higher than T2 (0 kg N/ha) treatment. No significant difference was found between the mean dry biomass at harvest values for T4 (77.6 kg N/ha – farmer practice) and T8 (77.6 kg N/ha – UDP) (Table 1 and Table 3).

Treatment Effects at the Yezin Site

The results of the ANOVA for the Yezin site rice harvest data are presented in Table 4. It is important to first note that the mean rice grain yield for the zero N treatment (T2) of 6.78 t/ha at the Yezin site is actually higher than the mean rice yield for the highest N rate treatment (T7 – 160 kg N/ha) at the Taungoo site, which was 5.24 t/ha (Table 1). This suggests that there were significant amounts of plant-available N being supplied to the rice crop at the Yezin site from the soil itself (soil mineral N reserves, mineralized N from organic N in the soil, N fixation from free living N_2 fixing microbes, applied water) before any N fertilizer was added. At present, we can only speculate as to the reasons for the higher yield at the Yezin site, but when we have all of the analytical results from the soil, plant, and water samples from the experiment, the reasons should be apparent.

No significant difference was found between the grain yield means for the nil control (T1) treatment and the zero N treatment (T2), indicating no grain yield response to the basal applications of P, K, S, and Zn at this site at 0 N/ha application rate. However, the T2 treatment did have a significantly higher mean dry biomass value compared to the nil control (T1), indicating that there was a crop biomass response to the basal fertilizers but that this did not translate into an increase in grain yield.

Table 4. Treatment mean grain yield (adjusted to 14% moisture) and dry biomass (t/ha) at harvest for the irrigated dry season rice crop at Yezin.

Treatment	Grain Yield (14% M) (t/ha)	S.D.	Dry Biomass (t/ha)	S.D.
T1 – nil Control	6.89bc	0.28	11.0c	0.44
T2 – 0 kg N/ha	6.78c	0.06	13.3b	0.37
T3 – 30 kg N/ha	7.10bc	0.78	15.2ab	1.48
T4 – 77.6 kg N/ha	7.62ab	0.29	15.0ab	0.85
T5 – 100 kg N/ha	8.13a	0.45	16.8a	2.20
T6 – 130 kg N/ha	8.15a	0.25	15.3ab	1.15
T7 – 160 kg N/ha	7.49abc	0.18	15.4ab	1.54
T8 – UDP – 77.6 kg N/ha	7.65ab	0.88	17.0a	1.14
LSD (P=0.05)	0.76		2.2	

Treatments with the same letter within each column indicates no significant difference between the treatment mean values at P=0.05. S.D. is standard deviation.

Even though the mean grain yield values for the treatments were greater than for the Taungoo site, the significant treatment responses are similar in some ways. The mean grain yield of the farmer practice N rate treatment, T3 (30 kg N/ha), was again not significantly different to T2 (0 kg N/ha). However, the results were highly variable with a very high S.D. The mean rice grain yield of 7.62 t/ha for T4 (77.6 kg N/ha) was significantly higher than the T2 (zero N) mean grain yield of 6.78 t/ha but not significantly different to the other N treatments (T3, T5, T6, T7, T8).

The grain yield results for the surface-broadcast urea application treatments (T2-T7) show that the application of urea at a rate of 77.6 kg N/ha increased the yield, on average, by 0.84 t/ha from 6.78 t/ha to 7.62 t/ha at the Yezin site. In contrast, an application of urea at a rate of 130 kg N/ha increased the yield, on average, by 1.37 t/ha.

Thus, the yield increase associated with increasing the N fertilizer rate from 0 to 77.6 kg N/ha urea application represented a yield increase of 10.8 kg of rice for every kg of N applied per hectare, which was less than the Taungoo site result of an extra 15.2 kg of rice for every kg of N applied up to 77.6 kg N/ha. This suggests that there may be some potential yield response to applying this rate of N at the Yezin site, but the environmental impacts would need to be assessed in addition to the economics before recommending this application rate.

The mean grain yields for T4 (77.6 kg N/ha – surface broadcast) and T8 (77.6 kg N/ha, as UDP briquettes) were not significantly different ($P=0.05$) at Yezin, being 7.62 and 7.65 t/ha, respectively. Likewise, no significant difference ($P=0.05$) was found between the mean dry biomass (t/ha) values for these treatments at harvest at the Yezin site.

In terms of crop dry biomass response, it can be seen in Table 4 that only the 100 kg N/ha (T5) and the UDP treatment at a rate of 77.6 kg N/ha had mean dry biomass values that were significantly ($P<0.05$) higher than the zero N treatment (T2) mean value of 13.3 dry t/ha. The T5 and T8 treatments increased crop dry biomass relative to the zero N treatment (T2) by 26.3 and 27.8%, respectively, at the Yezin site. The other treatment means for crop dry biomass at harvest were found to be not significantly different to the zero N treatment (T2) mean value.

N Response Curves for Grain Yield at the Two Sites

Plots showing the development of the preliminary N response curves for grain yield in dry season irrigated rice at the Taungoo and Yezin experiment sites are presented in Figures 1 and 2, respectively. Of these two response curves, the one for the Taungoo site (Figure 1b) is thought to be more representative of the typical local farm situation (with a zero N rate grain yield of around 3 t/ha) and more reflective of the likely crop response to N on the farmers' fields. In contrast, the rice grain yield response curve for the Yezin site represents the response at a higher soil fertility site, with its zero N rate grain yield >6.5 t/ha, which is higher than the grain yield for the highest N rate (i.e., 160 kg N/ha) at Taungoo. The grain yield response curve for Taungoo is thought to be the most relevant to the most common farmer situation. An exponential functional form (Yield = $\alpha + \beta(\rho^N)$) was considered most appropriate since it assumes the crop yield increases with added N to a maximum, or plateau yield, which is represented in this function form as an asymptote.

For the Taungoo site, it can be seen in Figure 1a, which includes all five N rates (0, 30, 77.6, 100, 130, and 160 kg N/ha), that two of these rates, 100 and 130 kg N/ha, appear to have had a subdued response, which did not fit well with the trend apparent from the other N rates. This contributed to a relatively poor fit ($R^2 = 0.498$) for response curve (I), which was fitted to the whole dataset (Figure 1b). When the grain yield data for these two rates were removed from the dataset, the response curve (i.e., curve II) achieved an improved fit ($R^2=0.792$) for the remaining four N rates (see Figure 1b). As such, the relationship for the fitted exponential curve for curve II in Figure 1b, which is $Y = 5.558 - 2.011(0.98859^{x})$, represents a relationship that better describes the yield response to N fertilizer at the Taungoo site. A simplistic substitution of the mean grain yield for the T8 (UDP treatment) at Taungoo from Table 1 (i.e., 5.23 t/ha) into N response curve II in Figure 1b, would suggest that the UDP application of 77.6 kg N/ha would be equivalent to a surface-broadcast application of 160 kg N/ha as urea.

For the Yezin site, it is apparent that the yield response for the 30 kg N/ha rate was highly variable and that the highest N rate, 160 kg N/ha, decreased to lower yields than the 100 and 130 kg N/ha rates. This had a dominant influence on the initial fitted response curve (curve I) and impacted data variability (R^2 = 0.437) (Figure 2a). One option for improving the description of the response curve is to remove the grain yield data for the top rate, which had an anomalous response, and also the data for the 30 kg N/ha rate, which Genstat identified as having high residuals in the curve (I) fitted in Figure 2b. When this was done, the exponential curve function fitted to the reduced data set slightly improved the proportion of data variability accounted for (R^2=0.621), but the curve (II) lost its classical asymptotic form, limiting its functionality (Figure 2a) and making it the less preferable of the two curves.

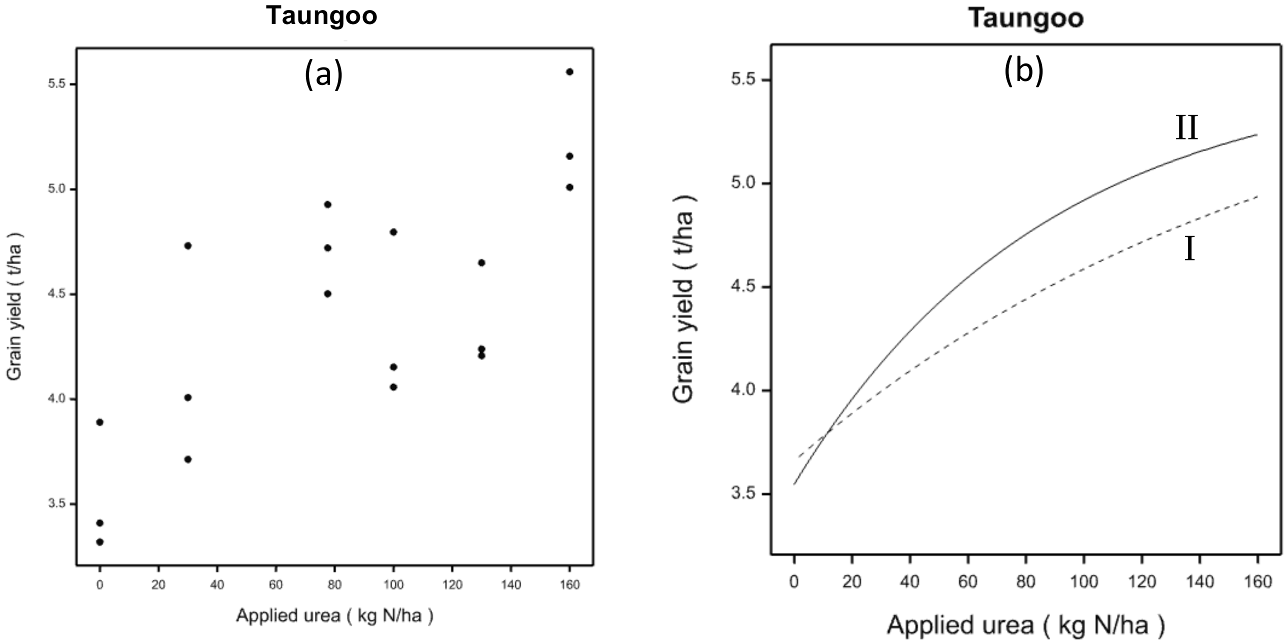

Figure 1. Crop grain yield (adjusted to 14% moisture) response to N application rate (surface broadcast) at the Taungoo site with (a) individual data and (b) response curves. I - fitted to whole dataset [$Y = 5.79 – 2.13 (0.9943^X)$; P=0.002, R^2 = 0.498].
II - fitted to treatments 0, 30, 77.6, and 160 kg N/ha [$Y = 5.558 – 2.011(0.98859^X)$; P<0.001, R^2 = 0.792].

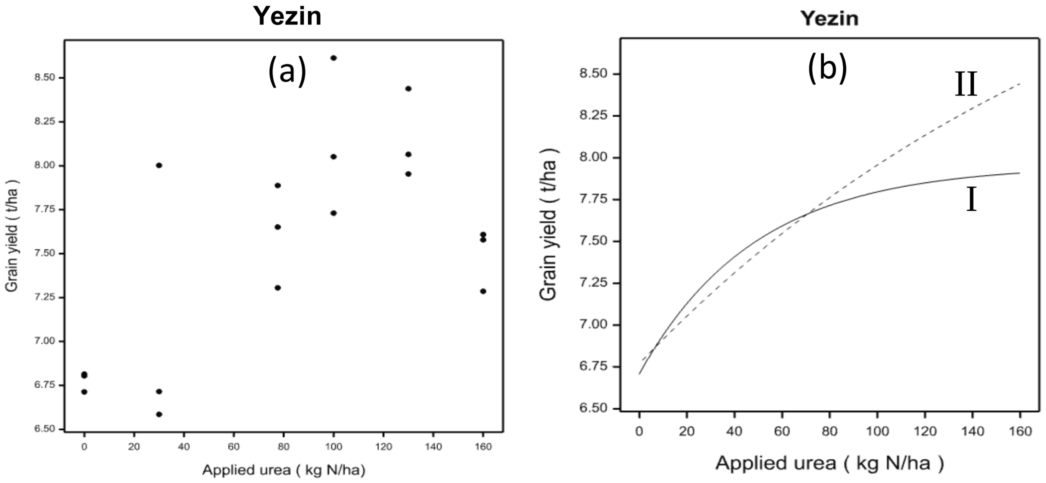

Figure 2. **Crop grain yield (adjusted to 14% moisture) response to N application rate (surface broadcast) at the Yezin site with (a) individual data and (b) response curves. I - fitted to whole dataset [$Y = 7.955 – 1.247 (0.9796^X)$; $P = 0.005$, $R^2 = 0.437$]. II - fitted to treatments O, 77.6, 100, and 130 kg N/ha [$Y = 9.93 – 3.16 (0.9953^X)$; $P<0.001$, $R^2 = 0.765$].**

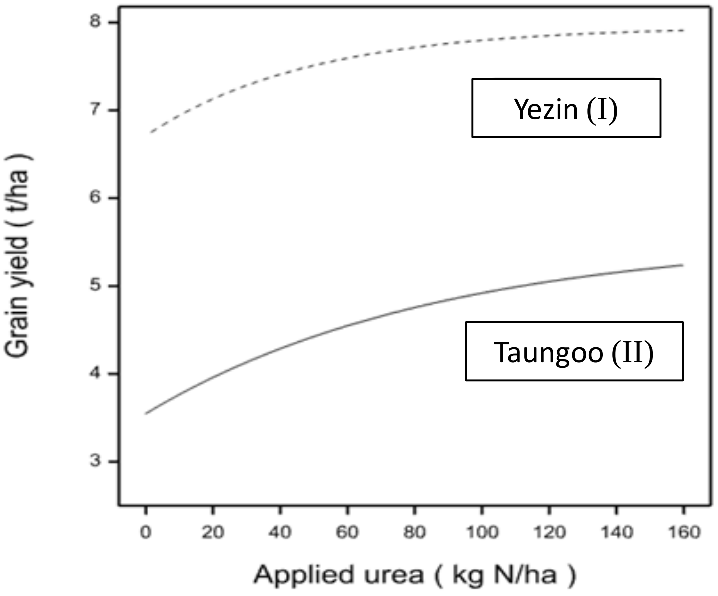

Figure 3. **A comparison of the dry season rice grain yield (adjusted to 14% moisture) response curve (II) at the Taungoo site (Figure 1b) with grain yield response curve (I) for the Yezin site (Figure 2b).**

The preliminary N response curve for dry season rice grain yields for the Yezin site is compared with that of the Taungoo site in Figure 3. The grain yield response curve for the Taungoo site is a fairly standard response curve form and is thought to be more representative of the typical farm situation in central Myanmar. In contrast, the Yezin site response curve is perhaps one reflecting a more fertile site with naturally higher background soil N levels or higher fertility levels resulting from its previous use as a research station. Although response curve II probably accounts for the trends and variability in the data for the Yezin site better than curve I, curve I provides a more standard response curve form (Figure 3). The Yezin curve (Yezin I) appeared slightly flatter overall than the Taungoo response curve (Taungoo II), with the Taungoo curve being noticeably steeper at the lower rates < 80 kg N/ha (Figure 3). The Taungoo N yield response curve function may prove to be of value for crop modeling applications and the development of tools for predicting yield response to N in irrigated rice in the dry season for central Myanmar. The results in this paper reflect the preliminary results from the first field experiments for this project, interpreted without the benefit of soil and plant data. As such, these results are preliminary and will be refined with further analyses.

Conclusion

The two field experiments at Taungoo and Yezin provided results on the response of irrigated dry season rice to N fertilizer at two central Myanmar sites with contrasting soil fertility. The results from the Taungoo site provided an adequate N response curve for what is believed to be the more common soil fertility conditions, which will allow for further analysis incorporating economics. The 77.6 kg N/ha urea rate achieved a significant increase in yield at the Taungoo site and at the Yezin site. The UDP treatment achieved a higher mean grain yield than the comparable surface-broadcast treatment at Taungoo, just falling short of 5% significance, but providing enough encouragement for future investigations. It is hoped that further soil and plant analyses, and data for ^{15}N-labeled urea micro-plots, when they become available, will allow a detailed assessment of the N use efficiency at these experiment sites to complete the study.

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Challenges Identifying Fertilizer Responses in Infertile Coarse-Textured Soils of the Central Dry Zone – A Field Perspective

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Abstract

Soil testing of sandy soils across the Central Dry Zone (CDZ) of Myanmar reveals potentially extensive phosphorus (P), potassium (K), and sulfur (S) deficiencies. Sixty-one field trials were conducted during 2014-2015 on a range of crop species to identify and confirm growth responses to applied fertilizer. Single-element fertilizer application resulted in no increase in grain yield in 95% of trials. There was also little evidence that applied fertilizer was recovered in plant biomass after seven weeks of growth in most trials. A revised program was conducted in 2015-2016 that included 21 full factorial omission trials. Again, application of a full basal suite of nutrients considered limiting resulted in increased yield at only one site (P and S responsive). Another site responded positively to boron (B) and S. Despite convincing evidence of low soil fertility, the application of fertilizer failed to materially increase grain yield in the majority of crops and seasons. Grain yields are generally below and often <50% of yield potential in these environments, strongly suggesting further research is required. Key factors driving consistent reliable responses of crops to fertilizer application in infertile soils under high rainfall intensity during the growing season include the timing of nutrient additions to better match plant demand and strategies to increase soil organic matter for both slow release of nutrients through mineralization and retention of water in the profile. Significant areas of the CDZ will move to mechanized farming systems as labor shortages increase, drastically changing the farming system by reducing the manure inputs upon which stable (but low) yields have been maintained.

Introduction

Surveys of soil chemical values in the CDZ of Myanmar indicate low P and S status in many fields. A recent survey identified 61% of sites were low in P, 48% of sites low in K, 35% of sites low in S with 18% of sites low in all three macronutrients P, K, and S (Guppy et al., 2017). The expectation is that yields for pulses in the CDZ of Myanmar would be considerably improved through the application of fertilizer, the current amount applied being typically low and predominantly consisting of manure or compound fertilizer applied before or early in the monsoon season (and hence susceptible to leaching) (Birchall et al., 2017). This paper describes five years of research into soil nutrient responses of pulses and sesame in the CDZ and the many challenges identified in demonstrating that nutrients are in fact limiting pulse production.

Materials and Methods

Over four years of field trials in the CDZ are summarized briefly in this paper. In the first season (2014-15), after soil surveys indicated that nutrient levels were low, simple on-farm demonstration trials were conducted in the monsoon and post-monsoon seasons in 61 locations, from Sagaing Region in the north of the CDZ to Magway Region in the southern CDZ. These trials examined the response to broadcast applications of 10 kg P/ha or 20 kg S/ha at the commencement of the season. Rates were estimated based on the coarse texture and lack of likely fixation of added nutrients. Farmers then sowed crops over the top of the nutrient trials and Department of Agricultural Research (DAR) staff harvested adjacent +/- P or S trials just prior to normal harvest. Two more complete trials with basal nutrients added and Zn included were undertaken on alkaline clay chickpea fields in the Sagaing Region. Biomass cuts and grain yield were recorded from all trials.

The second trial season (2015-16), considering the lack of response in the first season, was more detailed. We established replicated trials on farmer fields, with basal nutrient additions so that only the responses to the nutrients of interest would be measured. Twenty-one replicated trials were established in fields selected from soil survey data (Guppy et al., 2017), to allow critical soil test values to be determined when the range of sites were pooled. Factorial omission trials with rates of P (20 kg P/ha), K (50 kg K/ha), and S (20 kg S/ha) as both sulfate and elemental S were established. Basal B was also applied. Biomass cuts were undertaken 40 days after sowing (DAS) to record fertilizer uptake and early season nutrient responses. Surface soil samples were taken before and after the trials to indicate the fate of applied nutrients.

The last season of trials we report on (2017-18) involved intensive work with just four villages in the Magway Region. Three to five fields in each village were identified for nutrient trials using groundnut and sesame in the monsoon season. Fertilizer was either not applied as a control, applied as a basal application at sowing, or split into multiple applications through the growing season to account for the risk of leaching. Yield was recorded at harvest.

Harvested material was dried, ground, and analyzed for P and S at DAR, Yezin, and the University of New England (UNE), Armidale, using UltraWAVE nitric acid digestion followed by Inductively Couple Plasma-Optical Emission Spectrometer (ICP-OES) with appropriate standards for selected experimental data. One-way analysis of variance (ANOVA) test was used to determine significant treatment effects to fertilizer application at $P<0.05$ using R 2.3.3. Tukey multiple comparison analysis was also done to compare the treatments.

Results and Discussion

The first season of trials revealed minimal response to applied P or S fertilizer when farmers undertook demonstration plots (Figure 1). Twenty-five groundnut plots and 36 chickpea plots revealed minimal increase in yield as a result of broadcast, at-sowing nutrient application at a range of sites throughout the CDZ. In contrast, more carefully established trials for chickpea in the Sagaing Region identified responses to nutrient application when basal nutrients were applied (Figure 1).

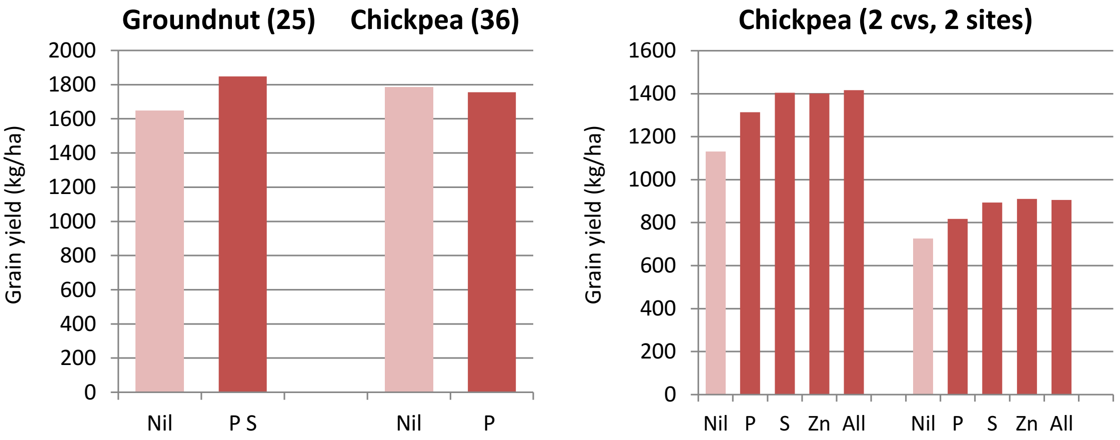

Figure 1. ***Effect of P or S application as a broadcast, pre-sowing fertilizer application on a range of low fertility sites throughout the CDZ of Myanmar grown in either the monsoon or post-monsoon season.***

Results from the first trial season resulted in consideration of the importance of basal fertilizer application to ensure other nutritional factors were not limiting yield. However, across 21 sites in the second season, inconsistent responses were observed to application of nutrients considered low according to soil tests. Average yields for groundnut ranged from 520 to 1,520 kg/ha at nine sites and from 780 to 2,350 kg/ha for chickpea at nine sites in the northern CDZ. Treatment effects to fertilizer were negligible at most sites, with the exception of significant responses to S and B in an earlier sown green gram crop at Magway (Figure 2). Although one groundnut crop did respond to basal nutrient addition, and combined P and K addition (Figure 2), the response in most fields demonstrated that either farmer treatments or nil fertilizer application out-yielded fertilizer addition. In fact, biomass cuts 45 DAS revealed applied nutrients were not being recovered by plant tops, with negative fertilizer recovery values at most sites (data not shown).

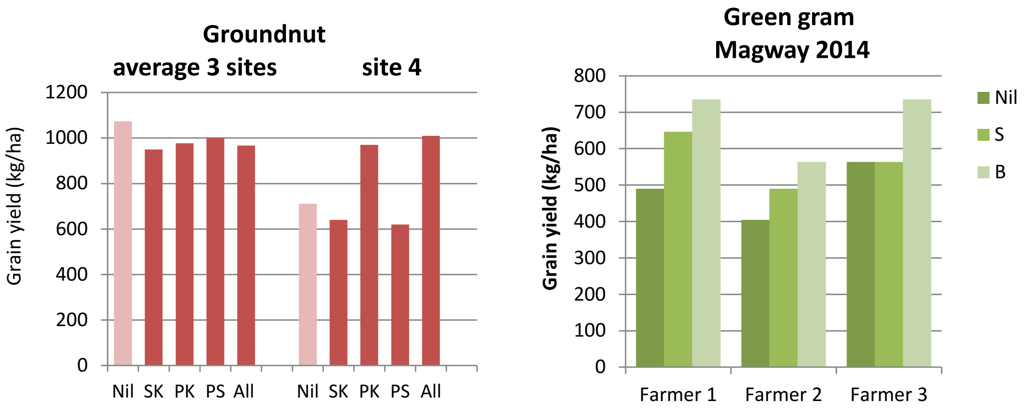

Figure 2. ***Response of groundnut to basal addition of P, K, and S in factorial combinations at four sites in the southern CDZ of Myanmar. Yield response of green gram to S and B application at three sites.***

In 85% of 2015-2016 experiments, groundnut and chickpea yields failed to reach 50% of benchmark-expected yields for the sites. Theoretical water-limited yields of 2,700 kg/ha for groundnut and 3,200 kg/ha for chickpea can be achieved in the CDZ when no other factors are limiting. The further lack of response to applied nutrients prompted a change in strategy within the project. Benchmarking trials of farmer fields to identify what factors, outside of nutrition, may be reducing the response to applied nutrients, or decreasing yields generally in the CDZ.

In the second season of benchmarking trials, the risk of leaching of nutrients in the intense rainfall associated with monsoon was addressed through a trial that split fertilizer applications of S (for groundnut) and of N and S (for sesame). In seven of nine fields, sesame yields more than doubled over the control treatments when fertilizer application was split. In six of nine fields, split application increased sesame yields over a basal application by at least 70%. Encouragingly, in all fields, the application of fertilizer resulted in yield increases in sesame (Figure 3).

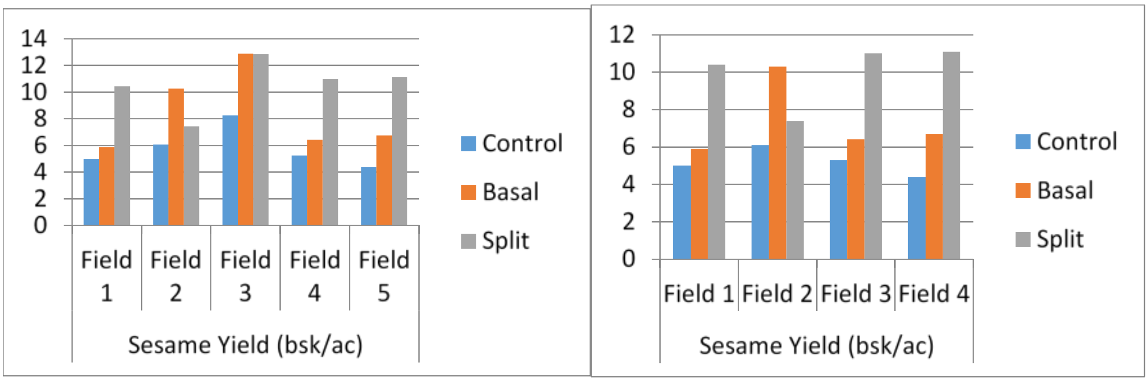

Figure 3. Response of sesame at Nat Kan (left) and Phoe Lay Lone (right) to either no fertilizer, basal addition of P, K, and S at sowing, or split application of P, K, and S in nine farmer fields in Magway Region during the monsoon season.

Groundnut trials were less successful (data not shown), both due to the inherently higher soil fertility of the benchmarked village (Ma Kyi Kan, Magway) and drier early season rainfall patterns that reduced the timing and leaching differences between basal and split fertilizer applications to 10 days. Yields in all three fields were close to benchmarked expectations. The only field lower than expected still doubled groundnut yield to nearly 3,300 kg/ha when nutrients were applied. However, there was no response to whether the nutrients were applied up-front or split over the season, as indicated above.

The results of these trials provided clues to successful fertilizer management strategies for pulse production systems in the CDZ of Myanmar. Lack of response to direct fertilizer application at sowing could be attributed to a number of factors. Firstly, early trials were conducted on “contact farmer” fields, or fields of more successful and innovative growers. These fields may have been more fertile than average and, hence, less responsive. However, as benchmark yields were not regularly achieved in these fields, this is less likely a driving factor in the absence of any yield responses. Secondly, multiple nutrient deficiency was addressed in the second series of trials. Yield is only as great as the most limiting plant growth production factor. It was possible that early failure to respond to fertilizer application was simply because another nutrient was limiting growth more than the nutrient applied. When basal fertilizer was applied, however, fertilizer responses became less likely, and results suggested that fertilizer was not visible to the root systems of the crops. While multiple deficiency remains an important factor, we suggest it is not the driving factor in lack of responses. Thirdly, basic agronomy associated with crop management, particularly weed management, could limit the ability of crops to respond to applied nutrients. A number of farmer plots had heavy weed burdens, and in many instances, plant populations were lower than ideal due to seedling diseases or planting times that did not provide ideal early season moisture conditions.

One key reason we believe fertilizer responses were challenging to observe was high rainfall leaching applied nutrients below the root zone, prior to plants having a root system dense enough to recover applied nutrients. Splitting fertilizer applications, as described and recommended in Birchall et al. (2017), resulted in a constant and steady supply of nutrients despite early leaching of applied nutrients (particularly N and S, but also P). Benchmarking trials identified that regular, small additions of gypsum doubled yields. These results agree with those of Sitthaphanit et al. (2009) who observed significant monsoon-driven leaching of applied nutrients early in the growing season, prior to root establishment in coarse-textured soils used for maize production in Thailand. Fertilizer application strategies that delay the supply of nutrients to match plant demand more closely in these sandy soils result in consistently higher yields. Historically, slow-release nutrient supply was maintained using manure additions, and that remains a key feature of nutrient management in these soils. This raises the important point that soil organic matter drives soil fertility and, indeed, fertilizer responses in the coarse-textured soils of the CDZ.

An early trial examining the response of forage sorghum to application of N and P fertilizer on a sandy soil at the Magway Research Station was confounded by trial placement. The third replication was located over a historically uncultivated berm between fields and hence was very high in organic matter due to lack of cultivation and the presence of permanent grass cover. While dry matter yield of forage sorghum was 56% higher following addition of N and P fertilizer, plants were still pale and clearly nutrient deficient in the majority of the trial. In contrast, the replicate over the organic matter-rich berm was 778% higher in yield, and was tall and dark green. An adjacent field of groundnut that also was planted over the berm had smaller visual differences, suggesting N availability from mineralized organic matter was particularly significant for the non-legume crop. The clear implication of this result is that the ability to respond to applied nutrients is compromised by lack of organic matter in the soil, and until strategies to increase organic matter are pursued, yields will continue to fail to reach potential throughout the CDZ.

Conclusion

Over five years of field research programs, the key factors driving consistently reliable responses to fertilizer application to infertile soils under high rainfall intensity during the growing season were identified. First, timing of nutrient additions needs to better match plant demand. Second, development of farming systems that increase soil organic matter in the soil, and to depth, are critical to achieving benchmark yield potentials. Building up soil organic matter is particularly critical as, over the next decade, significant areas of the CDZ will move to mechanized farming systems as labor shortages decrease the supply of workers for key planting, weeding, and harvesting operations. The shift to mechanization will drastically change the farming system, removing the manure upon which stable (but low) yields have been maintained.

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Phosphorus and Sulfur Placement Strategies for Improving Groundnut Production in Coarse-Textured Soils of the Central Dry Zone

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Abstract

Soil phosphorus (P) and sulfur (S) levels are low in coarse-textured soils of the Central Dry Zone of Myanmar. Surface soils may dry out frequently enough to affect nutrient recovery. An experiment was conducted to determine the effect of placement of P and S, either on the surface or at depth, on groundnut yield and nutrient recovery. No effect of P or S fertilizer, or placement strategy, was observed on groundnut yield ($P>0.05$). Application of P and S increased tissue P and S concentrations by 5-8% ($P<0.05$), but did not increase P and S uptake ($P>0.05$). Groundnut yields ranged from 0.8 to 1.1 t/ha, or approximately 40% of estimated groundnut yield potential. The lack of response suggests that other factors, including flooding, may have limited yield at this site, despite irrigation, high surface P and S, and basal nutrient application. Further research is required to identify other limits to groundnut yield prior to determining the benefits or otherwise of placement strategies of P and S.

Introduction

Surveys of soil chemical values in the Central Dry Zone of Myanmar indicate low P and S status in many fields (Guppy et al., 2017). P and S are elements that behave differently in many farming systems, with P less mobile than S due to higher P fixation by soil colloids (Pinkerton and Simpson, 1986). This often results in situations where P is enriched in the surface soil while S is leached and, hence, distributed more evenly through the soil profile and may be below critical requirements.

Recent analysis of rainfall patterns and distribution over the CDZ in the last 50 years (Cornish et al., unpub.) suggests that while annual rainfall has not changed, rainfall amounts are now larger, more intense, and occur 40% less frequently. This results in surface soil moisture conditions that could promote periodic surface drought and renders inaccessible the P-rich surface soil for longer periods throughout the growing season.

Therefore, placement strategies for P and S fertilizer may improve nutrient recovery by groundnuts, coupled with changed timing of application to ensure S is available at the time plants demand it. An experiment was conducted to determine the effect of P and S placement strategies on groundnut growth and fertilizer recovery in post-monsoon growing conditions in the Central Dry Zone of Myanmar.

Materials and Methods

An experiment was conducted in Thar Yar Gone Village, Nay Pyi Taw Region in Myanmar. The study site was situated at 19° 50' 16" N and 96° 13' 10" E and 132 meters above sea level. The average maximum and minimum temperature of the region are 31.3°C and 22.1°C, respectively. The average annual rainfall is 1,003 mm, and the main rainfall period occurs from May to October, accounting for about 94% of the average annual rainfall. The site was used to grow maize-groundnut-vegetables over the last three years.

The site was thought to be typical of many sandy farming soils of the CDZ and low in P and S. Soil samples were collected to 180 cm (0-10 cm, 10-30 cm, 30-60 cm, 60-120 cm, 120-150 cm, and 150-180 cm) prior to planting and analyzed for basic soil characteristics. Routine methods as used in the Soil and Plant Analysis Laboratory at the Soil Science Research Section at DAR Yezin were used (Table 1).

Table 1. Basic soil characteristics of field site.

Soil Depth (cm)	pH[a]	Soil Textural Class[b]	Soil Organic Matter (%)[c]	Available N (mg/kg)	Olsen P (mg/kg)[d]	Available K ($cmol_{(+)}$/kg)[e]	Sulfate S (mg/kg)[f]
0-10	6.5	Sandy loam	1.2	42	11	0.23	4
10-30	6.8	Sandy loam	1.4	49	7	0.16	4
30-60	7.1	Sandy loam	1.1	37	1	0.13	4
60-90	7.3	Loamy sand	0.5	27	3	0.14	3
90-120	7.5	Loamy sand	0.4	22	1	0.13	4
120-150	7.7	Loamy sand	0.6	17	1	0.10	4
150-180	7.6	Loamy sand	0.7	21	2	0.14	5

a. 1:5 in water; b. Pipette method; c. Tyurin method; d. Olsen P; e. 1N Ammonium Acetate; f. 0.01 M $CaCl_2$.

A 2 × 3 × 2 factorial experiment in randomized complete block design with four replications was established. Plots were 3.0 m × 3.7 m. Treatments were two fertilizer placement methods (surface and deep), three P rates (0, 20, and 40 kg P/ha) as triple superphosphate, and two gypsum rates (0 and 50 kg S/ha). Land was plowed and harrowed; then basal fertilizers were broadcast to prevent nutrient deficiencies. Urea, muriate of potash, ammonium molybdate, and borax were used as sources of nitrogen, potassium, molybdenum, and boron, respectively, and the rates applied were 20 kg N/ha, 35 kg K_2O/ha, 1 kg ammonium molybdate/ha, and 5 kg borax/ha. There were five consecutive days of rainfall after adding basal fertilizers so supplemental basal additions were repeated at the same rates. Triple superphosphate and gypsum were used for P and S sources. The full dose of P fertilizer was applied at seeding, but two equal applications of S fertilizer were added at the seeding and pegging stages.

On the day of seeding groundnut, deep rows were made across the site using a butterfly plow. There were six rows in one experimental unit that were 19 inches (48 cm) apart and 20 cm deep to ensure deep placement of tested fertilizers. The full dose of P fertilizer and half the amount of S fertilizer were drilled by hand into the deep rows of plots intended for deep placement of fertilizers. Then, deep rows were covered by using a wooden leveler, and surface rows of 7.5 cm deep were created above the same place of deep rows using a harrower. Surface placement of P and S fertilizers was also done inside those surface rows.

Seeds of the erect, 100-105 day duration groundnut variety, Sinpadaethar 11, were inoculated with rhizobium and fungicide and hand drilled into the rows at a spacing of about 5-6 cm. There were approximately 68 plants per row and 408 plants per plot. The standard agronomy practices for groundnut were undertaken throughout the growing season. Irrigation was done at peak flowering and pod-filling stages. A 1-m row was sampled 40 days after seeding (40 DAS) at the beginning of flowering from each treatment to determine dry matter yield and total P and S uptake. At harvest, all plants within 2-m rows were harvested, and dry matter yield, pod yield, seed yield, and yield component characteristics, such as plant population, shelling percentage, and 100-seed weight were recorded. Plant population was recorded at each sampling. Harvested material was dried, ground, and analyzed for P and S at DAR, Yezin, and UNE, Armidale, using UltraWAVE nitric acid digestion followed by Inductively Couple Plasma-Optical Emission Spectrometer (ICP-OES) with appropriate standards. A two-way analysis of variance (ANOVA) test was used to determine significant treatment effects at $P<0.05$ using R 2.3.3. Treatments were compared using Tukey multiple comparison analysis.

Results and Discussion

While there was a significant interaction between placement depth and P rate after 40 days of growth (Figure 1), this did not translate through to yield effects at harvest (Table 2). Yields of groundnut were less than half of what we consider the benchmark groundnut yield for the climate in this region (2-2.5 t/ha). The key reason for this loss of yield was an early growing period flood triggered by 150 mm rainfall (10 DAS) that inundated the experimental site for a week. As growing conditions, including surface temperatures and irrigation, were otherwise optimal for groundnut production, the setback on the crop likely reduced yields considerably.

After the early flooding of the trial, and reapplication of basal nutrients (but not treatment nutrients), growing conditions were ideal and dry. Irrigation was undertaken twice following recession of the flood waters to encourage pod-filling and harvest; however, the surface sealing following the flood event may have decreased pegging and reduced the harvest index by 5-10%. Early season flooding may also have resulted in S leaching.

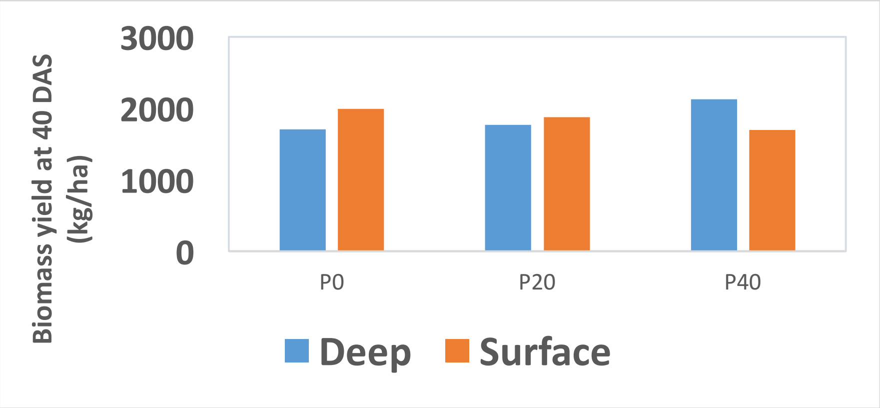

Figure 1. ***Effect of P application and placement depth on biomass yield of groundnut 40 DAS in a sandy soil.***

Although there were no observed yield responses to either P or S application, or placement strategy, recovery of applied P and S was indicated in tissue concentrations in the shoots of groundnut 40 DAS (Figure 2). A similar pattern in S and Ca uptake was observed for P uptake, with shoot concentrations increasing 5-8% with increasing P application. Average tissue concentrations at 40 DAS were within the sufficiency range for all important plant nutrients with the exception of slightly reduced tissue Mn (data not shown) (Reuter and Robinson, 1986).

Table 2. Effect of gypsum on biomass yield, pod and seed yield, and harvest index of groundnut grown in sandy soil with a range of P additions.

Gypsum Rates	Biomass Yield at Harvest (t/ha)		Pod Yield (t/ha)		Seed Yield (t/ha)		Harvest Index	
	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface
G0	1.96	1.93	1.05	1.09	0.61	0.65	0.35	0.36
G1	2.04	2.10	1.08	1.12	0.67	0.66	0.35	0.35
Experimental mean yield	2.01		1.09		0.65		0.35	

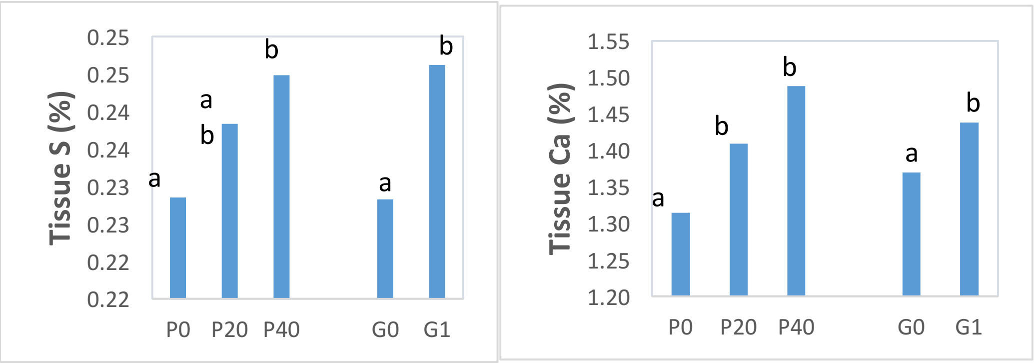

Figure 2. Effect of P or S application on tissue S and Ca concentrations of groundnut 40 DAS over two placement depths. Columns with the same letter are not significantly different.

Post-harvest soil sampling to determine the movement of applied P and S in this post-monsoon crop of groundnut revealed that P and S remained available and present at most depths at which they were placed (Table 3). Without the addition of P or S, available levels of P and S fell significantly from starting soil P (from 11 mg P/kg to ~5 mg P/kg) and S (4 mg S/kg to 1 mg S/kg) values, indicating crop removal of nutrients through the post-monsoon season.

Application of P increased Olsen P values by approximately 1 mg P/kg for every 6 kg fertilizer P applied but by only 1 mg S/kg for every 20 kg fertilizer applied. The increased amount of P required to increase Olsen P values is higher than that observed in pasture systems (Guppy et al., 2013) and may be related to leaching P losses. We suggest that movement of S is likely to be greater in the sandy soil used for this study (Sitthaphanit et al., 2009), explaining the higher S applications required to result in changed soil S status, although this is mitigated somewhat by the split application strategy for the fertilizer S. Placement depth of fertilizer had little effect on soil test values as the sampling strategy (0-10 cm; 10-30 cm) overlapped with placement depths for “surface”-applied nutrients (7-8 cm deep), so minimal movement of nutrients would be required for surface or deep applications to be recovered.

Table 3. Olsen extractable P (mg/kg) and available S (mg/kg) as affected by P (0-40 kg P/ha) and S (0 or 50 kg S/ha) application and placement depth in the surface layers of a sandy soil after harvest of groundnut in the CDZ of Myanmar.

P rate	P0		P20		P40	
Depth	Surface	Deep	Surface	Deep	Surface	Deep
0-10 cm	6.7	5.3	9.5	8.8	11.5	11.5
10-30 cm	4.8	5.1	8.2	9.0	11.5	11.5
Average	5.5^{a}		8.9^{b}		11.5^{c}	
S rate	G0				G50	
Depth	Surface	Deep			Surface	Deep
0-10 cm	0.1	1.8			3.8	3.5
10-30 cm	0.5	2.4			3.6	3.3
Average	1.2^{a}				3.5^{b}	

a. Average values followed by the same letter are not significantly different for P or S application rate.

Conclusion

There are significant challenges with the observation of nutrient responses in CDZ groundnut crops, most likely due to leaching of S, and occasionally P, below the root zone during monsoon crops. Careful treatment establishment resulted in measurable recovery of added fertilizer by groundnut in a physically constrained growing environment. The early flooding, and subsequent irrigation, may have minimized the potential effects of placement strategy of P and S on final groundnut yield, which we estimate was less than 50% of that which should be possible under those growing conditions (i.e., a fertile site with long periods of cloud-free skies and minimal water limitations). This indicates the trial, as designed and carefully established, should be repeated on a site less susceptible to flooding (unseasonal as it was) and during the monsoon season where higher rainfall intensity and longer dry periods are now the normal farming experience. These changes in climate are likely to result in changed fertilizer application strategies, particularly with the expected rise in mechanization in the CDZ of Myanmar in the foreseeable future.

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Soil Nutrient Limitations Define Farming Systems in the Central Dry Zone of Myanmar

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Abstract

Soil test values are regularly used to determine the likelihood of nutrient limitations to crop yield and response to applied fertilizer. A soil survey was conducted across the Central Dry Zone in 2013 in which farmers were asked to identify paddocks that they considered poorly performing areas, i.e., “bad,” and those they considered “good.” Two bulked surface soils from each field were subsequently collected from 148 farms. For a range of measures, there were minimal differences between “good” and “bad” areas, suggesting factors other than nutrition were driving crop performance in those villages. Soil acidity was not significant, with only one sample with a pH below 5.5. However, alkalinity was more prevalent, with 28% of sites with pH values above 8.3. Phosphorus nutrition was the greatest identified concern for farmers, with 61% of sites recording an Olsen P below 6 mg/kg in the surface 10 cm. Water extractable sulfate values below 3 mg/kg are often associated with sulfur deficiency, and 35% of sites were below this critical value. Cation nutrition is important in sandier soils (55% of sites had less than 10% clay), particularly as 27% of sites had cation exchange capacity less than 4 cmol/kg. This was reflected in potassium nutrition; 48% of sites had less than the critical 0.2 cmol K/kg. However, sodicity was not as significant a driver in reduced yield, because although almost one-third of sites were sodic (exchangeable sodium percentage >6%), only one-third of those sites had more than 10% clay and were likely to suffer from surface sodicity constraints and respond to gypsum application. This paper discusses these widespread nutrient limitations and the co-occurrence of multiple deficiencies.

Introduction

The Central Dry Zone (CDZ) of Myanmar contains farming systems dominated by pulses. Two crops are often grown, frequently intercropped with pigeon pea, during a monsoon and late-monsoon season. Frequently grown species include groundnut, sesame, green gram, and pigeon pea. Rainfall varies between 500 and 1,000 mm annually, with over 95% falling during the monsoon period between May and November.

Soils have been cultivated for centuries and are predominantly coarse-textured in the southern CDZ, with increasing surface clay contents in the northern CDZ. Fertilizer inputs are typically low (Birchall et al., 2017), but as yields are commensurately low, inputs and outputs from fields are most likely balanced for nutrients such as P. Soil K and S values may be lower than expected due to leaching loss and the regular removal of all crop residues from fields for feeding of draft animals. Notwithstanding some knowledge of nutrient inputs and outflows, there is scant information on typical nutrient availability for soils in the CDZ. This paper reports on a survey of 319 fields in the CDZ of Myanmar during 2013 as part of a crop nutrient management program conducted within an ACIAR-funded project (SMCN/2011/047) on improving pulse production in the CDZ.

Materials and Methods

Surface soil samples were collected from 148 farms across the CDZ of Myanmar. In order to quantify the importance of soil fertility on pulse production and yields, farmers were asked to select fields that they considered were “good,” fields that produced consistently high yields, and fields that they considered “bad,” areas that they considered poor yielding. Surface soil samples (0-10 cm) were then collected from a total of 319 fields in 57 villages in the CDZ. Samples were randomly taken from 10 locations in each field, bulked, and transported to the Department of Agriculture (DAR), Yezin, soil chemistry laboratories for analysis.

Soils were dried, ground to <2 mm using a mortar and pestle, then sieved prior to analysis using standard soil analysis techniques for Myanmar. Briefly, pH and electrical conductivity were measured in a 1:5 soil:water extract, shaken for 1 hour on a reciprocating shaker and determined using an Horiba pH and electrical conductivity (EC) meter. Available N was measured using the alkaline permanganate method (Sahrawat and Burford, 1982). Phosphorus was extracted according to the Olsen method (1954) with colorimetric phosphate determination using molybdate blue chemistry at 880 nm. Available S was extracted using a modification of Method 12C1 with 0.01 M calcium chloride extraction and a $BaCl_2$ turbidometric finish for sulfate determination (Rayment and Lyons, 2011). Available B was measured using Method 12C2 in Rayment and Lyons (2011). Exchangeable cations were extracted in 1N ammonium acetate for 1 hour prior to measurement by atomic absorption spectroscopy using a Shimadzu AA-6200. Organic matter was estimated using the Tyurin method (1931). Texture was characterised using the pipette method (Gee and Bauder, 1986). Statistical analysis was undertaken using basic t-tests to compare means between good and bad fields.

Results and Discussion

Average values for most soil properties were not significantly different between areas identified by farmers as “good” or “bad,” either within village, or between samples where values would indicate the likelihood of response to soil amendments such as fertilizers (Table 1). The only exception was clay content, where “good” soils had 26% higher clay content than “bad” soils ($P<0.05$). Possible explanations for this lack of difference between the “good” and “bad” soils include widespread deficiency limiting yield potentials across the CDZ or other agronomic factors playing a larger role in fields not reaching yield potentials.

Table 1. Mean soil values for areas considered “good” areas by farmers and those considered “bad,” as based on historic perceptions of yield.

Soil Test Value	Bad (N=136)	Good (N=183)
pH	7.7	7.7
EC	0.09	0.10
Olsen P (mg/kg)	6.0	6.8
Water-extractable S (mg/kg)	9.5	10.7
OM (%)	0.74	0.80
Available N (mg/kg)	40	45
Exchangeable K (cmol/kg)	0.25	0.28
Clay (%)	9.9	12.5*
ECEC (cmol/kg)	12.7	15.1
Sodicity (%)	4.6	4.3
Hot water extractable B (mg/kg)	1.1	1.2

* Indicates significantly higher clay % in good areas.

Although the average values for most chemical properties did not differ significantly between “good” and “bad” fields within villages, the range in values was large (Figures 1-5). Less than 0.3% of soils had pH values below 5.5, where the risk of Al toxicity to root systems, resulting in poor nodulation of pulses, becomes critical (Rout et al., 2001). However, a significant number of sites (28%) had alkaline pH values greater than 8.3, suggesting potential for sodicity deeper in the soil profiles. Only 3% of samples were high in salinity for pulses thought to cause yield reductions of 50% at equivalent saturated paste extract values for sandy soils (Shaw, 1997).

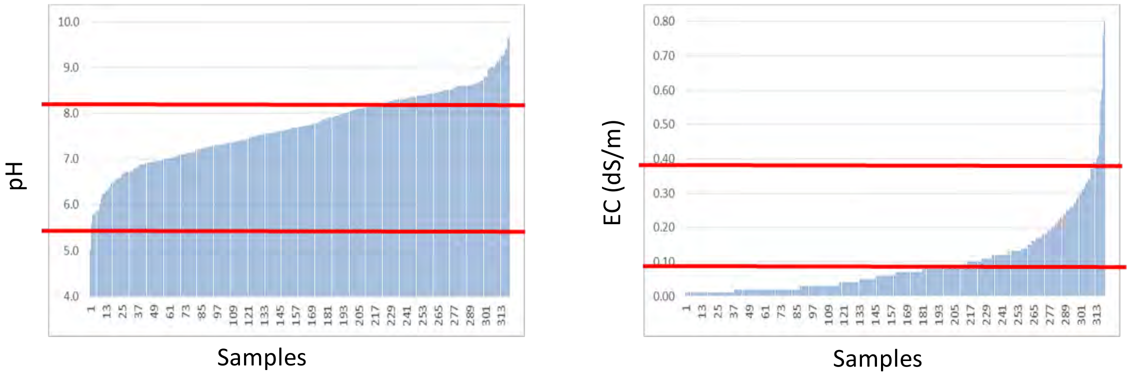

Figure 1. Range of pH and EC in 313 surface soil samples from the CDZ of Myanmar with critical ranges indicated between the red lines.

More than 60% of soils were low in available P, assuming a critical value of 6 mg/kg for legumes and sesame (Figure 2). The expectation based on these results is that about 60% of pulse and sesame crops in the CDZ would respond to applied fertilizer P. Samples will be analyzed for P buffer index during the next few months to determine the likelihhod of P leaching in these environments. Thirty-five percent of soils were low in available S (Figure 2), though critical values for this are inconclusive. The greatest risk with soil sulfate availability is likely to be related to organic matter mineralization and low total organic matter contents, because even small amounts of sulfate leach readily in sandy, high-rainfall environments, and without a steady supply of mineralized sulfate, surface sulfate concentrations can be expected to be low. Approximately 3% of samples had greater than 100 mg S/kg, indicating gypsiferous layers in surface soils.

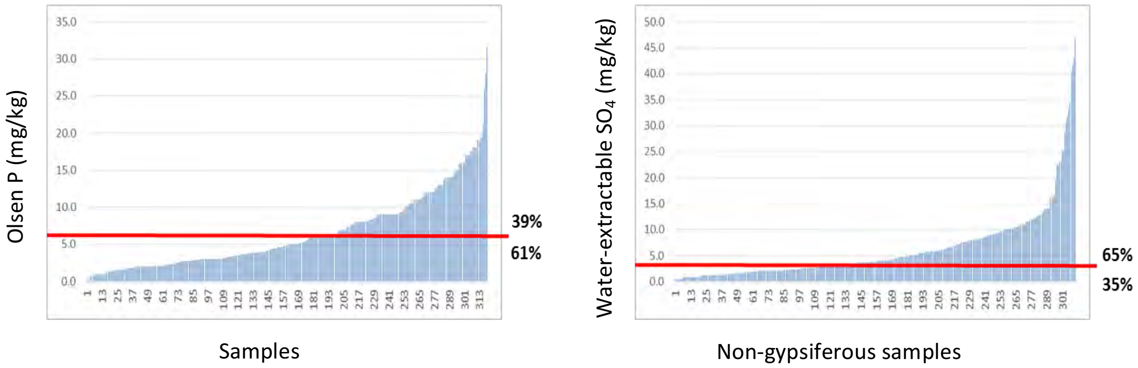

Figure 2. Range of available P and S in 313 surface soil samples from the CDZ of Myanmar with critical range indicated by red lines.

Although there is no recognized critical clay content in the scientific literature, soils with greater than 10% clay are often considered relatively fertile (Figure 3). More than half the surface soils in these samples had <10% clay, confirming the coarse-textured nature of surface soils in the CDZ. Soils with more than 30% clay were generally from the Sagaing and Mandalay regions and are often used for chickpea production post-monsoon on stored soil moisture. Organic matter concentrations are also dependant on climate in assessing levels that maintain healthy soils. For sandy soils with approximately 800-1,000 mm rainfall, values <0.8% could be considered very low in organic matter. It is unsurprising that a majority of CDZ soils can be considered low in organic matter; coarse-textured soils typically have lower carbon contents due to the inability to protect carbon from microbial action. More critically, however, residue removal is near universal in the CDZ to be used as livestock feed. While equilibrium soil organic matter is a balance between inputs and outputs of carbon, complete removal of aboveground residues reduces inputs to farmyard manure and the small amounts of root residues left in the fields after grain harvest. Substantial carbon is lost via respiration during the conversion of fresh crop residues taken from the fields to farmyard manure put back to the fields some months later.

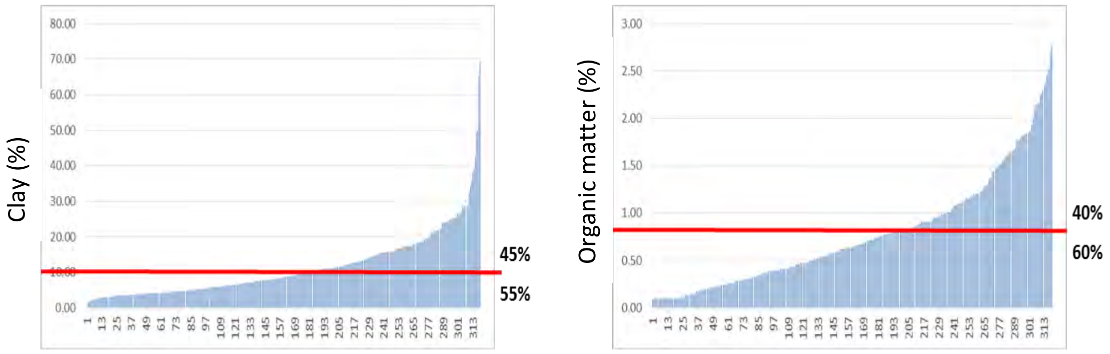

Figure 3. ***Range of clay and organic matter percentage in 319 surface soil samples from the CDZ of Myanmar with critical range indicated by red lines.***

Although studies identifying critical K requirements for pulses are again not extensive in the literature, values <0.2 cmol/kg are often considered responsive to K fertilizers (Srinivasarao et al., 2003). Nearly half of the samples measured were below this threshold (Figure 4). The small number of soils with particularly high exchangeable K contents (>0.8 cmol/kg) were from the northern region of the CDZ where surface clay contents are higher.

The effective cation exchange capacity (ECEC, sum of the base cations) in these samples was higher than would be expected given the low organic matter and clay content of the majority of soils (Figure 4). One-third of the soils were considered sodic (data not shown). However, of those soils, less than one-third of them had more than 10% clay, so typical problems associated with sodicity, such as hardsetting and terlogging, are unlikely to be prevalent. Significant areas though are likely to have face crusting where sodicity coincides with the presence of clay at the surface.

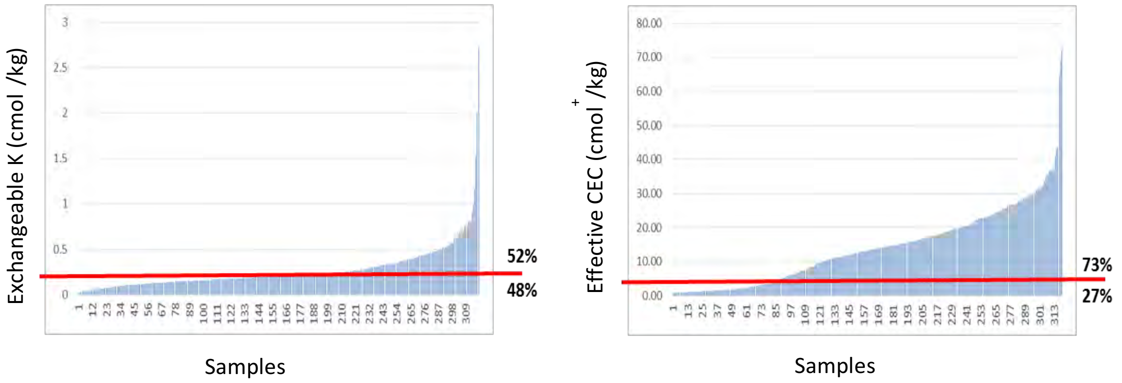

Figure 4. ***Range of exchangeable K and effective CEC in 319 surface soil samples from the CDZ of Myanmar with critical range indicated by red lines.***

Less than 5% of samples had hot-water extractable B values <0.2 mg/kg. The deficiency range for groundnut and black gram in Southeast Asia on sandy soils has been reported as about 0.14 mg/kg (Bell et al., 1990). Given anecdotal evidence of widespread responses to B application, this result is somewhat surprising and warrants further investigation as to whether rainfall events and subsequent leaching of B in neutral to alkaline surface soil samples is greater than expected.

Indeed, the main weakness in the soil survey is failure to account for nutrients that may leach below 10 cm. If clay contents in CDZ soils increase with depth, nutrient capture by deeper roots may limit responses that are indicated by low surface soil nutrient concentrations. Even so, the survey strongly suggests widespread infertility in soils of the CDZ. This accords with field observations of crops in the CDZ where symptoms of S, P, K, and Mn/Zn deficiency are frequently observed. Co-occurrence of nutrient deficiency is also extensive, with nearly one in five fields (18%) deficient in P, K, and S.

Conclusion

A soil survey of farmers' fields based on perceived fertility revealed little difference in basic soil fertility indicators. While soil pH was adequate for the majority of fields tested, many soils were low in P, K, and S, and nearly 20% were low in all three macronutrients. This suggests that fertilizer responses should be widespread, and nutrient management is a critical factor in increasing pulse productivity in the CDZ. Further research, including the fate of applied nutrients and subsoil fertility, are warranted given the results of this survey.

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Using a Simple Nutrient Balance Calculator to Build Awareness of Soil Nutrient Removal in Harvested Produce and the Importance of Fertilizers in Soil Fertility

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Abstract

Farm produce contains nutrients that crops acquire from soil, including major amounts of nitrogen (N), phosphorus (P), and potassium (K), moderate amounts of calcium (Ca), magnesium (Mg), and sulfur (S), and trace amounts of micronutrients, such as iron (Fe), copper (Cu), zinc (Zn), molybdenum (Mo), and boron (B). Therefore, removal of produce from the farm exports nutrients. Production can continue for a while using reserves of these nutrients in the soil, but these reserves are finite. Continuous removal in harvested products without replenishment with fertilizers ultimately causes deficiency and loss of production. We developed a nutrient balance calculator to inform extension workers and farmers of the amounts removed and to highlight the need to use fertilizers by estimating soil- and crop-specific fertilizer requirements. It consists of a database of crops and pastures and their published nutrient contents. The user simply inputs the species of the previous crop and the amount of product harvested, and the calculator then estimates the amounts of nutrients removed. For N, the calculator uses an estimate of the yield for the next crop – which may be a different species – to estimate the N requirement by assuming there is no carry over from the previous crop unless it was a legume. A basic fertilizer recommendation is made to balance the amount removed and incorporating soil-dependent efficiency based on likely N leaching loss or denitrification and P adsorption. This approach maintains the status quo by balancing removal and losses beyond the reach of plant roots.

The nutrient balance calculator also determines whether the soil is likely to be deficient in nutrients due to long-term under-fertilization. This is based either on whether fertilizer has been applied regularly for the past five years or on soil analyses, if available. Where soils are suspected to be nutrient-deficient, the nutrient requirements are boosted in order to build up soil fertility in addition to balancing nutrient removal and loss.

Introduction

Informal farmer interviews, discussions with colleagues, and several international agency reports suggest that fertilizer use is minimal in Myanmar. Negative nutrient balances due to removal of more nutrients in farm produce than added as fertilizers and manures are unsustainable and will eventually result in nutrient deficiencies and loss of livelihood. Sustainable nutrient management should aim to (1) correct nutrient deficiencies, likely to occur on agricultural land that receives little fertilizers; (2) minimize nutrient losses through denitrification, leaching, runoff and erosion, removal of animal manures and crop residues, and P fixation; and (3) replace nutrients removed from the field in the harvested parts of crops and by other losses through a maintenance program.

Annual removal of nutrients from farming systems used in Myanmar is dependent on local climate, position of the farm in the landscape, farm management, and availability of irrigation water. These factors determine the number of crops that can be grown each year and yields. For example, in Pakokku Township, Magway Region, three crops are often grown at locations close to the river. These can consist of two crops of rice followed by a crop of pulses such as green gram. Away from the river, pulses, sesame, and groundnut are grown on sandy loams. Double cropping is often practiced, with short season of green gram sown at the start of the monsoon, followed by pigeon pea, groundnut, or sesame using residual moisture. Farmers in Pakokku reported yields of monsoon rice of 3.4-3.9 t/ha, sesame seeds of 0.6-0.9 t/ha, green gram of 0.8-1.1 t/ha, and pigeon pea of 0.6-0.7 t/ha. Examples of annual nutrient removal at this location is given in Table 1.

Table 1. Estimates of annual nutrient removal in Pakokku Township, Magway Region, Myanmar, for examples of triple and double cropping, using yields indicated by local farmers.

Crop	Grain Yield	Nutrients Removed in Harvested Grains* kg/ha				
	(t/ha)	N	P	K	Ca	Mg
Triple cropping: rice-rice-green gram						
1. Rice	3.5	52.5	8.8	8.8	1.8	3.5
2. Rice	3.5	52.5	8.8	8.8	1.8	3.5
3. Green gram	1.0	55.0	4.0	17.0	4.0	3.0
Total		160.0	21.6	34.6	7.6	10.0
Double cropping: green gram-sesame						
1. Green gram	1.0	55.0	4.0	17.0	4.0	3.0
2. Sesame	0.7	19.9	4.4	3.3	6.8	2.5
Total		74.9	8.4	20.3	10.8	5.5
Double cropping: Sesame-pigeon pea						
1. Sesame	0.7	19.9	4.4	3.3	6.8	2.5
2. Pigeon pea	0.7	24.3	2.6	9.7	0.9	1.3
Total		44.2	7.0	13.0	7.7	3.7

** Nutrient contents of grains from Dierolf et al. (2001) for rice and green gram, and from USDA-ARS (2016) for sesame and pigeon pea.*

The current lack of awareness of the amount of soil nutrients removed in farm produce and of the importance of fertilizers may be addressed by calculating the nutrient budget. This tracks the movements of nutrients across the boundaries of a defined area. Nutrient movements include fertilizer additions, product removal, and nutrient losses through leaching, erosion, runoff, and denitrification. Nutrient budgets can be calculated at a variety of scales, such as a country, district, catchment, whole farm, field, and plot scales, depending on the objective of the study. Country, district, and catchment scale studies serve policy and management needs, for example to guide research priorities, investment in infrastructure, and the pricing structure for fertilizers. As the basis for underpinning fertilizer recommendations for farmers, nutrient balances should be calculated for much smaller areas. Most farms in Myanmar have a number of field plots supporting different crops. These field plots are typically <1,000 m^2. Such plots are the areas for which nutrient balances should be calculated for supporting nutrient management. In this context, a plot is defined as a contiguous area of land that is managed in the same way and has the same soil properties. Nutrient budget calculations are performed on an area (m^2) basis to take account of small plot sizes and to facilitate interpretation and adoption.

The calculator described below is intended to introduce the concepts of nutrient balance and soil fertility management in situations where there is little awareness and information about crop responses to fertilizer. It was originally developed for fertilizer management in Negara Brunei Darussalam (Ringrose-Voase et al., 2008). As better information becomes available on nutrient management, it should be replaced by more sophisticated nutrient management methods.

Nutrient Balance Calculator – Principles

In Myanmar, limited local information exists on responses of crops to fertilizers. The calculator is designed to require minimal user inputs by gleaning as much information as possible from the literature. However, it also has the option of using inputs of locally derived information as it becomes available. It is intended that, as well as educating the user on the amounts of nutrients removed in produce and providing fertilizer recommendations directly, it will help prioritize topics requiring data gathering to overcome knowledge gaps in the calculator.

The calculator recommends the amounts of fertilizer required based on replacing nutrients removed by previous crops and offsetting nutrient losses during the cropping season. In addition, it assesses the nutrient status of the soil at sowing. Where the status of individual nutrients is low, it includes extra inputs to build up soil fertility. For N, it assumes minimal residual N (unless the previous crop was leguminous) and calculates the N input required to match estimated N removal by the next crop together with likely losses during the crop.

The estimation of nutrient removal by the calculator is based on the nutrient contents of crop produce and the yields of the previous and current crop. The former are obtained from the literature and should relate to the harvestable parts of the crop that are removed from the field, not just the edible parts. The calculator uses the measured yield of the previous crop and an estimate of yield for the current crop, which should be based on previously measured yields of that crop in the location. These are the only measurements required by the calculator. This is a deliberate tactic to encourage users to measure and record yields as part of improving crop management. It also means fertilizer recommendations made by the calculator are tailored to local conditions and yields.

The amount of nutrient taken up by a crop depends not only on the yield and nutrient content of harvestable produce but also on the amount of crop residue and its nutrient content. For example, rice grain removes about 2.5 kg K/t, whereas rice straw removes about 25.0 kg K/t of straw. A crop of 20 t/ha of banana bunches removes ~115 kg K/ha compared with only 35 kg K/ha by similar yields of papaya or watermelon, which have lower tissue K concentration. A major avoidable loss of nutrients from a plot occurs when crop residues are removed. Lack of information on the amounts of residues produced and their management prevents their incorporation in the fertilizer calculator. The calculator therefore assumes that residues are retained and that their nutrients return to the soil as they decompose. Export of animal manures from the farm also constitutes an important loss of nutrients. Using the calculator with farmers should be accompanied by discussion about the importance of residue retention.

In fields with low soil fertility due to lack of fertilizer inputs, the calculator recommends extra fertilizer. This not only helps to build up soil fertility, but also prevents perpetuation of low yields where these are due to lack of soil nutrients. Where the soil nutrient concentration is known, the nutrient status of the soil is checked against fertility status thresholds for different crops quoted by Dierolf et al. (2001). The status of each nutrient, other than N, is then classified as low, medium, high, or very high. Where soil nutrients have not been measured, the soil nutrient status is ranked as “low” if the soil has not been regularly fertilized for the previous five years and “medium” if it has been.

If the nutrient status is ranked “low,” as is the case for many nutrients in many soils of Myanmar, the nutrient requirement is multiplied by a “fertility factor” of 2 so that the status can be built up to optimal levels. Levels of P and exchangeable K, Ca, and Mg that are considered deficient for a wide range of crops are given by Dierolf et al., 2001: Bray II P <15 mg P/kg, K <0.2 cmol/kg, Ca <0.3-0.8 cmol/kg, and Mg <0.2 cmol/kg. Using a “soil fertility factor” of 2 builds up the soil nutrient reserve to overcome the deficiency. This is the build-up phase of nutrient management. It is important to take a balanced nutrition approach by ensuring that fertilizers supply N in addition to P and K to ensure that no major nutrients are limiting. An alternative recommendation to using an arbitrary “soil fertility factor” of 2 is to use an incremental approach by applying slightly more than the crop needs. This approach is preferred when a yield response to small applications of fertilizer is expected, and applies for nutrients such as K, Ca, and Mg that can accumulate and have long residual effects in soils. It allows the cost of rehabilitation of nutrient-depleted land to be spread over several years. The danger of this approach is that for some nutrients, notably P, initial applications on soils with high P fixation may be too small for a response to be observed. This may deter farmers from applying further amounts to rehabilitate the land. If cost is an issue, it may be better to apply the full amount to part of the plot, observe the response and, based on profitable results, treat the rest of the plot.

If the nutrient status is ranked as “medium,” the soil is not deficient and its fertility is maintained by using a fertility factor of 1. If this amount of fertilizer is applied, the status of each nutrient should be maintained at the end of the crop. This is the maintenance phase of nutrient management. Maintenance is achieved by offsetting the amount of nutrient removed by the crop and lost from the soil by leaching, volatilization, runoff, etc., against maintenance applications of fertilizer and manure. If the nutrient status is ranked as “high” or “very high” for a particular nutrient, then a fertility factor of 0.5 is used to reduce fertilizer costs by using soil reserves.

Estimation of Nutrient Requirements

Nutrients Other Than Nitrogen

The estimates of nutrient removal and losses are used to estimate the nutrient requirements of the current crop. For each nutrient, except N, namely P, K, Ca, and Mg, the requirement is based on the amount of nutrient removed by the previous crop. The calculator assumes all crop residues are returned to the field.

$$Requirement = \frac{Yield_{previous} \times Nutrient\ content_{previous}}{Fertilizer\ efficiency} \times Fertility\ \ factor$$

- *Requirement* is the amount of each nutrient required in g/m^2.
- *Nutrient content$_{previous}$* is the nutrient content of the previous crop and is obtained from a database of values gleaned from the literature and expressed as g/kg yield. There is also a facility to use locally measured nutrient contents if they are available.
- *Yield$_{previous}$* is the only measured input required by the calculator. The calculator can accept yield measurements in a variety of forms, making it flexible for different crops and cultivation practices. It is important to ensure that the yield measurements are on the same weight basis (either “fresh weight” or “dry weight”) as those in the database of nutrient contents.

  a) For plots or raised beds, the weight of produce removed from a sample length (e.g., 5 m) of the plot or raised bed can be used:

  $$Yield_{previous} = \frac{Measured\ weight_{produce}}{Length_{bed} \times Width_{bed}}$$

  where *Yield* is in kg/m^2, *Measured weight* in kg, and *Length$_{bed}$* and *Width$_{bed}$* are in m and refer to a sample of raised bed.

  b) For field crops, the quantity produce removed from a sample area can be measured – either the whole field or a measured part of it if this is more practical. Product removal is calculated as:

  $$Yield_{previous} = \frac{Measured\ weight_{produce}}{Length_{area} \times Width_{area}}$$

  where *Length$_{area}$* and *Width$_{area}$* are in m and refer to a random, rectangular sample area.

  c) For tree crops, the quantity of produce removed from a sample of trees can be measured, together with the spacing between trees. Removal is calculated as:

  $$Yield_{previous} = \frac{Measured\ weight_{produce}}{Distance_{trees} \times Distance_{rows} \times N_{trees}}$$

  where *Distance$_{trees}$* and *Distance$_{rows}$* are in m and refer to the distances between trees in a row and between rows, and *N$_{trees}$* is the number of sample trees.

- *Fertilizer efficiency* is an estimate of nutrient losses that might occur during the current crop. These losses can be caused by leaching, erosion, and P fixation. Losses from all sources are estimated as a proportion of nutrient applied. Until locally derived efficiencies are available, the calculator uses reported efficiencies of uptake of nutrients to estimate the amounts to be returned to the soil. Accepted recoveries or uptake efficiencies of applied nutrients are 40% for P and 60% for K (Dierolf et al., 2001). In some cases, it is adjusted by the calculator depending on soil properties.

  P: 0.4. This is reduced to 0.2 if the soil has high P fixation due to the presence of Fe and Al oxides.

K: 0.6
Ca: 0.6
Mg: 0.6

- The *Fertility factor* is set as described earlier in order to build up soil fertility if it is deficient.

Nitrogen

The requirement for N is calculated differently to the other nutrients, and it is assumed that there is no residual N unless the previous crop was leguminous:

$$Requirement = \frac{\left[Yield_{current} \times N\ content_{current} \times \left(1 - N\ \ fixation\ \ factor_{current}\right)\right] - \left[Yield_{previous} \times N\ content_{previous} \times Residual\,N\ \ factor_{previous}\right]}{Fertilizer\ efficiency}$$

- $N\ content_{current}$ and $N\ content_{previous}$ are the N contents of the current and previous crops obtained from a database of values gleaned from the literature.
- $Yield_{current}$ is an estimate of the yield that can be obtained by the current crop, which should be based on past experience at the site. $Yield_{previous}$ is the measured yield of the previous crop. Both are calculated as described above for other nutrients.
- $N\ fixation\ factor_{current}$ is the amount of the current crop's N requirement that can be met by biological fixation of atmospheric N. N fixation is generally not a complete external source of soil nitrogen because the amount fixed is usually less than the requirement of the legume crop. However, it can reduce the N requirement of legumes. Between 50-250 kg N/ha/yr can be fixed to partly offset removal in harvested product (Dierolf et al., 2001). For example, in limed soil, soybeans can fix 30-60 kg N/ha per crop. This only partly offsets the removal in seed harvest of >100 kg N/ha. Similarly, biological nitrogen fixation allows pasture legumes to deplete the soil stock of N less quickly than grasses. Inputs of N through fixation are uncertain. The factor is set to zero for non-leguminous crops. Examples of the factor for leguminous crops are 0.9 for fodder legumes, 0.75 for soybean and mungbean, and zero for vegetable beans.
- $Residual\ N\ factor_{previous}$ allows for residual N fixed by the previous crop if it was a legume. The amount is very uncertain but is assumed to be 0.1 of the N requirement of the previous crop.
- *Fertilizer efficiency* is an estimate of N losses that might occur during the current crop due to leaching losses, denitrification, volatilization, and immobilization. The calculator uses reported efficiencies of uptake of N of 30-50% for N (Dierolf et al., 2001). The values used depend on soil type:

  0.5 Default

  0.4 Waterlogged soils with grey mottles within 50 cm of the surface or saturated for more than 60 days per year.

  0.3 Soils with prolonged waterlogging where the soil is saturated for more than 200 days per year.

0.3 Coarser textured soils with high potential for N to be leached, having effective cation exchange capacity (ECEC) less than 4 cmol/kg.

Estimation of Fertilizer and Manure Application Rates

The previous section describes how the calculator estimates the nutrient requirement. The next stage is to estimate how much fertilizer and/or manure should be applied to meet this requirement.

Manure

First, the supply of nutrients from manure is estimated if manure is to be used. In the absence of locally measured values of the nutrient contents of manures, the calculator uses default values for poultry manure with a default water content. Given the importance of manure in Myanmar agriculture it will be important to replace this default with a selection of measured values for different types of manure. The calculator estimates the minimum quantity of manure to be applied to completely meet the requirements for one nutrient. It is then assumed the requirements for the remaining nutrients will be met by inorganic fertilizer.

$$Manure\ application = \frac{Requirement_i \times \left(1+\theta_g\right)}{Nutrient\ content_i} \times 0.1$$

Where *Manure application* is the fresh weight of manure to be applied in kg/m^2 to meet the requirement for nutrient *i*, *Requirement*$_i$, calculated above in g/m^2; *Nutrient content*$_i$ is the content of nutrient *i* of the manure on a dry matter basis in %; and θ_g is the gravimetric water content of the manure in g/g.

Fertilizer

The strategy for calculating the fertilizer requirement is to calculate, for a range of locally available compound fertilizers, the minimum amount of fertilizer needed to completely meet the requirements for one nutrient. If manure is used, the amounts of nutrients supplied by the manure are first subtracted from the nutrient requirements. This is supplemented with single-element fertilizers to meet the requirements of the other nutrients. The steps are as follows for each compound fertilizer:

- The amounts of the fertilizer required to meet each nutrient, *i*, is calculated:

  $$Fertilizer\ requirement_{nutrient\ i} = \frac{Nutrient\ requirement_{nutrient\ i}}{Fertilizer\ content_{nutrient\ i}} \times 100$$

  Where *Fertilizer requirement* $_{nutrient\ i}$ is the amount of a given fertilizer required to match the requirement for nutrient *i* (g/m^2); *Fertilizer content*$_{nutrient\ i}$ is the elemental content of nutrient *i* in the fertilizer (%); and *Nutrient requirement*$_{nutrient\ i}$ (g/m^2) is the amount of nutrient *i* calculated above.

- Clearly, for compound fertilizers the amount of a fertilizer required to meet the requirements of each nutrient will vary. Therefore, the lowest amount of fertilizer from the previous step is selected, *Fertilizer requirement*$_{min}$. This completely meets the requirement for one nutrient.

- The amounts of supplemental fertilizers needed to meet the nutrient requirements of the other nutrients are then calculated. Urea is used to make up the outstanding

N requirement, triple superphosphate the P requirement, and either muriate or sulfate of potash the K requirement. The amount required is:

$$Supplemental\ requirement_{nutrient\ j} = \frac{Nutrient\ requirement_{nutrient\ j} - \left(Fertilizer\ requirement_{\min} \times \frac{Fertilizer\ content_{nutrient\ j}}{100} \right)}{Supplement\ content_{nutrient\ j}} \times 100$$

Where *Supplement requirement*$_{nutrient\ j}$ is the amount of a supplement fertilizer required to match the outstanding requirement for nutrient *j* (g/m^2) above that supplied by the compound fertilizer; and *Supplement content*$_{nutrient\ j}$ is the elemental content (%) of nutrient *j* in the supplemental fertilizer. The selection of muriate or sulfate of potash as the K supplement depends on the crop being grown.

- The steps above are repeated for each compound fertilizer that is locally available. The results consist of an amount of compound fertilizer and the accompanying amounts of supplemental fertilizer required to meet crop requirements.
- By default, the calculator selects the combination with the least weight of fertilizer. Alternatively, costing the various compound/supplementary fertilizer options could be used to select the most profitable combination.

Using the Calculator as an Education and Nutrient Management Tool

This calculator is intended as the first step in improving nutrient management. It informs the farmer and agronomist of the amounts of nutrients taken from the farmer’s plots and farm when produce is removed. This, together with the knowledge that soil nutrient reserves are finite, should help focus attention on the importance of fertilizers in soil fertility and rural livelihoods. The approach to fertilizer recommendation used here is sound and should work well as initial recommendations until better information becomes available. These recommendations can be improved with better local data specific to Myanmar and its regions. It should be noted that healthy crops are needed to take up soil nutrients efficiently. Therefore, other soil constraints, such as soil acidity and compaction, should be addressed to allow better nutrient use. The calculator does not consider socio-economic issues.

The calculator estimates a maintenance amount of fertilizer to replace nutrients removed by the crop, and then uses a fertility factor to increase fertilizer applications in order to build up soil nutrients (except N) where they are depleted. In the absence of measurements of soil nutrients, an arbitrary period of five years without fertilizer application is used to determine whether a soil is deficient. Once fertilizer has been regularly applied over five years, the extra amount ceases. Clearly, this approximation can be greatly improved by measuring soil nutrients. If extension officers in an area use the calculator to encourage farmers to start improving their management of soil fertility, the next step would be to refine the advice provided by using measured values of soil nutrients. This would require setting up local laboratories with simple equipment to measure soil nutrients so that extension officers can get timely analyses of farmers’ soil and, in turn, provide timely advice on the amounts of fertilizer required.

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Session 2.
Fertilizer Recommendations and Their Extension to and Adoption by Farmers

Urea Deep Placement Technology and Its Extension to Farmers in Myanmar

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Abstract

Urea deep placement (UDP) technology has been introduced to Myanmar by the International Fertilizer Development Center (IFDC) as a science-based technology that can increase nitrogen use efficiency by 40%, allowing less urea to be applied to produce higher yields. Farmers can save money, maintain soil fertility of their lands, and can get higher yields. Through the Fertilizer Sector Improvement (FSI) project, IFDC implemented UDP adaptation trials in the 2014 wet season in Yangon, Bago, and Ayeyarwady regions. Extension activities started among farmer communities in the 2015 dry season through a program of “Balanced Nutrient Management and Urea Deep Placement Technology.” This included farmer trainings with field demonstrations that publicized the benefits of the new technology.

Demonstration plots were established during the 2015 dry season to 2016 wet season with three treatments: (1) UDP on transplanted rice; (2) UDP on broadcast-seeded rice; and (3) farmers’ practice of planting and fertilizing. The layout of the demonstration was simple, without replication, but there were at least 30 demonstration plots established in each season. According to the results from four seasons, UDP on transplanted rice was the best nitrogen application practice, followed by UDP on broadcast-seeded rice. The FSI project also took crop cuts from a random sample of farmers’ fields who apply UDP in each season. UDP plots produced between 750-1,000 kilograms per hectare (15-20 baskets/acre) more yield than non-UDP plots. These results showed farmers that UDP technology can reduce cost of urea and increase income.

Key Words

Urea deep placement technology

Introduction

Most Myanmar farmers normally broadcast prilled or granular urea fertilizer into paddy field by hand. Broadcast application of urea results in losses of N mainly through volatilization (Zhao et al., 2012). Broadcast application stimulates weed growth, and crops are deprived of full benefits of fertilizers (Mohanty et al., 1999). Weed competition reduces both yield and quality of the crop produce (Singh, 1996). IFDC and others have proven UDP technology can increase the yield of transplanted lowland rice by 15-20% with less use of urea (up to 40%) compared to broadcast application (Gaihre et al., 2016). UDP technology is a one-time application that allows plants to access nitrogen whenever it is needed. It also reduces weed infestation, reduces the cost of weeding, and increases yield. Also, hidden hunger due to the absence of N is minimized. The plant gets a continuous supply of N during the growing period. With sufficient nitrogen, the plant is able to make better use of other essential elements, and a healthier plant is more resistant to pests and diseases. Even straw has a higher nitrogen content and becomes a higher quality animal food. As an environmental benefit, deep placement reduces greenhouse gases entering the atmosphere (Gaihre et al., 2017), and there is less leaching of nitrogen compounds into the groundwater and less runoff of nitrogen compounds into waterways (Kapoor et al., 2008).

A five-year Fertilizer Sector Improvement (FSI) project funded by the United States Agency for International Development (USAID) was launched in March 2014 to improve food security and increase income for smallholder farmers in Myanmar by sustainably increasing agricultural productivity through using UDP technology. The extension activity of the FSI project started in Myanmar in the 2015 dry season with local non-governmental organizations (NGOs) and an international NGO (INGO) as collaborating partners. The aim was to promote the application of UDP to increase rice production with less urea. To extend its reach, the FSI project provided grants to local partner organizations to implement extension activities, such as farmer training, field demonstrations, field days, and motivational field trips. FSI generally implements 60 farmer trainings and 30 field demonstrations per season in its three target regions. On average, 1,800 farmers per year have a chance to learn about the UDP technology and to test UDP on about 0.15-0.2 acre of their land. In every season, crop cuts are harvested in fields of farmers who apply the UDP technology to measure the benefits of UDP over non-UDP.

Materials and Methods

1. Field Demonstrations

FSI collaborated with eight local NGOs and one INGO to implement field demonstrations, farmer trainings, field days, motivational field trips, and crop cuts for every season since the dry season of 2015 (Table 1). The objective of field demonstrations was: (1) to demonstrate UDP technology on transplanted rice and broadcast-seeded rice to farmers, (2) to demonstrate a balanced fertilizer application on broadcast-seeded rice to farmers, and (3) to show the benefits of UDP in terms of reduced urea use and more yield per hectare.

Table 1. FSI Collaborating Partners.

Names	Acronyms	Status
Welthungerhilfe	WHH	INGO
Golden Plain	GP	NGO
Myanmar Heart and Development Organization	MHDO	NGO
Nine Network	NN	NGO
Village Integrated and Development Association	VIDA	NGO
Group of Development Research and Index	GDRI	NGO
Green Land	GL	NGO
Technical Alliance for Farmers	TAF	NGO
Karuna Myanmar Social Service	KMSS	NGO

In the dry season of 2015 and the wet season of 2016, demonstration plots were established with three treatments as: (a) UDP on transplanted rice, (b) UDP on broadcast-seeded rice, and (c) farmers' practice (usually broadcast-seeded rice with broadcast urea). They were established to show the benefits of UDP technology as an agronomic benefit, socio-economic benefit, and environmental benefit. A basal fertilizer dose of 80 kg triple superphosphate (TSP)/ha, 40 kg muriate of potash (MOP)/ha, and 25 kg gypsum/ha was applied at the last leveling to the two UDP treatments.

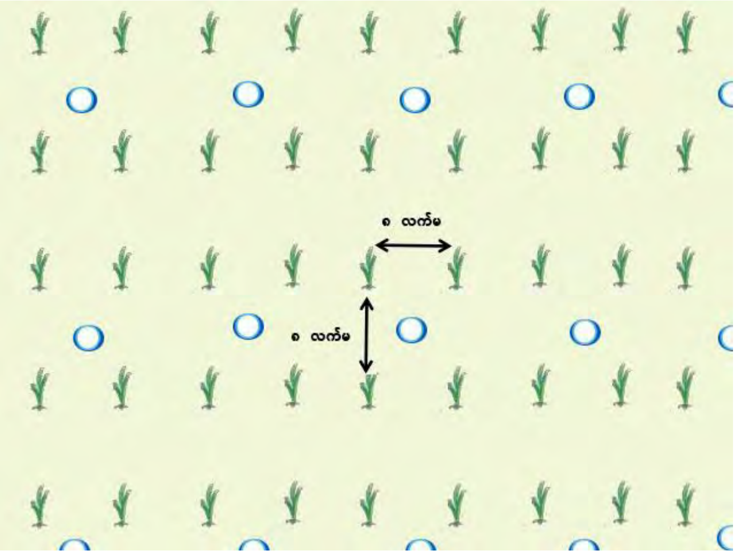

Figure 1. Schematic diagram for placement of urea briquette.

Treatment 1 comprised of: 25-day-old seedlings as two to three seedlings per hill for transplanting with a plant spacing of 20 cm x 20 cm. Deep placement of urea briquettes was done by hand at seven days after transplanting. One briquette was deep-placed at the middle of every alternate four rice hills at 7-10 cm depth (Figure 1). Briquette size of 1.8 g for the wet season gave a rate of 109 kg urea/ha, and briquette size for the dry season of 2.7 g gave a urea rate of 164 kg/ha. Treatment 2 with broadcast-seeded rice used the same basal fertilizers (UDP, TSP, MOP, and gypsum) as Treatment 1. The broadcast seed rate was 80 kg/ha for the wet season and 100 kg/ha for the dry season. Deep placement was done by hand at 20-25 days after sowing. One briquette was placed at a depth of 7-10 cm using a marked rope for the same spacing as in Treatment 1 (Figure 1). Briquette size and rate were also the same as Treatment 1 for each season. Treatment 3 (farmers' practice) followed the local farmers' practice for broadcast or transplanted rice. The fertilizer dose and time of application also followed farmers' practice. Information on the number of demonstration plots, implementing partners, and locations are given in Table 2.

Table 2. Demonstration plot distribution over seasons and locations.

Season	Number of Demo Plots	Implementing Partners	Number of Townships	Regions
2014-15 dry	23	5	8	3
2015 wet	30	4+ FSI	14	3
2015-16 dry	31	7	18	3
2016 wet	30	7	24	3
2016-17 dry	35	7	16	3
2017 wet	40	8	24	3

Sample plot harvesting was done in every season with a sample plot size of 10 m^2 (2 m x 5 m). Yield and moisture content were measured at harvest, and plot yields were reported with 14% moisture content correction.

2. Farmer Trainings

In the dry season of 2015 and the wet season of 2016, all farmer training was provided to new recruits. Two batches of trainings were conducted in each village tract that contained one demo plot. Each batch holds 30 farmers, and priority was given to lead farmers, interested farmers, and smallholder farmers. The trainees were asked to transfer their knowledge to friends and neighbors and become advocates of UDP technology and all other technologies learned from training. In the 2017 dry season, revision training was started and run in parallel with the training of new recruits. In these revision batches, there were 40 past trainees invited to return to keep in touch with the technology and re-energize their interest. Additional details on the number of trainings, farmers, and villages are given in Table 3.

The training message was supported by brochures, videos, field days, television presentations, and FSI extension activities. Within the training, farmers learned about balanced nutrient management, urea deep placement, best management cultivation practices, seed production technology and seed treatment, pest and disease management, and Syngenta's five "golden rules" when using plant protection products. During training, FSI provided pamphlets on UDP, balanced nutrient management, and seed treatment and a booklet on seed production, best management practices, pest and disease control, and the five golden rules. All new trainees also received 10 kg of urea briquettes together with guide bags to allow every trainee to test UDP technology in their fields.

Table 3. Farmer trainings per year.

Season	Number of Training	Attended Farmers			Village	Observer	DOA Staff
		Male	Female	Total			
2014-15 dry	48	952	513	1,465	99	0	8
2015 wet	60	1,268	527	1,795	202	0	11
2015-16 dry	58	1,241	554	1,795	165	0	32
2016 wet	65	1,386	547	1,933	243	10	32
2016-17 dry (new training)	30	732	182	914	94	21	24
2016-17 dry (re-training)	53	1,096	525	1,621	141	19	45

3. Motivational Field Trips

The motivational field trips or farmer cross visits were aimed to allow farmers (both hosts and visitors) to exchange and share experiences, views, and perceptions among themselves. This can occur at any time but is best during maximum tilling stage or ripening stage. The hosts are experienced farmers from the village where the demonstration plot is established, and visitors are from different villages within the same township (Table 4). The host farmers are selected as advocates to share their experience and discuss the benefits of the new technology. Project staff and partners' staff are facilitators on the field trips. The visitors walk through the field to observe the differences in tillers, plant height, and crop color between plots that are using UDP technology and plots of non-UDP.

Table 4. Distribution of field trips over years and location.

Season	Locations	Host			Visitors			Village	DOA
		M	F	Total	M	F	Total		
2014-15 dry	6 Townships	55	20	65	75	24	99	20	0
2015 wet	6 Townships	20	10	30	103	10	113	20	0
2015-16 dry	6 Townships	32	7	39	106	18	124	30	14
2016 wet	6 Townships	35	10	45	98	23	121	20	5
2016-17 dry	6 Townships	42	10	52	108	18	126	29	8

4. Field Days

Field days are conducted around the demonstration plots at harvest time to share a positive message about the benefits of the technology being demonstrated (Table 5). Fifty farmers, farm laborers, teachers, fertilizer dealers, and community leaders are invited from surrounding villages. All the attendees can see the benefits of balanced nutrient management and UDP technology by harvesting, threshing, and weighing the demonstration plots on that day. This reinforces the message given at training and is a big motivator for farmers to apply the new technologies after they see the response of each treatment.

Table 5. Summary of field days – years, locations, and attendance.

Season	Locations	Times	Attendance Male	Female	Total	Village	DOA
2014-15 dry	7 Townships	11	365	265	630	58	10
2015 wet	9 Townships	9	360	188	548	43	0
2015-16 dry	11 Townships	11	403	188	591	68	18
2016 wet	7 Townships	7	251	102	353	25	35
2016-17 dry	7 Townships	7	234	82	316	30	24

5. Crop Cuts

Crop cuts are taken from a random selection of farmers who have applied UDP in the season. The sample plot size is 10 m^2 (2 m x 5 m) and a crop cut is taken from each of the UDP fields and an adjacent non-UDP field to allow comparison. UDP fields used an N rate of 109 kg/ha and non-UDP fields used an N rate between 124 kg/ha and 185 kg/ha in the wet season. UDP fields used an N rate of 164 kg/ha, and non-UDP fields used an N rate between 185 kg/ha and 370 kg/ha in the dry season. The N rate in UDP fields is a standard rate, but the N rate in non-UDP fields can change depending on farmers' desires. A short gross margin questionnaire is filled out with the farmer at the time of the cut. Paddy crop cuts have been taken since the 2015 dry season. From 2016 and 2017 dry seasons, crop cuts from the following gram crop have also been taken to check the residual effect of UDP into the gram crop after rice (Table 6). The crop cut size was 10 m^2.

Table 6. Number of paddy and gram crop cuts.

Season	Crop	Quantity of Crop Cuts
2014-15 dry	Paddy	97
2015 wet	Paddy	113
2015-16 dry	Paddy	137
2015-16 dry	Gram	40
2016 wet	Paddy	121
2016-17 dry	Paddy	86
2016-17 dry	Gram	71

6. Cooperation with Department of Agriculture

The Department of Agriculture (DOA) is particularly helpful in identification of progressive farmers and site selection for demonstration plots. DOA township managers or village tract staff members attend farmer trainings and encourage farmers to apply UDP technology during their field visits. DOA staff members also attend field days and help in showing results to farmers. In cooperation with DOA in the 2016-17 dry season, UDP technology was evaluated with (1) System of Rice Intensification (SRI), (2) good agricultural practices (GAPs), (3) use of a seeder, and (4) local transplanted rice in Taikkyi, Kungyangon, Maubin, Kangyidaunt, and Zalun townships.

7. Analysis of Variance for the Demonstrations

The analysis of variance to test the effects of treatment, variety, and the interaction of treatment*variety was performed using a Generalized Linear Mixed

Model (Gbur et al., 2012). The mixed model had two types of terms: the fixed effect terms (treatment, variety, and treatment*variety) and the random effect terms (latitude and longitude of the farmers' fields). The residual was used as the random error for testing hypotheses about treatments, varieties, and the interaction of treatments with varieties.

The set of methodologies developed by Gbur et al. allows for making the analysis of variance in situations away from the conventional randomized complete block design (RCBD), such as in this situation in which the demonstration plots have no replications. The farmers' fields are assumed to be the replications, and the spatial variability between the fields is used to estimate the error term needed in the analysis of variance.

The data generated by the demonstration plots are unbalanced because the different rice varieties were not tested in every farmer's field; this condition makes necessary an adjustment of the means by least square regression. The least square adjusted means (LSMEANS) are used for comparison of treatments, varieties, or treatments within varieties depending on whether treatment, variety, or the interaction are significant in the analysis of variance. Comparisons between means were done using the Least Significant Difference (LSD). Results from the analysis of variance or from the comparison of a pair of means were considered significant at P-values (Pr>F in the analysis of variance or Pr>t in the LSD) of 0.1 or lower. The 0.1 boundary for the significance, instead of the conventional 0.05, is due to the need for allowing higher tolerance under the condition of high uncontrolled variability that occurs in trials and demonstration plots run in farmers' fields.

Analyses were done using the Statistical Analysis System (SAS) software.

Results

1. Demonstration Plots of All Seasons

Seasonal demonstrations are located in different regions, different townships, and different soil conditions. Different partner organizations implemented the demonstrations with the same protocol. Regardless of these variations, the yields from UDP on transplanted rice usually produced the highest yield, followed by UDP on broadcast-seeded rice.

2015 Dry Season

In the 2015 dry season, five partner organizations (CDDCET, PRC, Shan Maw Myay, KMSS, and WHH) implemented 23 demonstration plots in eight townships. Sample plots were harvested from 19 of 23 demonstration plots. The detailed data from the 19 harvests for all three treatments are given in Appendix 1.

The analysis of variance (ANOVA) table showed that only the effect of fertilizer treatments was significant; there were no effects of variety or fertilizer treatment x variety interaction on paddy yield (Table 7). Yield from the transplanted UDP treatment was significantly higher than the other two treatments (Table 8). There was no significant yield difference between UDP and farmers' practice treatments on broadcast-seeded rice. On average, the UDP transplanted yield was 1.1 t/ha and 1.4 t/ha higher than broadcast-seeded rice with UDP and farmers' practice, respectively.

Table 7. Analysis of Variance for 2015 dry season.

Effect	Num DF	Den DF	F Value	Pr>F
Fertilizer Treatment	2	15.43	4.65	0.0263 (significant)
Variety	2	5.783	0.25	0.7902
Fertilizer*Variety	4	15.43	1.95	0.1530

Table 8. Treatment comparison of rice grain yield for 2015 dry season.

Treatment	Mean (t/ha)	
Transplanted with UDP	5.42	a
Broadcast-seeded with UDP	4.34	b
Broadcast-seeded with FP	4.04	b

** Least square means with the same letters are not significant at p < 0.05.*

2015 Wet Season

In the 2015 wet season, four partner organizations (VIDA, PRC, KMSS, and WHH) and the FSI project implemented 30 demonstration plots in 14 townships; 29 of the 30 demonstration plots were harvested. Depending on the location, 15 demonstration plots used broadcast-seeded rice (FP-BR) and 14 demonstration plots used local transplanted rice (FP-TPR) in farmers' practice plots (Appendix 2). The ANOVA for the 2015 wet season (Table 9) showed significant fertilizer treatment by variety interaction. Hence, the fertilizer application effect on rice yield varied between varieties (Table 10).

UDP application on transplanted rice (UDP-TPR) gave significantly higher yield than on broadcast-seeded rice (UDP-BR) for all varieties except Ayar Min and Thee Htat Yin, for which there was no significant difference (Table 10). Overall, on transplanted rice, UDP gave higher yield by 0.82 t/ha, 1.18 t/ha, and 0.85 t/ha than farmers' practice on high-yielding varieties (HYV), hybrid varieties, and local varieties, respectively. Rice yields were significantly higher for Sin Thu Kha, Sin Thwe Latt, and Thee Htat Yin with UDP than farmers' practice on transplanted rice (Table 10).

UDP application on broadcast-seeded rice gave higher yield than farmers' practice. The yields were significantly higher for Sin Thu Kha, Sin Thwe Latt, Hmwabi-2, and Yadanar Toe (Table 10).

In this season, yield of UDP-TPR with HYV variety was 0.77 t/ha more than FP-BR, 0.82 t/ha more than FP-TPR, and 0.68 t/ha more than UDP-BR. In general, rice grain yield with farmers' practice for both transplanted and broadcast-seeded rice was similar.

Table 9. Analysis of variance for 2015 wet season.

Effect	Num DF	Den DF	F Value	Pr>F
Fertilizer Treatment	3	31.16	13.44	<.0001
Variety	5	17.8	1.32	0.2987
Fertilizer*Variety	14	30.75	2.00	0.0529

Table 10. LS means comparison of rice grain yield with different fertilizer treatments and varieties.

	Mean Treatment Differences in Yield for a Given Variety (Pr >t)					
Treatment Comparison	Hmawbi - 2	Manaw Thu Kha	Sin Thu Kha	Sin Thwe Latt	Thee Htat Yin	Yadanar Toe
Broadcast UDP vs Farmer Practice (Broadcast)	0.087	ns	0.049	0.028	-	0.02
Broadcast UDP vs Farmer Practice (Transplant)	ns	ns	ns	ns	0.016	ns
Broadcast UDP vs Transplant UDP	0.01 (-)	0.02 (-)	0.0003 (-)	0.017 (-)	ns	0.02 (-)
Transplant UDP vs Farmer Practice (Broadcast)	0.0003	ns	<0.0001	0.0002	-	ns
Transplant UDP vs Farmer Practice (Transplant)	ns	ns	0.007	0.007	0.017	ns
Farmer Practice Broadcast vs Farmer Practice Transplant	ns	ns	0.086 (-)	ns	-	ns

Comparisons that are not significant ($p \geq 0.1$) are designated ns.

2016 Dry Season

In the 2016 dry season, seven partner organizations (VIDA, PRC, KMSS, WHH, Ayar Aung Tagon, Yadanar Ayar, and Golden Plain) implemented 31 demonstration plots in 18 townships. All farmer practice plots during the dry season were broadcast-seeded with one plot in Mawlamyinegyun Township sown with a drum-seeder. All demonstration plots used HYV rice. A demonstration plot at Twantay Township was damaged by animal feeding and was not harvested (Appendix 3).

The main treatment effect on grain yield as shown in the ANOVA table was due to fertilizer treatments (Table 11). Since all demonstration plots had used HYV, it was not surprising that there was no effect of variety or fertilizer by variety interaction. Rice grain yield of both transplanted and broadcast-seeded rice with UDP was significantly higher by 1.2 t/ha and 0.9 t/ha, respectively, than farmer practice (Table 12). There was no significant difference between transplanted and broadcast-seeded rice with UDP application; on average, transplanted yield was higher by only 0.3 t/ha.

Table 11. Analysis of variance table for 2016 dry season.

Effect	Num DF	Den DF	F Value	Pr>F
Fertilizer Treatment	2	42.85	9.36	0.0004
Variety	3	19.96	1.67	0.2065
Fertilizer*Variety	6	42.85	1.71	0.1422

Table 12. Comparison of rice grain yield for 2016 dry season.

Treatment	Mean	
Transplanted with UDP	5.5088	a
Broadcast-seeded with UDP	5.2162	a
Broadcast-seeded with FP	4.3453	b

Least square means with the same letters are not significant at p < 0.05.

2016 Wet Season

In the 2016 wet season, seven partner organizations (VIDA, Nine Network, KMSS, MHDO, GDRI, Golden Plain, and WHH) implemented 30 demonstration plots in 24 townships. HYV rice was planted in 29 demonstration plots and only one plot used quality rice, Paw San Yin in Bogale Township. Of the 30 demonstration plots, one (in Mawlamyinegyun Township) could not be harvested due to rodent and bird damage as a result of an earlier growing time than neighbors' plots (Appendix 4).

Since all but one plot had quality rice, the effect of variety was not considered in the ANOVA. The fertilizer treatments were significantly different from each other (Table 13). The UDP application with transplanted rice gave significantly higher grain yield than UDP application and farmers' practice with broadcast-seeded rice (Table 13). The UDP transplanted yield was 0.69 t/ha higher than broadcast-seeded UDP and 1.21 t/ha higher than farmers' practice. On broadcast-seeded rice, UDP also gave significantly higher grain yield by 0.52 t/ha than farmers' practice.

Table 13. Effect of fertilizer treatment on rice grain yield for 2016 wet season.

Treatment	Estimate	
Transplanted with UDP	5.004	a
Broadcast-seeded with UDP	4.310	b
Broadcast-seeded with FP	3.792	c

Least square means with the same letters are not significant at p < 0.05.

2. Paddy Crop Cuts

Crop cut data from four seasons, as presented in Table 14 and Figure 2, show that rice grain yields from UDP fields were consistently and significantly higher ($p<0.01$) than non-UDP fields. On average, the rice grain yield with UDP was from 14.33 baskets/acre to 18.20 baskets/acre higher than the non-UDP fields.

Table 14. Comparison of rice crop cut yield from four seasons for UDP versus non-UDP fields.

Season	Quantity of Crop Cuts	Average Yield of UDP (t/ha)	Average Yield of Non-UDP (t/ha)	Yield Difference (UDP> non-UDP) (t/ha)	Yield Difference (UDP> non-UDP) (baskets/acre)	Significant ($p < 0.01$)
2014-15 dry	94	4.82	4.01	0.81	15.68	**
2015 wet	113	4.49	3.75	0.74	14.33	**
2015-16 dry	137	5.40	4.63	0.77	14.91	**
2016 wet	121	4.44	3.67	0.77	14.91	**

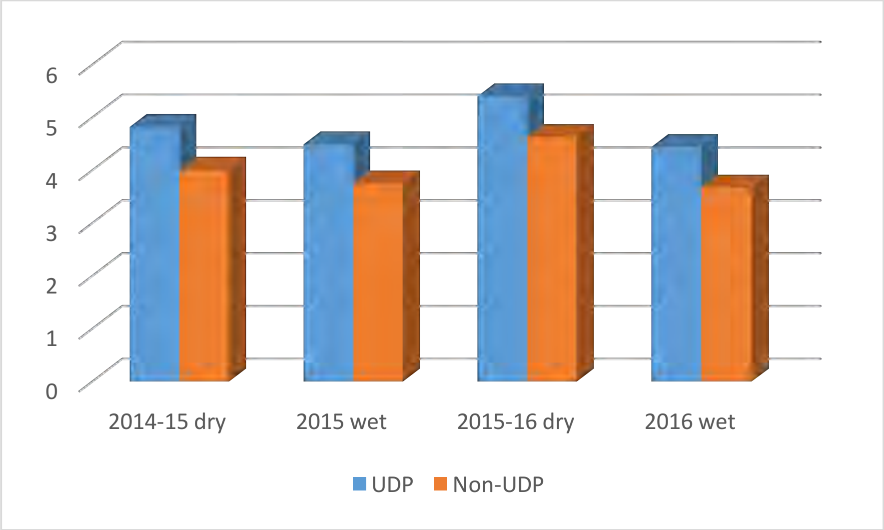

Figure 2. Rice grain yield (t/ha) based on crop cuts for UDP vs. non-UDP fields.

3. Gram Crop Cut

Gram crop cuts are taken from gram fields where UDP was applied in the previous rice crop and compared with cuts from fields without UDP application. Overall, due to the residual effect of UDP, gram yield was higher by 0.27 t/ha, or 25%, compared to non-UDP fields (Table 15). In general, UDP from paddy crops had a positive effect on the yield of the following gram crop.

Table 15. Comparison of gram crop-cut yield from two seasons with residual effect of UDP versus non-UDP.

Season	Quantity of Crop Cut	Average Yield of UDP (ton/ha)	Average Yield of Non-UDP (ton/ha)	Different Yield (UDP>Non-UDP) ton/ha
2016 dry season	40	1.38	1.10	0.28
2017 dry season	40	1.26	0.99	0.27

4. DOA Results

The DOA's technology demonstration plots for SRI, GAPs, and drum seeders compared to local transplanted rice all used UDP. The average results from five townships are shown in Table 16. The highest yield gains were obtained with the combination of UDP and SRI. On average, the yields were 1.14 t/ha (22 baskets per acre) more than local transplanted rice. UDP in combination with GAPs produced 1.03 t/ha (19.86 baskets per acre) more than local transplanted rice with UDP.

Table 16. Yield on four cultivation types with UDP application.

Sr	Township	Village Tract	Village	Variety	SRI	GAPs	Farmer Transplant	Seeder
					Yield ton /ha (14% M)			
1	Zalun	Pet Tan	Tin Koke Su	Hmawbi-3	5.83	6.09		5.94
2	Kangyidaunt	War Du	War Du	90 days		4.83	5.17	3.98
3	Maubin (a)	Tar Pat (west)	Tar Pat (west)	Thee Htat Yin	6.18	6.83		
	Maubin (b)	Let Pan Kone	Let Pan Kone	Yae Nel Lo-7	6.99			5.21
4	Kyungyangon	In Ga Lone	Yan Gyi Aung	Thee Htat Yin	4.63	5.14	3.86	
5	Taikkyi	Oke Pon	Yae Twin Gyi	Yadanar Toe	5.28	5.47	4.91	
					28.91	28.36	13.94	15.13
			Average yield		5.782	5.672	4.6467	5.0433

Discussion

According to the results of crop cuts from demonstrations over four seasons, yields in transplanted rice with urea deep placement technology (UDP-TPR) were higher than the farmers' practice every year. UDP-TPR was higher than FP-BR by 1.4 t/ha in the 2015 dry season and by 0.82 t/ha over FP-TPR and 0.68 t/ha over FP-BR in the 2015 wet season. It was higher than FP-BR by 1.2 t/ha in the 2016 dry season and by 1.21 t/ha over FP-BR in the 2016 wet season.

Yield with urea deep placement technology in broadcast-seeded rice (UDP-BR) was 0.3 t/ha higher than FP-BR in the 2015 dry season, 0.87 t/ha higher than FP-BR in the 2016 dry season, and 0.52 t/ha higher than FP-BR in the 2016 wet season. Even when there was no significant difference between UDP-BR and FP in the 2015 wet season, UDP-BR was still 0.1 t/ha higher than FP-BR and 0.14 t/ha higher than FP-TPR in this season.

UDP plot yields were also 0.74-0.81 t/ha higher than non-UDP plots in crop cuts in farmers' fields over the four seasons and crop cuts in the gram crops after UDP in rice indicated a residual effect of UDP.

All results were well-noted by farmers as day-to-day observations of growth and color and during field days, field trips, and crop cuts. The contact farmers and related farmers became strong advocates of the technology and shared the information among the farmers in their community. Despite this, the adoption has been slow. Most farmers have not adopted the new technology even though they acknowledge the benefits. Despite the positive results from the demonstrations, crop cuts, and famers' own experience with UDP technology, farmers are not adopting it due to the labor intensity involved, the increasing trend of labor outmigration, and the resulting lack of available labor.

It is well-known among extension workers that despite the benefits and the understanding of any technology by farmers, not all farmers accept the new technology at the same time. According to Rogers (1962), there are five different categories of farmers in terms of their ability to adopt new ideas: innovators (2%), early adopters (14%), early majority (34%), late majority (34%), and laggards (16%). FSI has found that innovators and early adopters have been following up with the new technology since the beginning of their training. They have used the 10 kg of briquettes provided during the training as a test, and in the following seasons, they bought briquettes and applied to them more areas. They also shared the information on the benefits with their relatives and neighbors.

Normally, it takes a long time to change traditional practices, cultural practices, and mindsets of risk-averse smallholder farmers. The FSI project introduced UDP in the 2014-15 dry season. In the past two years, the UDP technology, as shown from the results of the demonstration plots and crop cuts, has increased rice yield and, in most cases, also reduced the cost of urea. In the demonstration plots, in every year, transplanted rice with UDP gave the highest yield, followed by UDP on broadcast or direct-seeded rice. According to the crop cut results of four seasons, farmers who applied UDP technology increased yield by 15-20%. Results can vary depending on soil conditions, management practices, including water management, and seed quality and variety, but UDP yield was significantly higher than non-UDP yield. The positive residual effect of UDP on gram yield – up to 25% increase – also improves farmers' income and food security.

Given the diverse cultural and planting practices (transplanting, drum-seeding, broadcast-seeding), land preparation, land topology, soil types, and water management, more methods, types, and timing of UDP need to be evaluated. Every UDP-adopting farmer is convinced of the benefits of the technology. They can see the superior yield over their own practice. However, even though they are convinced of the benefits, their adoption is constrained by lack of labor for manual application. A mechanized applicator is likely to have a big impact on adoption.

Conclusion

Through the extension activities of the FSI project, farmers are given the opportunity to learn about balanced nutrient management and UDP technology in farmer training together with field practical application. They also see the actual results of the classroom teachings in field days and motivational field trips and have the opportunity to test the technology in their field using the sample provided during training. Farmers have observed taller, greener, and more tillers and higher yield on UDP plots than broadcast prilled urea plots. Another advantage was the reduction in weeding, especially in the dry season.

In the 2017 dry season, the FSI project has added two more treatments to its demonstrations to promote not only urea deep placement technology but also balanced fertilization. The five demonstration plot treatments are: (1) UDP on transplanted rice (with basal P and K); (2) UDP on broadcast seeded rice (with basal P and K); (3) farmers' practice; (4) basal compound fertilizer application with urea topdressing on broadcast-seeded rice (dry season)/transplanted rice (wet season), and (5) urea-only application dressing on broadcast-seeded rice (dry season) and on transplanted rice (wet season).

FSI is trying to build a strong network between the farmer community, briquette machine operators (BMOs), and retailers to improve the availability of inputs. IFDC has been working on applicators for several years and has introduced a number of different types to Myanmar on a trial basis. The manual injector type and the push type still required labor and were difficult to manage. Now, in collaboration with John Deere and Khedut Engineering, a mechanical applicator has been developed and is undergoing field tests during the wet season of 2017.

Going forward, FSI has to encourage partner organizations for strong participation in multiplying the diffusion rate, to strengthen cooperation with DOA extension activities, and finally to maintain intensity on the message of balanced fertilizer with UDP.

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Appendix 1. 2015 Dry Season Paddy Yield for 19 Demonstration Plots

Sr	Township	Village Tract	Village	Variety	Yield (ton/ha)		
					TPR (UDP)	BR (UDP)	FP (BR)
1	Htantabin	Sat Ka Lay	Ein Lay Lone	Shwe Pyi Htay	4.32	2.54	3.98
2	Htantabin	Tha Pyay Khone	Tha Pyay Khone	Hmaw Bi San	4.73	3.67	3.57
3	Htantabin	Hnget Thaik	Hnget Thaik	Thee Htet Yin	7	7.92	6.34
4	Htantabin	San Da Yaw	Boe Wea Gyi Su	Shwe Pyi Htay	4.53	4.04	3.87
5	Htantabin	Htein Hnit Pin	Pet Inn Gyi	Shwe Pyi Htay	5.8	4.2	4.57
6	Bago	Ma Yin	Ma Yin Kan Gyi	Thai Manaw	5.78	5.26	4.66
7	Bago	Wan Be Inn	Wan Be Inn	Thai Manaw	6.29	5.19	3.94
8	Letpadan	Kyoet Pin Sa Khan	Shwe Nyaung Pin	Yatanar Toe	5.87	5.42	4.2
9	Letpadan	Chan Thar Kone	Chan Thar Kone	Yatanar Toe	6.27	5	5.72
10	Letpadan	Gon Min Kwin	Shar See Hpo	Yatanar Toe	4.68	4.91	4.59
11	Letpadan	Na Be Kwin	Ywar Thar Yar	Yatanar Toe	6.59	5.33	5.49
12	Taikkyi	Oke Pon	Oke Pon	Yatanar Toe	5.9	4.46	5.14
13	Taikkyi	Hpa Lon Ywar Ma	Hpa Lon Ywar Ma	Yatanar Toe	6.04	5.94	5.69
14	Hlegu	Thu Ngeit Chaung	Min Lwin Kone	IR 90	4.1	3.1	2.33
15	Hlegu	Kyun Kone	Kyun Kone	Vietnum	6.03	1.85	0.89
16	Hlegu	Sar Ta Lin	Sar Ta Lin	Manaw Thu kha	5.27	4.64	3.29
17	Thanlyin	Hpa Yar Kone	Hpa Yar Kone	Palae Thwe	6.76	4.1	4.4
18	Thanlyin	Thama College		Vietnum	5.48	3.83	3.02
19	Thanlyin	Ba Yet	Ba Yet	Palae Thwe	6.09	4.76	4.59

Appendix 2. 2015 Wet Season Paddy Yield for 29 Demonstration Plots

					Yield (ton/ha)			
Sr	**Township**	**Village Tract**	**Village**	**Variety**	**TPR-UDP**	**BR-UDP**	**FP-BR**	**FP-TPR**
1	Htantabin	Hnget Thaik	Htoo Lay Su	Sin Thwe Latt	4.17	3.23	2.228	
2	Htantabin	San Da Yaw	San Da Yaw	Sin Thu Kha	4.538	3.88	3.602	
3	Htantabin	Daunt Gyi	Set Su	Sin Thu Kha	3.9	3.92	2.59	
4	Htantabin	Kyar Hone	Kyein Paik	Sin Thu Kha	4.03	3.11	2.49	
5	Bogale	Nyi Naung	Min Hla Su	Sin Thwe Latt	4.16	3.66	3.33	
6	Bogale	Sa Bai Kone	Dar Chaung	Sin Thwe Latt	4.82	4.02		3.52
7	Bago	Tat Ka Lay	Ka Li	Manaw Thu Kha	6.53	5.41	6.08	
8	Bago	Ka Twin Chan	Ka Twin Chan	Sin Thu Kha	5.948	5.34	5.1	
9	Letpadan	Kun Chan	Kun Chan	Sin Thu Kha	4.36	3.8		4.5
10	Letpadan	Thaik War Chaung	Thaik War Chaung	Yadanar Toe	4.125	3.06		3.62
11	Daik-U	Ka Toke Hpa Yar Gyi	Ka Toke Hpa Yar Gyi	Hmawbi-2	5.45	4.88	3.52	
12	Daik-U	Kyaik Sa Kaw (East)	Kyaik Sa Kaw (East)	Sin Thu Kha	4.01	3.65		3.32
13	Thayarwady	Ma Gyi Kwin	Leik Inn (Ah Lel Su)	Yadanar Toe	4.05	3.27		3.69
14	Thayarwady	Kywe That	Kywe That Gyi	Sin Thu Kha	4.77	4.03		4.37
15	Taikkyi	Tar Gwa	Inn Yet Gyi	Hmawbi-2	2.625	2.437		2.29
16	Taikkyi	Oke Kan Kan Kone	Oke Kan Kan Kone	Hmawbi-2	4.86	3.268	3.64	
17	Hlegu	Sar Bu Taung	Sar Bu Taung	Manaw Thu Kha	4.656	4.053		4.46
18	Hlegu	War Net Kone	War Net Kone	Ayar Min	2.958	3.359	3.482	
19	Thanlyin	Kayin Seik	Kayin Seik	Taung Pyan Yin	6.42	4.61	4.19	
20	Kyauktan	Tadar	Tadar	Yadanar Toe	3.12	3.6	3.78	
21	Kangyidaunt	Ah Htet Ta Khun Taing	Ma Gyi Kone	Thee Htat Yin	4.86	4.97		3.9
22	Kangyidaunt	Myin Ka Seik	Sar Hpyu su	Pa Khan	4.74	4.8	4.31	
23	Kangyidaunt	Kyon Gyi	Kyu Chaung	Thee Htat Yin	3.68	3.6		2.88
24	Pantanaw	Ba Waing	Ba Waing	Palae Thwe	5.05	4.27		3.87
25	Pantanaw	Kyon Tone Gyi	Zee Hpyu Su	Sin Thu Kha	6.55			6.02
26	Nyaungdon	Tu Chaung	Tu Chaung	Sin Thu Kha	5.73	5.14	5.2	
27	VaNyaungdon	Nat Pay	Nat Pay	Swawanar	7.22	5.62	6.13	
28	Maubin	Nga Gyi Ga Yet	Nga Gyi Ga Yet	Sin Thwe latt	5.31	5.05		4.73
29	Maubin	Thu Htay Kone	War Yon Ga Yet	Sin Thu Kha	5.78	4.36		4

Appendix 3. 2016 Dry Season Paddy Yield for 30 Demonstration Plots

					Yield (ton/ha)		
Sr	Township	Village Tract	Village	Variety	TPR (UDP)	BR (UDP)	FP (BR)
1	Hmawbi	Myaung Tagar	Yoe Wa	Yadanar Toe	7.93	6.16	5.05
2	Hlegu	Moke Soe Nyaung Pin	Shan	Thee Htet Yin	5.22	4.96	7.6
3	Taik Kyi	Yin Taik Kwin	Yin Taik Kwin	Yadanar Toe	5.8	5.99	5.23
4	Taik Kyi	Taung Boet Hla	Taung Boet Hla	Yadanar Toe	6.508	5.63	4.78
5	Twan Tay	Htaw Tho	KyaukSayit Kone	Shwebo	6.39	5.32	5.11
6	Kungyangon	In Ga Lone	In Ga Lone	Thee Htet Yin	5.602	4.618	3.547
7	Kungyangon	Taw Kha Yan (West)	Taw Kha Yan (West)	Thee Htet Yin	3.62	4.34	3.61
8	Htantabin	Yoe Gwa	Yoe Gwa Myauk Su	Yay Nae Lo-4	6.13	5.18	4.076
9	Htantabin	Yoe Gwa	Yoe Gwa KayinSu	YN 3153 (IRRI)	5.885	5.455	4.865
10	Pantanaw	Dawwar	Daw War A Htet Su	Sinthukha	5.19	5.35	4.38
11	Myaungmya	Kyon War	Kyon War	Thee Htet Yin	5.73	3.65	4.98
12	Myaungmya	Kyar Hpu Ngon	Kyar Hpu Ngon	Thee Htet Yin	6.58	6.16	5.77
13	Kangyidaunt	Kyaik Lat	Kyaik Lat	Thee Htet Yin	3.15	3.49	2.62
14	Kangyidaunt	War Du	Ahnauk Su Gyi	Thee Htet Yin	4.943	5.96	4.206
15	Maubin	Tar Pat (west)	Tar Pat (west)	Thee Htet Yin	5.95	6	5.53
16	Nyaung-don	Sarmalauk	Sarmalauk	Sin Ayar	5.44	4.08	2.89
17	Bogale	Tha Kan Wa	Kyon Hpar	Thee Htat Yin	5.31	5.9	5.13
18	Bogale	Boe Di Kwe	Kun Thee Chaung	Thee Htat Yin	4.683	4.463	4.425
19	Kyaiklat	Bon Lon Chaung	KhayawPin Seik	Thee Htat Yin	7.36	6.205	6.148
20	Kyaiklat	Hle Seik	Hle Seik	Thee Htat Yin	6.75	5.45	5.31
21	Mawlamyinegyum	Myinkakone Ka Lay	Daung Yae Kyaw	Thee Htet Yin	7.02	6.778	5.155
22	Mawlamyinegyum	Kyar Chaung	Kyar Chaung	Pakhan Shwe War	7.19	6.702	6.52
23	Mawlamyinegyum	Htiparlel Thaung tan	Thaung Tan	Thee Htat Yin	5.957	7.086	5.973
24	Mawlamyinegyum	Kyaik Pi	Shwe Ta Chaung	Thee Htat Yin	6.28	6	5.43
25	Bago	Kawt Che	Pauk Taw	Thai Manaw	4.09	5.133	3.897
26	Daik-U	Pyin Ma Lwin	Pyin Ma Lwin	Thai Manaw	3.83	5.39	4.1
27	Daik-U	Ka Toke Ywar Ma	U Daung Su	Thai Manaw	5.34	4.21	3.68
28	Letpadan	Pyin Htaung Twin	Pyin Htaung Twin	Thai Manaw	8.156	8.045	5.84
29	Thayarwady	Thityar Kone	Ohntaw Su	Shwe Thwe Yin	5.6	5.57	4.257
30	Thayarwady	Kyun Kone	Late Oo Kone	Yadanar Toe	7.92	6.26	3.81

Appendix 4. 2016 Wet Season Paddy Yield for 29 Demonstration Plots

Sr	Township	Village Tract	Village	Variety	Yield (ton/ha)		
					TPR (UDP)	BR (UDP)	FP (BR)
1	Thanlyin	Sit Pin Kwin	Sit Pin Kwin	Thai Manaw	4.97	4.86	3.08
2	Daik-U	Ein Chay Lay Se	Ein Chay Lay Se	Sin Thu Kha	5.34	4.96	3.91
3	Pantanaw	Pa Thwei	Ta Loke Su	Sin Thu Kha	6.39	5.6	4.69
4	Kyauktan	Nyaung Waing	Myaing Thar Yar	Thee Htat Yin	5.52	4.52	3.85
5	Kyauktaga	Than Pu Yar Khon	Than Pu Yar Khon	Sin Thu Kha	6.37	4.42	5.48
6	Zigon	Wet Sa Poe	Wet Sa Poe	Yadanar Toe	4.67	4.09	4.01
7	Twantay	Hpa Yar Gyi	Za Yat Kone	Sin Thu Kha	4.16	4.56	3.37
8	Maubin	Thone Gwa	Thone Gwa	Thee Htat Yin	4.9	4.74	4.29
9	Mawlamyinegyun	Sa Khan Gyi	Nauk Pyan Toe	Sin Thwe Latt	6.54	4.86	4.35
10	Kyaunggon	Ka Nyin Thone Sint	Ka Nyin Thone Sint	Sin Thu Kha	5.22	4.496	3.865
11	Kungyangon	Ka Mar Par	Ka Mar Par	Thee Htat Yin	6.424	5.629	2.644
12	Kyauktaga	Myo Chaung	Myo Chaung	Sin Thu Kha	5.294	2.68	4.39
13	Letpadan	Ma Gyi Kwin	Shwe Bo Su	Sin Thu Kha	4.76	4.47	3.96
14	Pyay	Ah Shey Let Khoke Pin	Min Kone	Yadanar Toe	4.73	3.98	5.41
15	Einme	Htein Ngu	Kywe Lan	Sin Thu Kha	5.13	4.73	2.96
16	Hmawbi	Nyaung Kone	Nyaung Kone	Sin Thu Kha	4.95	3.59	3.45
17	Kangyidaunt	Khon Zin Kone	Kyun Chaung	Mashuri	3.64	2.92	2.49
18	Pyapon	Koe Ein Tan	Naung Taw Gyi	90 days	4.72	3.66	3.04
19	Myaungmya	Tha Pyay Chaung	Tha Pyay Chaung	Sin Thu Kha	3.71	1.92	2.63
20	Hlegu	Hpaung Gyi (East)	Hpaung Gyi (East)	Sin Thu Kha	4.6	4.37	4.23
21	Kungyangon	War Kauk Taw	War Kauk Taw	Sin Thu Kha	6.988	6.622	5.46
22	Bago	Hpa Yar Ngoke To	Ah Shey Kone	Manaw Thu Kha	4.92	4.197	3.82
23	Bogale	Tha Kan Wa	Da None Chaung	Paw San Yin	3.49	3.37	3.11
24	Taikkyi	U To	U To	Sin Thu Kha	5.29	4.08	3.8
25	Hlegu	Dar Pein (South)	Dar Pein (South)	Sin Thu Kha	4.68	3.89	3.32
26	Kawhmu	Ma Gyi Kan	Za Loke Gyi	Sin Thu Kha	4.735	5.719	4.135
27	Pyay	Twin Bye	Kyoet Yat Thar	Sin Thu Kha	3.76	3.55	3.45
28	Thayarwady	Nga Hpyu Ka Lay	Nga Hpyu Ka Lay Ywar	Yadanar Toe	4.59	4.46	3.87
29	Kyaiklat	Pan Be Su	Pan Be Su	Thee Htat Yin	4.63	4.04	2.89

UDP Technology and Rice Yields Among Farmer Beneficiaries of Rainfed Lowland Project Areas in Myanmar

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Abstract

Since its inception in 2014, the Fertilizer Sector Improvement (FSI) project in Myanmar has introduced urea deep placement (UDP) fertilizer technology, aimed at improving yields and fertilizer use efficiency among rice farmers in its project intervention areas. For this purpose, selected farmers from three major rice-growing regions of Myanmar, located in Yangon, Bago, and Ayeyarwady were given training through effective farm demonstrations and other extension services to promote the use of technology along with other improved inputs. Extensive data were collected among project beneficiaries to determine the effect of UDP technology on yields in comparison to the traditional use of fertilization methods. In this paper, we have made an attempt to use part of the data documented to estimate the factors responsible for variability in productivity levels of rice with the adoption of UDP technology under rainfed conditions during the 2016 wet season. A log linear regression model was employed for empirical estimation to determine the effect of UDP along with other external factors that jointly influence the rice yields in the intervention areas. Our analytical results indicate a significant and positive impact of UDP technology use on rice yields; improved crop intensification practices adopted by farmers also played a crucial role in improving the rice yields. In addition to these factors, male farmers were very successful in adopting the technology and in realizing higher yields in their plots compared to their female counterparts. Other variables, such as area allocated for rice, resulted in yield reduction, implying lack of purchasing power among farmers for additional input use. Along with low credit access, this results in underuse of external inputs. From a policy perspective, these results have wider implications. For instance, limited opportunities exist for crop land expansion in the intervention areas; thus, any increase in yields should come from the effective and efficient use of agro-input technologies, such as high-yielding varieties (HYVs), UDP, and other crop management techniques. The evidence from our empirical analysis further suggests increased and focused government efforts are needed toward promoting the use of efficient soil and fertilizer management technologies, such as UDP, and promoting crop intensification practices among farmers in the lowland rainfed rice cropping system in Myanmar to achieve higher yields and profits from limited expansion of cropping land. The gross margin results also indicate the likely and positive effect of increased access to technologies and participation by women farmers in extension programs for greater benefits to society as a whole.

Introduction

The Myanmar economy is largely dependent on the agriculture sector, which contributes 29% of national gross domestic product (GDP) and 23% of total export earnings in 2014/2015 and in which 65% of the labor force is engaged (CSO, 2015/2016). Growth in the agriculture sector has played a crucial role in the development of Myanmar. Production of the staple food – rice – is central to the country's agriculture sector as it is the main livelihood activity of farmers and a major export item of the country. It occupies more than half of total cultivated land and is a key economic crop that dominates most agricultural economies in developing countries like Myanmar.

Due to limitations of planting area and imported material inputs, raising productivity of paddy should be given a higher priority to meet the objective of national food security and export earnings of the country.

Between 1995 and 2010, paddy yield has increased by 1 t/ha (from 3.08 t/ha to 4.07 t/ha) (Department of Planning, 2015). However, productivity of paddy (2.84 t/ha in 2015) still has been relatively low compared to other Southeast Asian countries, such as Indonesia, Vietnam, Philippines, and Malaysia (USDA, 2016). According to the Department of Planning (2015), paddy yield was stagnant at 3.8 t/ha during 2011 and 2014. Raitzer et al. (2015) pointed out that most farms – with low-input, low productivity, low-quality output, and low returns – are caught in a low equilibrium trap in Myanmar. In order to raise the productivity of paddy production in Myanmar, it is important to identify the core factors influencing it. The FSI project, implemented by the International Fertilizer Development Center (IFDC), began on April 1, 2014, as a three-year project funded by the United States Agency for International Development (USAID), and it was expanded and extended in May 2015 to a five-year project. The goal of the project is to improve food security and increase profitability for smallholder farmers by sustainably increasing agricultural productivity. IFDC is implementing the project with collaborating partners in geographic focal areas covering Yangon, Bago, and Ayeyarwady regions.

The productivity constraints for paddy stem largely from an insufficient supply of good seeds, fertilizer prices rising more quickly than paddy prices coupled with a lack of farmer knowledge on soil nutrient management, and the slow pace of mechanization outside of several commercial rice-producing areas (World Bank, 2016). Therefore, the FSI project seeks to improve paddy yield and farm income by promoting the application of balanced fertilizer with UDP as well as use of good seed, in addition to strengthening the capacity of input retailers to improve their business management and provide an advisory service to farmers. The FSI project targets farmers in the rainfed lowland rice production areas of Yangon, Bago, and Ayeyarwady regions.

The FSI project methodology involves a series of capacity-building activities that include farmer-level and agro-input dealers' training combined with field demonstrations on the use of improved technologies (seeds, fertilizers, agri-implements) and technology transfer through on-farm as well as organized field days and motivational field trips. The agro-input dealer trainings are designed to enhance agricultural advisory services, which play a crucial role in promoting rice-based cropping system productivity and farm income. Most of the progressive farmers in the project intervention areas participate in farmer training and apply UDP technology. As a part of the FSI project, a crop cut survey is conducted seasonally to determine the yield improvement with UDP technology over the farmers' conventional practice on fertilizer application and to calculate the yield differences between them.

In this paper, we have made an attempt to assess the influencing factors on rice productivity levels in the project intervention areas, namely among farmers who adopted UDP fertilizer technology practices in the rainfed lowland areas in Myanmar. This would further allow us to derive suitable policy implications along with recommendations necessary to promote efficient soil and fertilizer management practices and necessary actions and support required to achieve higher rice productivity levels especially under lowland rainfed environments in Myanmar.

Methodology

Sample of Direct Beneficiary Farmers for Rainfed Paddy Season in 2016

During the 2016 wet season, farmer training on UDP was provided to 1,933 farmers: 1,386 male and 547 female farmers (Table 1) selected from nine townships in Yangon, seven townships in Bago, and 11 townships in Ayeyarwady. A list of direct beneficiary farmers who attended the farmers' training and applied UDP was received following field monitoring by subgrant partners and the project extension team and through key farmer informants (Table 1). The total number of beneficiary farmers (at the end of September 2016) who applied UDP in the wet season of 2016 was 1,617 (1,164 male and 453 female farmers). Table 1 shows that, among the direct beneficiaries, the percentages of UDP users across all regions were 82.8% and 83.9% of female and male farmers, respectively. The lowest percentage of UDP technology beneficiaries were found in Ayeyarwady Region, regardless of gender (Table 1).

The farmer list was sorted first by gender, and from the list, a random sample of farmers was selected for each township. Based on resource availability, crop cuts were conducted across 7% of the total sample (34 female and 83 male farmers).

For the current analysis, we have used data and information collected through crop cuts from 115 farmers (34 female and 81 male farmers).

Table 1. Percentage of direct beneficiary male and female farmers who used UDP during wet season paddy in the FSI project regions.

Region	No. of Direct Beneficiary Farmers in Wet Season 2016			No. of Beneficiary Farmers Using UDP in Wet Paddy 2016			% of Total Beneficiary Farmers Using UDP in Wet Paddy 2016		
	Female	Male	Total	Female	Male	Total	Female	Male	Total
Yangon	211	459	670	176	392	568	83.41	85.40	84.78
Bago	169	371	540	160	352	512	94.67	94.88	94.81
Ayeyarwady	167	556	723	117	420	537	70.06	75.54	74.27
Total	**547**	**1,386**	**1,933**	**453**	**1,164**	**1,617**	**82.82**	**83.98**	**83.65**

Source: FSI extension team, subgrant partners and key farmers.

A direct beneficiary farmer is any farmer who attended a project training event at any time over the term of the project.

Implementation of Crop Cut Survey

The extension team of the FSI project is well-experienced in conducting crop cut surveys. Six enumerators (who are working as FSI Field Officers and Training

Officers) and a supervisor (FSI Extension Specialist) were involved in conducting the crop cuts and survey during the rainfed paddy season in 2016. They were provided with instructions for crop cuts from the Chief of Party (CoP) and the list of random sample farmers and a questionnaire from the Monitoring and Evaluation Specialist to be used to collect data for gross margin calculations.

The main objective of the crop cut survey is to measure the impact of the UDP technology on rice yield. At the end of each season, the project takes crop cuts in a random sample of beneficiary farmers who used UDP in that season to compare with their fields without UDP. Two 5 meter x 2 meter plots are cut in each farmer's field with and without UDP. The plots are threshed, weighed, and moisture measured to calculate yield per hectare at 14% moisture. In addition, information on the inputs used and their cost, area of wet paddy cultivated and harvested, percentage of the total production sold, and farm-gate paddy price received were collected to estimate the gross margin of wet season paddy in 2016.

Data Analysis

Descriptive statistics: Measures such as percentages, frequencies, means, and standard deviations were used in characterizing rice farmers based on farm size groups (small, medium, and large landholding groups), area harvested under wet land, cultivated rice varieties, cultural practices (broadcasting seeds and transplant paddy), mechanization, agro-inputs used, etc., during the production of wet season paddy in 2016.

Tests of significance: The Chi-square test and analysis of variance were used to find the differences in wet paddy yield with UDP and without UDP, harvested wet paddy land, cultural practice(s), paddy variety, farm size group, sources of seeds, total production cost of wet paddy, and quantity of sales between male and female beneficiary farmers.

Gross margin analysis: The gross margin (GM) by gender, by variety, by cultural practice, and by cropping pattern was calculated to estimate the returns of wet season paddy production in 2016.

The GM is calculated from five data points (USAID, 2013):

1. Total production (TP).
2. Total value of sales (VS).
3. Total quantity of sales (QS).
4. Total recurrent cash input costs (IC).
5. Total units of production (UP), i.e., area in hectares.

$$GM = \frac{(TP \times VS/QS) - IC}{UP}$$

Empirical model:

Productivity is a basic and intuitive measure of crop or varietal performance in the use or adoption of improved technology. Coelli et al. (2005) argued that productivity is the ratio of the output(s) that it produces to the input(s) that it uses (Productivity = Outputs/Inputs). Productivity is raised when growth in output(s) outpaces growth of input(s). Productivity growth without an increase in input(s) is the best kind of growth to aim for rather than attaining a certain level of output (Nin-Pratt et al., 2008).

The rice production decisions by farmers are affected by pricing factors, such as farm-gate price of rice, farm-gate price of substitute food crops like maize, world price of rice and maize, and prices of fertilizer, influencing yields indirectly. Also, non-price factors, such as irrigation, investment in research and development, extension services, capital and credit access, and biotic factors, such as favorable agro-climatic conditions, and development of rural infrastructure, affect farmers' production (Yu and Fan, 2009).

Glenn et al. (2013) suggests that improvement in soil fertility management is one of the nine areas of intervention for increasing productivity at the farm level in Myanmar. Very few studies have estimated the influence of fertilizer on rice productivity levels and increased efficiency in Myanmar. This paper seeks to further address the gap in the existing literature on the specific subject matter, namely in estimating the determinants of improved paddy yield with UDP technology use among the farmers in the lowland rainfed region during the wet paddy season of 2016.

Based on the household-level crop cut survey data collected in wet paddy season 2016, we herein derive the output-response relationships from estimated production function, assuming profit maximization objective by farmers. The log linear regression model (using natural logs for variables on both sides of the model) was estimated to generate the desired linearity in parameters. By this, the coefficient of such log-log model estimated can be interpreted as *percent change* in the dependent variable for a *percent change* in the independent/explanatory variables.

$$In(Y) = \beta_0 + \beta_1 In(x_1) + \beta_2 In(x_2) + \beta_3 In(x_3) + \beta_4 In(x_4) + \beta_5 In(x_5) + \beta_6 In(x_6) + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \mathcal{E}_i$$

where Y = Average wet season yield of paddy with UDP (kg/ha)
X_1 = Log lagged average price of paddy (MMK/kg)
X_2 = Log average price of prilled urea (MMK/kg)
X_3 = Yield difference between yield with UDP and without UDP technology (t/ha)
X_4 = Harvested land of wet season paddy (ha)
X_5 = Number of crops grown in a year
X_6 = Cost of harvesting machine (MMK/ha)
X_7 = Number of labor use in paddy production (number of labor/ha)
X_8 = Dummy variable for gender of sample farmer (male=1, female=0)
X_9 = Dummy variable for paddy variety (HYV=1, local=0)

The above model was employed due to the simplicity in the interpretation of the parameters and the data meeting the Ordinary Least Square criteria. The model was subjected to a diagnostic test. The double logarithmic model was tested for normality to ascertain the nature of the distribution of the residuals. The presence or absence of multicollinearity was verified with the help of the Variance Inflation Factor. Lastly, the value of R^2 adjusted was used to determine the goodness of fit of the model.

Results and Discussion

Family Size, Rainfed Paddy Land With and Without UDP, and Farm Size Group

The average family size of sampled male farmers was 4.86, which is higher than the average family size of sampled female farmers (4.54). The mean wet paddy land with UDP was nearly the same for both sampled male and female farmers (male 0.099 ha and female 0.094 ha). The wet paddy land without UDP of sampled female and male farmers was 4.0 and 3.56 ha, respectively.

According to the Settlement and Land Record Department (2010), different farm size groups are classified into five categories: landless, marginal (less than 2 acres), small (less than 5 acres), medium (less than 10 acres) and large (more than 10 acres). Following that criteria, the majority of sampled female farmers (40%) owned/worked with small paddy land, while the majority of sampled male farmers (40%) owned/worked with medium paddy land (Figure 1). Nearly the same percentage of both sampled male and female farmers were classified in the other two farm size groups of marginal and large landholders.

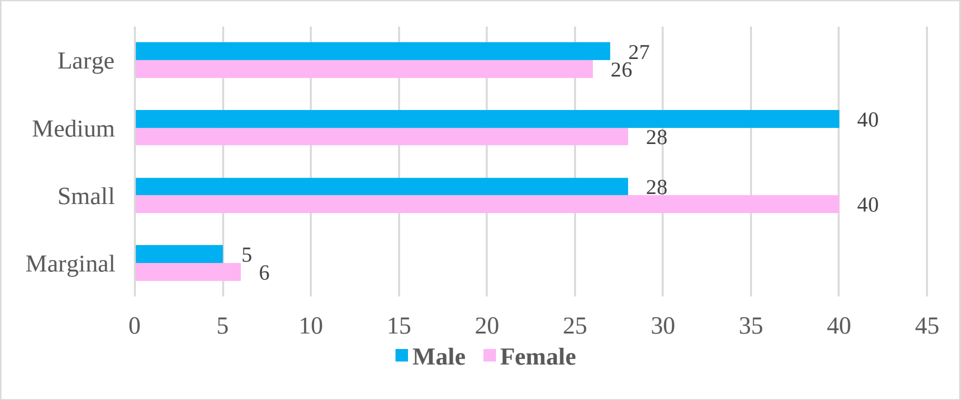

Figure 1. Different farm size groups of sample beneficiary farmers by gender.

Cropping Pattern, Cultural Practice, Paddy Variety Used, and Effect of UDP on Yield

The majority of both female and male sampled farmers grew gram crops after rainfed paddy (Figure 2). Summer paddy production was determined by the availability of water. Thirty-one percent of female and 16% of male farmers planted summer paddy (or dry paddy) after wet paddy. Furthermore, 11% of female and 8% of male farmers grew three crops per year (wet paddy, gram crops, and dry paddy). The rest of the farmers (23% of female and 15% of male farmers) grew only one crop – rainfed paddy only. Therefore, the mean number of crop grown per year for the sampled farmers was about two.

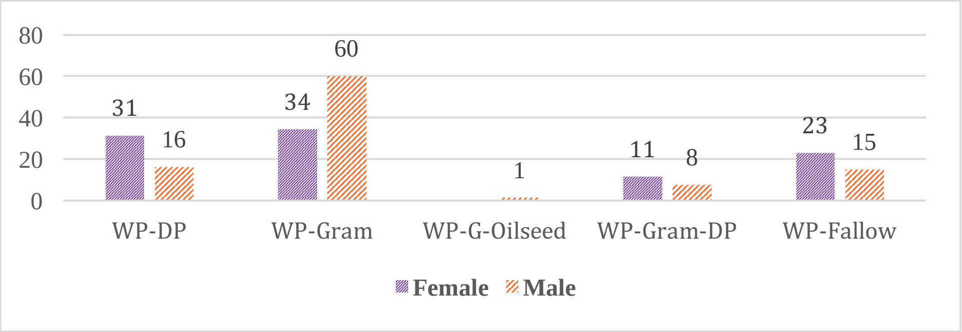

Figure 2. Cropping pattern of sample beneficiary farmers by gender.

The majority of both sampled male and female farmers used HYVs in wet paddy season production (Table 2). A quarter of sampled female farmers and 14% of sampled male farmers used local varieties because of the higher sale price received for the local rice variety, such as Paw San Yin. More than half of the sampled female farmers and nearly half of sampled male farmers practiced transplanting for wet paddy production.

The analysis of variance indicated a significant increase in yield with UDP at a 1% significance level regardless of variety (Figure 3A). The same amount of briquette urea (BU) (108 kg/ha) was applied in wet season paddy regardless of variety. The quantity of broadcast prilled urea used varied between the two types of paddy variety (Figure 3B).

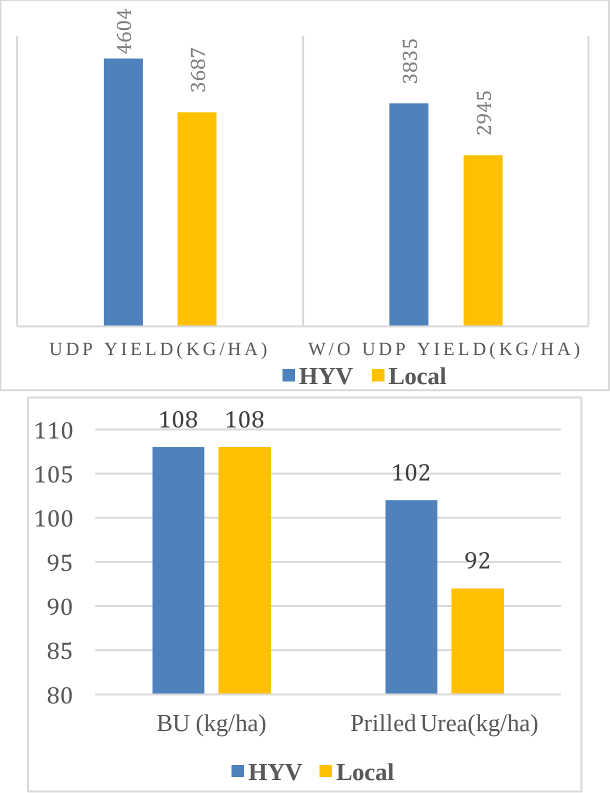

Figure 3. (A) Rainfed paddy yield with and without UDP by variety and (B) different types of urea used by variety.

More than half of the sampled female farmers and 48% of the sampled male farmers transplanted paddy (Table 2). The sampled farmers applied nearly the same amount of prilled urea regardless of the cultural practices. The sampled farmers who broadcast seeds received a little higher yield, with or without UDP, than sampled farmers who transplanted.

Regarding sources of seeds, the majority of sampled male and female farmers used their own seeds for wet season paddy production. A quarter of both male and female farmers bought seeds from other farmers, and 16% of total sampled farmers bought seeds from the Department of Agriculture (Table 2). Farmers usually keep grain as seeds for planting in the next season. The sampled farmers, through project training activities, became aware of the value of using good seeds, which can be bought from both public (Department of Agriculture) and private (seed growers and seed dealer/company) sectors.

Table 2. Paddy variety, cultural practice, and sources of seeds by gender (%).

Gender	Paddy Variety		Cultural Practice		Sources of Seeds			
	Local	HYV	Broadcast Seeds	Trans-planting	Own Seeds	Buy from Seed Growers	Buy from DOA	Buy from Dealer/ Company
Female	25.7	74.3	45.7	54.3	62.9	25.7	11.4	0
Male	13.8	86.2	51.2	48.8	53.8	26.2	18.8	1.2
Total	17.4	82.6	49.6	50.4	56.5	26.1	16.5	0.9

Source: Authors' computations.

Used of Fertilizers, Cost of Fertilizer, and Yield of Wet Season Paddy by Gender

Depending on the soil fertility and pH level, 36% of both female and male sample farmers applied a basal fertilizer such as triple superphosphate (TSP), muriate of potash (MOP) and compound fertilizers in wet season paddy. The majority of sample farmers (86% of total sample) used TSP as a basal fertilizer.

BU was applied once, 25-35 days after sowing time at the rate of 108.68 kg/ha. On the other hand, various fertilizers such as prilled urea, compound fertilizer, TSP, MOP, compound fertilizer with herbicide (most popular), Comet brand fertilizer with S, special fertilizer to get a maximum tiller number, and special fertilizer to get good panicles, etc., were applied in the paddy field without BU (or UDP). In Ayeyarwady Region, three males and one female farmer did not use fertilizer in their paddy field.

The majority of sampled male and female farmers used prilled urea (at an average rate of 114 kg/ha). Only 28% of sampled female and 39% of sampled male farmers applied compound fertilizer at an average rate of 82 kg/ha for female and 99 kg/ha for male farmers (Table 3). The total fertilizer cost for the sampled female farmers was not much different with or without UDP, but the cost of fertilizer in wet paddy fields without UDP was significantly higher than the fertilizer cost with UDP in sampled male farmers (Table 3).

The average rainfed paddy yield with UDP was significantly higher than the average yield without UDP in both male and female sampled farmers at the 1% level of significance (Table 3). Both paddy fields with and without UDP were under the farmer's management and they used the same variety of paddy. It is concluded that the yield response is due to deep placement of the urea.

Table 3. Average fertilizer used, cost of fertilizer, and yield of wet season paddy in 2016.

		Use Prilled Urea without UDP (kg/ha)	Use Compound Ferterilizer without UDP (kg/ha)	Total Fertilizer Cost with UDP (MMK/ha)	Total Fertilizer Cost without UDP (MMK/ha)	Average Paddy Yield with UDP (kg/ha)	Average Paddy Yield without UDP (kg/ha)
Female	Mean	98.66	81.75	66,449.63	68,847.26	4,070.28	3,303.32
	N	30	10	35	35	35	35
	Std. Dev	55.71	40.85	15,994.02	38,170.54150	1,018.75	1,025.39
Male	Mean	120.87	98.76	67,039.01	83,334.92	4,607.70	3,845.95
	N	71	31	80	80	80	80
	Std. Dev	63.55	36.10	15,882.85	43,520.31	1,021.29	927.78
Total	Mean	114.27	94.61	66,859.63	78,925.64	4,444.13	3,680.80
	N	101	41	115	115	115	115
	Std. Dev	61.89	37.52	15,848.76	42,330.72	1,045.96	986.39

Source: Authors' computations.

Gross Margin of Rainfed Paddy Production of the Sample Male and Female Farmers

With UDP, the average net returns over cash costs of the sampled beneficiary male and female farmers was U.S. $278 and U.S. $228/ha, respectively (Figure 4A). Without UDP, the sampled male and female farmers received $177 and $109/ha, respectively. By means of technology, GM increased by 109% in female and 57% in male farmers.

A higher gross margin was received with an HYV of paddy both with and without UDP (Figure 4B). By applying UDP, the sample farmers received $280/ha for the HYV of paddy, while a lower GM, $173/ha, was received in an HYV without UDP. Without UDP, GM of the local variety was $76/ha, and it was $173/ha with UDP. Due to UDP technology, GM increased by 126% in local variety and 62% in HYV of paddy.

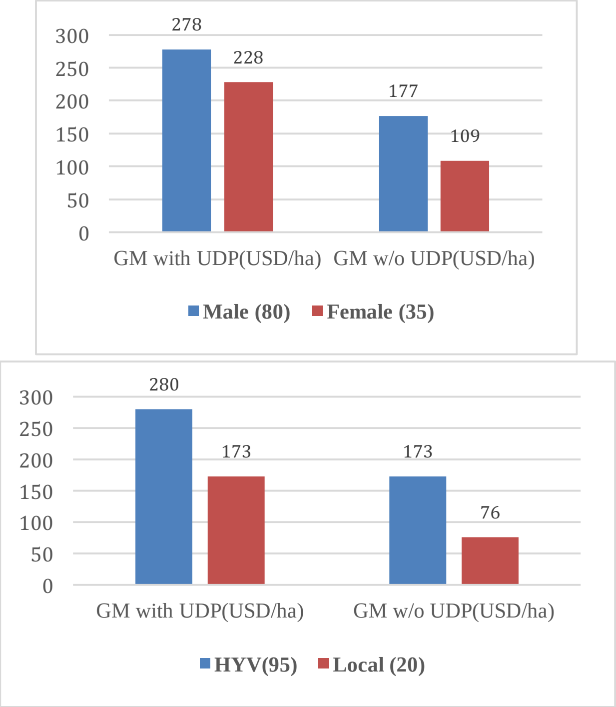

Figure 4. ***(A) Gross margin of wet season paddy with UDP and without UDP by gender and (B) by paddy variety.***

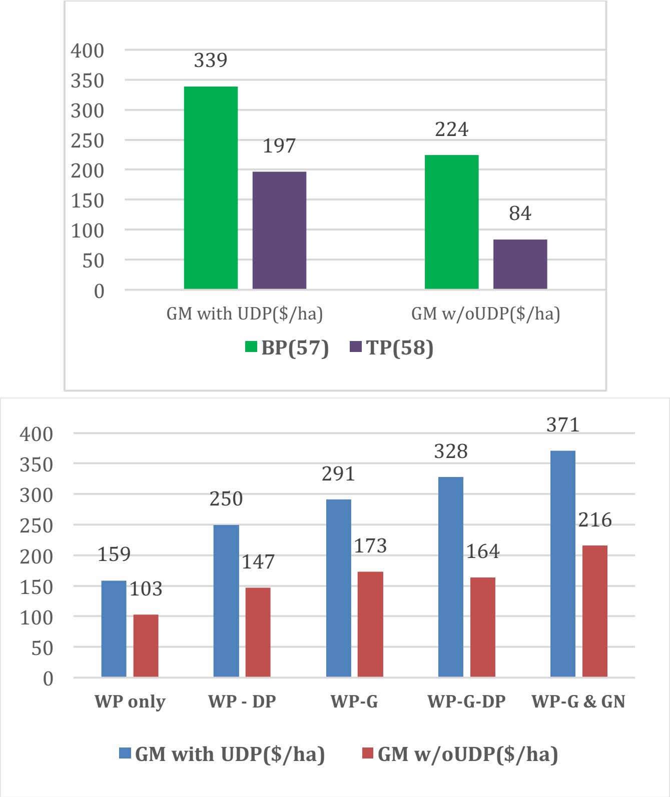

Figure 5. ***(A) Gross margin of wet season paddy with UDP and without UDP by practice and (B) by cropping pattern.***

Due to higher cost of labor for transplanting paddy plants and other extra costs, such as seedbed preparation cost, weeding cost, etc., the total cost of production was much higher. Moreover, the sample farmers who practiced broadcasting seeds received a little higher yield both with and without UDP. Therefore, the GM of paddy with UDP using the broadcast-seed method provided $339/ha, and it was $224 without UDP (Figure 5A). Applying UDP with the transplanting method gave $197/ha, and it was $84/ha without UDP. By means of UDP technology, the GM increased by 134% with transplanting paddy plants and 51% with broadcast paddy seeds.

Figure 5B shows that the sampled farmers who grow three crops (such as wet paddy, then gram and oil seeds, or wet paddy followed by gram and dry paddy) in a year received higher GM than the farmers who grow two crops or only one crop. The GM with UDP was significantly higher than the GM without UDP in all cropping patterns. The GM with UDP was more than $300/ha for the sampled farmers who grew (i) wet paddy followed by gram and oil seeds, and (ii) wet paddy followed by gram and then dry paddy (Figure 5B). Due to technology, the GM increased by 54% in wet paddy (WP) only, 70% in WP followed by dry paddy (DP), 68% in WP followed by gram (G), 113% in WP-G-DP, and 72% in WP-G-Groundnut.

Descriptive Statistics of the Variables in the Model

Table 4 shows the means, minimum, maximum, and the standard deviations values of the continuous variables used in the yield respond model. Two dummy variables were created for gender (male = 1, female = 0) and paddy variety (HYVs of paddy = 1, local paddy variety = 0).

It is shown in the table that the maximum and the minimum average UDP yield of paddy in the project intervention regions are 6.75 t/ha and 1.93 t/ha, respectively. On average, the beneficiary farmers produce 4.44 t/ha, leading to 56% opportunity improvement over the stagnant yield of paddy 2.84 t/ha in 2015.

Table 4. Summary of the explanatory variables.

Continuous Variable	**Unit**	**N**	**Mean**	**Min.**	**Max.**	**Std. D.**
Paddy price	Kyats/kg	115	237.45	222.74	269.08	12.92
Prilled urea price	Kyats/kg	115	428.47	393.47	484.44	17.19
Paddy yield with UDP	t/ha	115	4.44	1.93	6.75	1.04
Number of total crops grown	Number/ year	115	1.94	1.0	3.0	0.535
Harvested paddy land	hectares	115	3.79	0.61	20.24	3.20
Yield difference with UDP and without UDP (t/h)	t/ha	115	763.35	-917.49	2,436.92	585.43
Harvesting machine cost	Kyats/ha	115	47,048.00	0.00	136,000.00	53,097.70
Number of labor used	Number	115	11.57	0.00	49.40	10.30
Dummy Variable		**N**	**Mean of UDP Yield**	**Min. of UDP Yield**	**Max. of UDP Yield**	**Std. D. of UDP Yield**
Male	t/ha	80	4.607	1.93	6.75	1.021
Female	t/ha	35	4.07	2.42	5.94	1.01
HYVs	t/ha	95	4.603	1.93	6.75	1.024
Local variety	t/ha	20	3.687	2.42	5.20	0.799

Source: Authors' computations.

According to the results of the estimation (Table 5), seven continuous variables and two discrete variables were included in the final model. The value of adjusted R^2 denoted that 56.5% of the variation of the dependent variables, for the sample of 115 crop cuts, can be explained by five significant independent variables. The significant values of F-test and t-statistics show that both the model and each independent variable can help identify the variation. The variance inflation factors (VIFs) of all variables were less than 10, and thus the probability of collinearity was eliminated.

In Table 5, for each continuous variable (X_i), the coefficient is the elasticity of UDP paddy yield with respect to X_i. The lagged price of rice that rice farmers are likely to receive and the lagged price of prilled urea that rice farmers are likely to pay have significant effects on the UDP yield of rice in the rainfed area of the project intervention regions. Also, the *a priori* signs of all the variables are met. From Table 5, it was found that the lagged price of prilled urea is statistically significant at 0.05 as the probability value (0.037) is less than 5% and exhibits the right *a priori* expectation. A 1% decrease of the transformed value of prilled urea can increase UDP paddy yield by 1.219% (for more exact calculation, by $1.01^{1.233} - 1 = 1.219\%$) (Wooldridge, 2013), holding other variables fixed.

There is a direct relationship between the farm-gate price of rice and paddy yield, but it is not significant. If farmers apply fertilizers more efficiently and effectively in the paddy field without UDP, the yield difference between with UDP and without UDP would be reduced. A 1% increase in the yield difference between UDP and non-UDP yield can increase significantly (at 1% level) the UDP paddy yield by 0.097%.

Ceteris paribus, if farmers diversify or grow more crops per year, the UDP yield will increase significantly at 1% level. The sampled farmers received higher gross margin from practicing three crops (wet paddy followed by oilseeds and dry paddy or wet paddy followed by gram and dry paddy), especially in UDP paddy fields

(Figure 5B). The calculated coefficient 0.356 implies, with UDP, when the number of crops grown increases by 1%, it will lead to a 0.356% increase in the yield of rice.

Based on the results in Table 5, the calculated coefficient for harvested paddy area was 0.047% having a negative sign, and this was significant at 10% level. The data indicate that when a farmer increases his or her field of rice by 1%, it will lead to 0.047% reduction of UDP paddy yield. Insufficient credit and poor knowledge of fertilizers and their application lead to low and imbalanced fertilizer application and low yields, and this problem increases when a farmer increases his or her field. There is limited opportunity for crop land expansion in the project regions. Increased output of rice must come from the adaption of modern technology to improve yield rather than area expansion.

It was found that there was an increase in yield as the cost of harvesting (machine) and the number of hired labor increased, but it was not significant. With adequate machinery and labor, all farming activities and critical cultural practices, such as sowing, weeding, pesticide application, UDP fertilizer application, and timely harvesting, can be carried out in a timely manner, and this will lead to an increase in yield.

For the dummy independent variable of gender (D_1), when D_1 shifts from 0 (female) to 1 (male), the UDP yield will increase significantly at 5% level by 32%, keeping other explanatory variables constant. If the dummy variable of variety (D_2) changes from 0 (local variety) to 1 (HYV), the UDP yield will increase by 11%, but it is not significant.

Table 5. Results of the log-linear multivariate regression estimation.

Independent Variable	B^a	$\Delta Y\%^b$	Std. B	t	VIF
Constant	8.032*		4.466	1.799	
Lagged paddy price (X_1)	0.067	0.066	.417	0.160	1.145
Lagged prilled urea price (X_2)	-1.233**	-1.219	.575	-2.148	1.803
Yield difference with UDP & without UDP (X_3)	0.098***	0.097	.028	3.480	1.128
Wet paddy harvested land (X_4)	-0.048*	0.047	.028	-1.726	1.132
Total crop grown/year (X_5)	0.358***	0.356	.080	4.498	1.722
Harvest machine cost (X_6)	0.027	0.026	.048	0.586	1.164
Total labor used (X_7)	0.015	0.0149	.023	0.630	1.715
Gender (D_1) (male=1, female=0)	0.126**	32.53	.044	2.835	1.071
Variety (D_2) (HYV=1, local=0)	0.045	11.45	.067	0.679	1.345
N=115					
Adjusted R^2 = 0.566					
F value = 8.839***					

*Note: Dependent Variable: LN UDP yield (t/ha), a: *, ** and *** imply significant at 10%, 5% and 1% level respectively. b: Percentage of paddy yield changes due to a 1% increase of X_i by $100*(1.01^B – 1)$ and due to value of D_i shifting from 1 to 1 by $100*(e^B -1)$.*

Conclusions

Agricultural advisory services play a crucial role in promoting agricultural productivity and farm income. Extension can bridge the gap between potential and actual yield by addressing the technology gap and management gap (Anderson and Feder, 2003). Alternative extension models rather than traditional public extension services including local partners or NGOs and agro-dealers are applied in transferring

UDP technology and the best farm management practice (balanced and efficient use of fertilizers, use of good seeds, etc.). The paper presents the outcomes of extension activities and evaluates the gap between farmers' yield with UDP and without UDP in rainfed lowland production system in the target areas of Yangon, Bago, and Ayeyarwady regions.

The UDP yield of rice in the study area was found to change significantly with fluctuations in area harvested for rice, prices of fertilizer, crop intensification (or number of crops grown per year), yield difference or technology gap, and gender of rice farmers. Of the overall variations observed in UDP rice yields, 56.6% were explained by the independent variables in the model. Wet season paddy yield with UDP has an increasing relationship with the number of crops grown per year, technology gap, and gender of rice farmers. This could be attributed to the purchasing power of farmers and the affordability of inputs for non-UDP paddy fields, which would be increased with crop intensification with gram, oilseeds, and dry season paddy. There is also an indication that women's participation in extension education and training should be promoted as the increases in GM due to technology were more than 100%. Also, yield has an inverse relation with harvested area; thus, when harvested area increases, yields would decrease, likely due to the challenge in accessing the input and cost of fertilizer, insufficient cash required for balanced fertilizer application, and low access to credit.

To meet the national and export rice market demand, the yield potential for cultivating high-yielding rice varieties with UDP should be fully exploited as a first option. The evidence from our empirical analysis further suggests that increased and focused government efforts are needed toward promoting the use of efficient soil and fertilizer management technologies, such as UDP, and promoting crop intensification practices among farmers in the lowland rainfed rice cropping system in Myanmar to achieve higher yields and profits from limited expansion of cropping land.

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Economic and Social Issues for Fertilizer Decisions of Smallholder Farmers in Myanmar

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Abstract

Cereal (rice and maize) crop yields in Myanmar are considered to be relatively low due, in part, to inadequate fertilizer use, especially nitrogen (N). Field trials of cereal crop yield responses to fertilizer are being implemented in the project "Management of nutrients for improved profitability and sustainability of crop production in Central Myanmar." These will show the scope for improved crop yields with increased fertilizer use. A decision-support tool will be developed in the project. But the fertilizer decisions that farmers make have important economic and social dimensions that determine why smallholder farmers "do what they do."

In this paper, we report initial results of Focus Group Workshops and a Baseline Survey of smallholder farmers in townships surrounding the project sites. From the workshop discussions, we found that crop types and systems varied from our initial perception of mainly rice, maize, and black/green gram crops to include higher value vegetables, fruits, and others such as sesame and sugar cane. High-yielding varieties of rice are generally used, but for maize the relatively old hybrid CP888 is still widely grown. Many farmers use Yezin Hybrid maize in the Tatkon area. Dry season water supplies were of concern, with water from Yezin Dam being diverted to other civil uses and tube-well water depths becoming deeper. Other dams in the Tatkon area cannot collect enough water to irrigate dry season crops.

A number of smallholders emphasized the economic aspects of crop management decisions – the need for profits and returns on investment in crop inputs to maintain family livelihoods. These farmers were very aware of the changing climate (including increased climatic variability) and were concerned for their own welfare when working in the field. They understood that maintaining soil fertility is necessary to increase crop yields and are using a variety of fertilizer types for their crops.

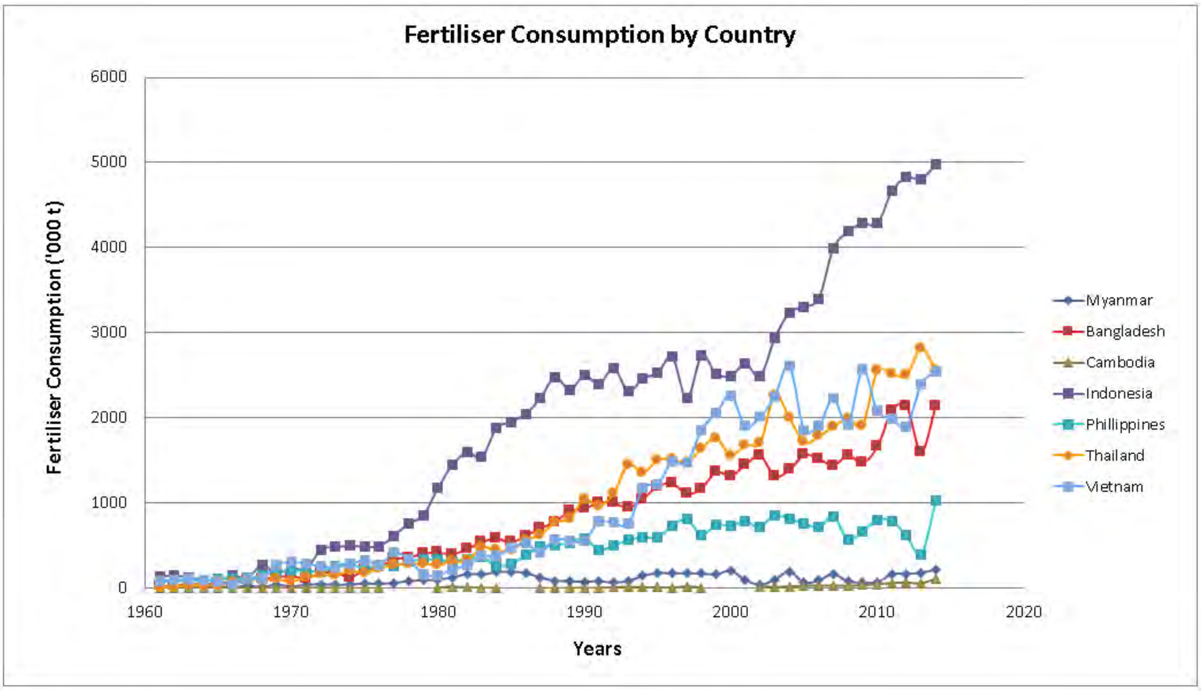
Survey results confirmed the generally small farm sizes (averaging 2-4 ha). Rice and maize crop yields averaged 4-5 t/ha, which is higher than the average for Myanmar but consistent with other survey results. However, fertilizer use (both compound and urea) for cereals was relatively low (averaging 20-30 kg/ha for these fertilizers combined) and even lower for other crops. Further work to confirm these findings is required.

Key Words

Myanmar, cereals, nitrogen fertilizer, decision support, economic, social, CommCare

1. Introduction

The Australian Centre for International Agricultural Research (ACIAR) has funded a project "Management of nutrients for improved profitability and sustainability of crop production in Central Myanmar." The project is premised on the apparently low use of fertilizer for crops in Myanmar (Figure 1).



Source: IRRI World Rice Statistics, http://ricestat.irri.org:8080/wrsv3/entrypoint.htm.

Figure 1. Total fertilizer consumption from chemical sources ('000 t) by selected country.

1.1 Project Objectives

The overall aim of the project is to "increase incomes and strengthen local food security of small-scale farmers and their families in central Myanmar by improved fertilizer use and associated crop management practices. Research will be complemented by capacity building of Myanmar agricultural scientists and academics to sustain and promote improved management practices, and resulting improvements to livelihoods, well into the future."

The locations of project trial sites in the southern margin of the Dry Zone and upper Bago of central Myanmar are shown in Figure 2. The project trial sites are within the townships of Tatkon (one site), Zeyarthiri (two sites), and Taungoo (one site).

The Socio-Economic (SE) sub-project is addressing the question "What are the economic and social contexts and incentives to appropriately increase fertilizer inputs?"

1.2 This Paper

The premise of this project is that Myanmar smallholder farmers use small amounts of fertilizer (Figure 1) and have relatively low crop yields; therefore, improving fertility management can increase farm income and improve poverty and food security. But is this thinking realistic? What are the actual fertilizer applications of local farmers, and what is the economic and social context for farmer crop-fertilizer decisions?

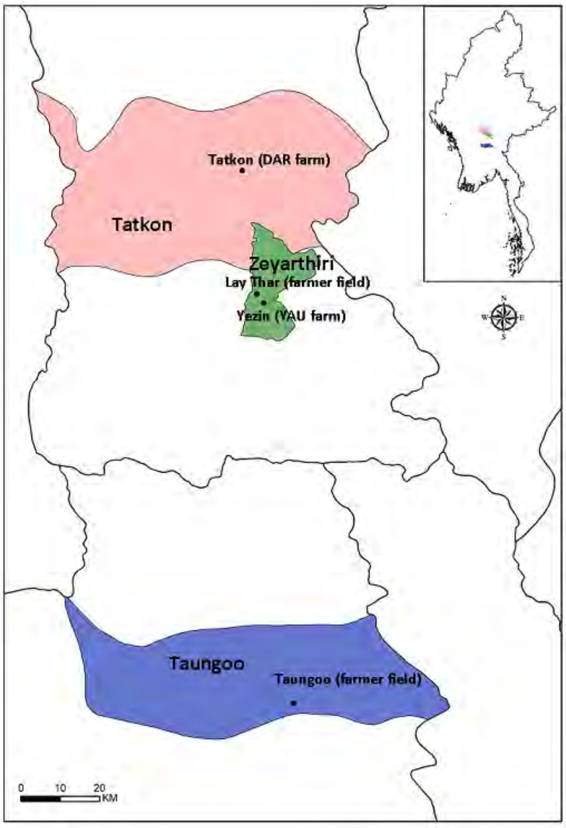


Figure 2. Project trial sites and townships.

2. Socio-Economic Activities

Two initial activities in the SE project have been to conduct Focus Group Workshops (FGWs) with smallholder farmer groups in villages surrounding the project trial sites and implement a Baseline Survey (BLS) of farmers around the trial sites

2.1 Focus Group Workshops

The objectives of the FGWs were to investigate Myanmar smallholder farmer perceptions of their farming systems and family livelihood decisions and to determine their knowledge and understanding of, and attitudes to, crop production and fertilizer use. Other aspects of their production systems, such as the climate, water sources, crop varieties, and labor/mechanization, were also investigated.

FGW discussions are a valuable way of interviewing groups of people (Yin 2011). Moderately sized groups who are "focused," because they have common experiences and share some common views, have advantages in being more efficient than speaking to people individually, but with the trade-off of not obtaining in-depth information from individuals. However, focus group discussions have the advantage that some individuals may feel more comfortable speaking in a group setting rather than directly to a moderator.

The FGWs were moderated and recorded by Myanmar SE project members. Notes of the conversations were manually recorded and then typed into a document for classification in project reports. Villages were selected for their proximity to the four trial sites. In each village, the farmers were selected with the help of local Department of Agriculture (DOA) extension staff. Farmers were invited to the workshops by the village chief.

Information about the FGW locations within townships, village tracts, and villages, and participating farmer numbers, is shown in Appendix Table A.1. Interviews were conducted over the period 9-11 March 2017. Total farmers attending the 18 workshops were 156, of whom 20 were female. A map of the village tracts and villages is in Figure 3.

2.2 Baseline Survey

The BLS was conducted to gather information of the current status of smallholder farmers in central Myanmar – information about their farms and families. In particular, we asked about current farm cropping activities, crop sequences, their current fertilizer management practices, and crop yields. Information was also collected on their income levels and off-farm work by family members. This information will be used to develop activity (gross margin) budgets and whole-farm models to assess potential management changes and impacts of changed policies.

Villages surrounding the project trial sites were selected for the BLS; some were the same as FGW villages but others were closer to the project trial sites. The overriding aim was to interview smallholder farmers located close to the project trial sites so that information made available from the fertilizer-yield response trials could be directly related to SE analysis for the same group of farmers. Field days and farm walks are planned as part of the project. A decision-support app will be developed for these villagers. Farmers from villages surrounding the trial sites are the target audience or recommendation domain of the project. BLS sample information is given in Appendix Table A.2. Interviews were conducted with 232 farmers over the period 2-8 May 2017.

In each village, the survey team contacted the local village head and DOA extension staff to arrange for up to 20 farmers per village to be selected randomly and invited to a central location for interviews. These locations could be village head houses or local Knowledge Transfer Centres. Interviews were conducted by 10 Yezin Agricultural University (YAU) master’s students using a questionnaire programmed into the CommCare application.

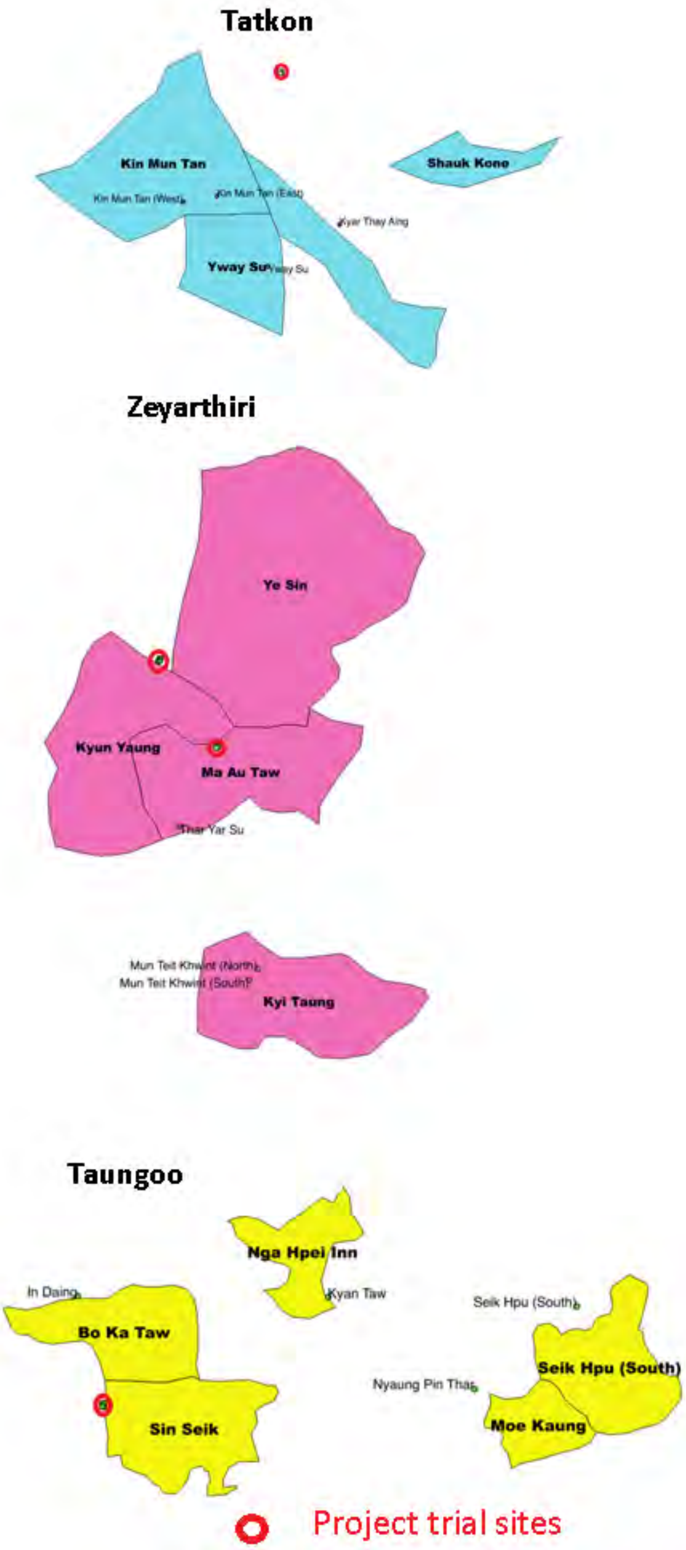


Figure 3. Village and village tract locations surrounding the trial sites.

2.3 Questionnaire Development and CommCare Programming

A survey questionnaire was developed based on information considered to be necessary for the SE project activities. The questionnaire was reviewed and translated into CommCare (Dimagi, Undated). CommCare is an open-source mobile data collection platform that enables social scientists to build mobile apps. The survey questionnaire was translated into Burmese language in the CommCare app and was loaded onto Samsung tablets for survey interviews and data collection.

3. Focus Group Workshop Results

3.1 Farm Descriptions

Land types as described by the smallholder farmers were both lowland and upland, with some rainfed and some irrigated. Their descriptions of crop seasons included monsoon (rainy) and dry (winter or summer).

With respect to cropping patterns, we originally thought that the main crop sequences would be mainly rice-irrigated rice, or maize-legume, for monsoon and dry seasons, respectively. Although rice and maize are regularly grown in these villages, the workshop information showed that there is a diversity of other crops being grown. These include legumes (lablab, black gram, groundnut, green gram, and chickpea), vegetables (onion, chili, tomato, potato, cabbage, sweet corn, eggplant, and radish), fruit (banana, watermelon), and others (sesame, sugar cane).

Some smallholder farmers are now diversifying out of the traditional crops into more profitable crops. Rice is still the major crop in central Myanmar but some smallholders seem to be growing other higher-priced crops. Some farmers are selling their fruits and vegetables directly to local buyers or markets, or transporting them to the Chinese border to sell directly into China.

A possible implication of this diversity in crops is that smallholders may not be interested in improving the productivity of their traditional crops if those crops provide relatively low returns. Some smallholders may be less interested in N fertilizer improvement for rice and maize yield improvement if the same financial resources could be used more profitably in higher-value crops.

Two important comments were made about irrigation and water supplies. The first from Yezin smallholders was that the water in Yezin dam is no longer available for irrigation due to it being diverted to Nay Pyi Taw city and for other purposes (military, zoo). Independent information shows that dams in the Tatkon area cannot collect enough water to irrigate dry season crops. The second comment was that some smallholders reported that their tube-wells were exhibiting deepening water depths so that less water is available at higher pumping costs.

The main livestock are cattle (ox), pigs, and chickens (for meat). There are declining numbers of cattle because of the increased use of tractors (4-wheel and 2-wheel) in the villages. Some cattle are still used for land preparation, but there is a trend for replacement of animals for draught power by mechanization.

3.2 Crop Varieties

The crop varieties grown in each village are shown in Table 1. There are several rice varieties, but for maize CP888 is still widely used.

The Green Revolution process of developing high-yielding rice varieties (HYVs) for use with high fertilizer rates has been very successful for irrigated agriculture but less so for rainfed agriculture (de Janvry et al., 2016). De Janvry et al. (2016) reviewed agricultural development projects in rainfed regions in Africa and elsewhere. They noted that although there was often low use of fertilizer in project regions, the issue of crop varieties was also relevant when considering low crop yields and low smallholder farm incomes. In their opinion, for rainfed agriculture, the low use of N fertilizer was a symptom of the underlying problem – the non-adoption of appropriate HYVs. If the crop varieties currently used by farmers do not have the potential to express an increased yield, or fully respond to increased fertilizer application, then a focus on increasing fertilizer applications to low-yield-potential varieties will not be appropriate.

The cereal crop varieties in Table 1 were classified according to whether they were open-pollinated, hybrid, and/or HYV as identified by Dr. Aung Kyi (personal communication). For monsoon rice, all the varieties except Palal Thwal (hybrid) and Paw San Bay Gyar (traditional fragrant) are HYVs. The maize varieties were classified as hybrids but not HYVs.

Table 1. Crop varieties grown.

Project Site	Township	
Yezin (YAU)	Zayarthiri	
Village	*Rice varieties*	Maize varieties
Sein Sar Pin	Monsoon rice: Ma Naw Thuka (135 days), Sin Thu Ka (145 days), Shwe Thwal Yin (105 days) Hybrid rice: Palal Thwal	Black gram: Yezin 6
Shwe Baho		Maize for seed: CP888, CP008, CP339 Lablab: Shwe Kyun Pe
Htan Ta Pin	Monsoon rice: Ma Naw Thuka (135 days)	
Shwe Twin Gone		Maize: CP888
Lay Thar	Zayarthiri	
Lay Thar		Maize: CP888
Moe Te Kwin	Monsoon rice: Ma Naw Thu Ka, Sin Thwal Latt, Aye Yar Min	Maize: Pan Nga Chate, Pan Shwe/ Pan Phyu
Aung Thar		Maize: CP888 Sugarcane: K9582 (Thai variety), K8892
Thar Si		Maize: CP888
Tatkon	Tatkon	
Lat Pan Taw		Green gram: Yezin 11, Yezin 14 Cotton: Ngwe Chi 6 Maize: CP888, CP029?
Kinn Mon Tan	Monsoon rice: Ma Naw Thuka, Palal Thwal, Sin Thuka	Maize CP888
Ywe Su		Maize: CP888 Sweet corn: Pan Shwe, Pan 75
Kyarr Thae I	Monsoon rice: Ma Naw Thuka	Maize: CP888
Shout Gone	Monsoon rice: Ma Naw Thuka, Sin Thuka, Ayeyar Min	Maize: CP301, CP888

Project Site	Township	
Taungoo	Taungoo	
Inn Dine	Monsoon rice: Byow Htun, Ayeyarmin, Ma Naw Thuka Hybrid rice: Palal Thwal	
Kokoh Pin Su	Monsoon rice: Byow Htun, Thuka 2	Black gam: Palal Htun Summer rice: Thai 80, Thai 90, Thai Kout, Thai 60
Kyan Taw	Monsoon rice: Ayeyarmin, Byow Thuka, Paw San Bay Gyar, U Kyi Ma Thi (150-170 days)	Summer rice: Thai 90, Pyi Taw Yin, Kout Nyin
Nyaung Pin Thar	Monsoon rice: Sin Thuka, Pyi Taw Yin, Byow Thuka	Black gram: Yezin, Ar Phyu, Ywet Chon

3.3 Important Issues and Sources of Information

Important issues raised by these farmer groups were market instability and price decline, the need for profits and maintenance of farm-family livelihoods, farm heritage, weather, quality seed, new technologies for higher yield, capital, water, fertilizer prices, mechanization, high-yielding varieties, and market prices.

Overall, the flavor of the issues expressed emphasized the economics of agricultural production and the major factors generating instability in crop profits – price fluctuation (markets), weather fluctuation (crop yields), and the need for improved technology to increase crop returns. Myanmar smallholder farmers have changed from a subsistence to a semi-subsistence or semi-commercial focus, so the costs and productivity of inputs and the value of outputs are now very important to them. Two quotes from Nyaung Pin Thar Village demonstrate this economic focus: “We would rather do nothing if the cost of production and the income we get are the same,” and “we would like to get 3 kyats if we invest 1 kyat.”

CIMMYT (1988) advocated a “2 for 1” rule as a hurdle (or minimum) rate of investment return before any change to a farming system or technology is recommended for extension programs in developing country agriculture. If 1 kyat is borrowed, for fertilizer, which is used in crop production, then a gross return of 2 kyats (2 for 1) provides a net return of 1 kyat (after repaying the borrowed money). The 1 kyat net return to the 1 kyat investment provides a 100% return on that investment. The “3 for 1” requirement expressed by this smallholder farmer is requiring an even higher return on investment (200%) before he would invest in a change to technology or management.

With respect to sources of information for their farming decisions, many smallholders said that they ask each other for information or opinions, or rely on their own experience. Seed/fertilizer shops and fertilizer companies give advice, and smallholders also make decisions by looking at their plant conditions. DOA staff and field days were not mentioned positively, with some farmers stating they did not listen to DOA advice.

With respect to finance, credit sources include Myanmar Agricultural Development Bank. But farmers felt it was difficult to pay back loans, or they use the money for something else. There are also private lending sources in the villages. If they borrow money, it must generally be paid back at harvest, when the crop prices may be low.

3.4 Smallholder Objectives, Motivations, and Priorities

The main objectives expressed by smallholders were profit, sustaining livelihoods, family consumption, and farming heritage. Farmers in the workshops made many references to off-farm work. Major types of off-farm and non-farm work were farm laborers, casual work, construction, various types of work in Singapore, Thailand, and Malaysia, carpentry, mining, driving and phone cabling. The young women worked on farms, in the sewing/garment industry, and as maids. The purpose of this work is to remit money back to the farm family.

The daily wage rate for casual workers or farm laborers was 4,000-5,000 Myanmar kyats (MMK) (1,400 MMK ~ U.S. $1). The amounts sent back from working overseas ranged from 100,000 MMK per month (Malaysia) to 200,000-300,000 MMK per month (Thailand and Singapore).

3.5 Climate Change

Farmers in Sein Sar Pin Village said that during the past 10 years they have seen irregular weather patterns such as sudden heavy rainfall during harvesting time and drought during cultivation time, which leads to crop failure and loss. Pest outbreaks after rain were also mentioned.

In Lay Thar and Moe Te Kwin villages, farmers reported that the yield of crops has declined over the last 10 years. They can not longer predict the weather for crop cultivation. There have been extreme heat conditions. One farmer talked about El Niño having impact on the weather patterns with extreme heat and extreme cold conditions. A number of comments were to the effect that extreme heat and drought conditions are causing yield reduction. There were shorter monsoon seasons (monsoon starts late and finishes early), with associated pest and disease outbreaks.

With respect to this yield uncertainty due to weather, farmers don’t apply as many inputs to crops because they cannot afford to risk a crop failure, since they buy most inputs on credit.

3.6 Knowledge of Fertilizer Concepts

Smallholders stated that they use urea, compound fertilizers (15:15:15), and basal fertilizer. They are generally aware that using fertilizer can increase crop yield. They use fertilizer brands from Armo and Awba companies, and fertilizers from China.

Some said that they use more pesticides than fertilizers. Some said that they rarely use fertilizer because there is no water, because of climate change or because of market price instability. They buy fertilizers from village or township shops.

With respect to the decision about how much fertilizer to use, some look at plant conditions (their experience), some have attended training, and in other cases fertilizer company agents tell them how much to use. They mostly buy fertilizer on credit; there are no contracts so the loans are based on trust.

4. Baseline Survey Results

4.1 Farm Characteristics and Cropping Patterns

Average farm sizes within townships are shown in Table 2. Farm sizes were generally larger in Taungoo than in Tatkone and Zeyarthiri. The largest farms in the sample were 10.1 ha, 14.2 ha, and 12.1 ha in Tatkone, Taungoo, and Zeyarthiri, respectively.

Table 2. Average farm size by township.

Township	Responses	Size	
		Acres	Hectares
Tatkone	82	7.46	3.02
Taungoo	81	10.13	4.10
Zeyarthiri	72	6.07	2.46

Cropping sequences or patterns for townships are shown in Appendix B. The size of blocks representing each crop is determined by the number of records of each crop reported by surveyed farmers. Rice is the main crop grown followed by maize, but there is a wide range of other crops grown on the surveyed farms.

4.2 Crop Yields and Prices Received

Average yields for crops within townships are shown in Figure 4. Maize and rice yields are highest, and there are some variations between townships, although these differences have not been tested statistically. These crop yields correlate broadly with those from the Livelihoods and Food Security Trust Fund (LIFT, 2016), although the regions covered in the LIFT survey differ from this project.

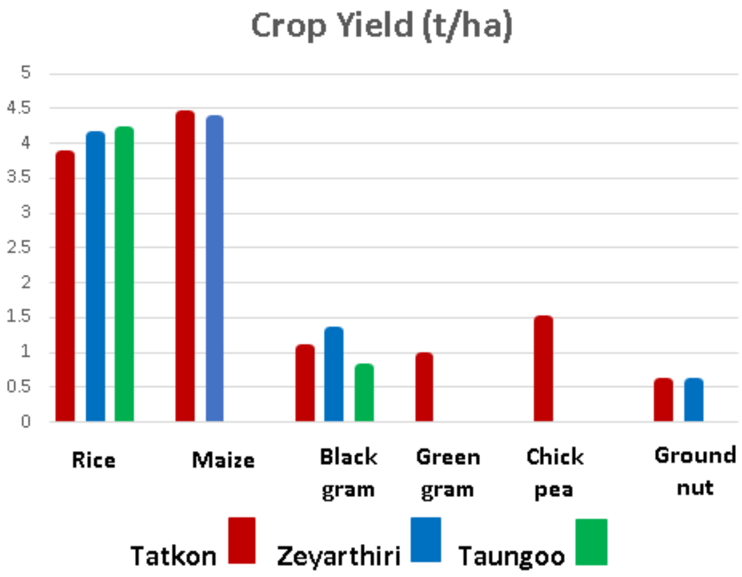


Figure 4. Crop yields within townships.

Prices received by farmer respondents for crops are shown in Figure 5. These prices are in AUD/t, and they compare reasonably with the information presented by LIFT (2016). Prices are relatively low for rice and maize compared to other crops, especially sesame. These price relativities mean that crops other than rice and maize may be more profitable (depending on the variable costs) and more desirable for smallholders interested in increasing net farm income and improving farm family livelihoods.

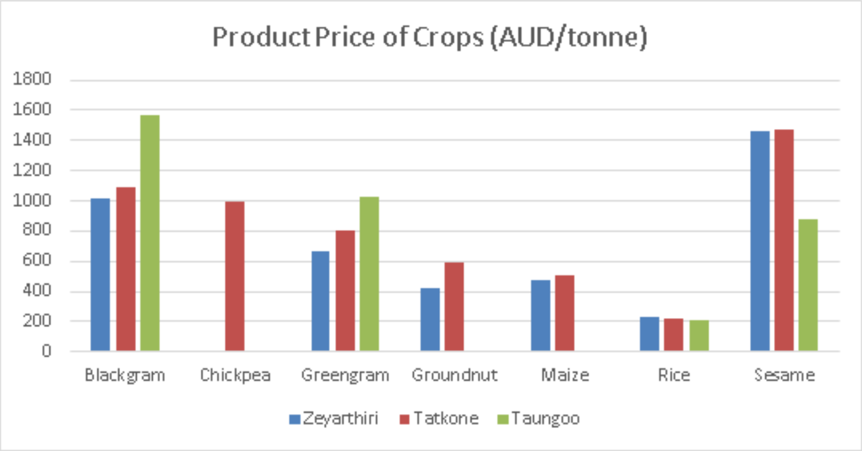


Figure 5. Prices received for crops by township.

4.3 Fertilizer Use

Fertilizer use for crops within townships is shown in Table 3. Fertilizer applications are higher for cereals than other crops. Both Compound (15:15:15, as NPK) and Urea fertilizers are applied to rice and maize crops. Fertilizer application rates are relatively low, higher for Rice and Maize than other crops.

Table 3. Fertilizer use by crop and season.

Crop	Season	Fertilizer Type	
		Urea kg/ha	Compound kg/ha
Rice	Monsoon	18	11
Maize	Monsoon	16	14
Black Gram	Winter	0	1
Green Gram	Monsoon	1	2
Sesame	Monsoon	2	2
Chickpea	Winter	0	1

5. Discussion

5.1 Workshop Results

Most of the stated smallholder objectives related to profits, sustaining livelihoods, family consumption, and their farming heritage.

Many of the important issues raised by farmers relate to more of a focus on the economics of their crops and farms; these included the need for profits to maintain family livelihoods, market instability, and the price of fertilizer. Other important issues included a farming heritage, weather, seeds, water, and new technologies.

The crop types and crop systems reported in the villages surrounding the project trial sites extend beyond traditional rice, maize, and black gram to a range of legumes, vegetables, fruits, and other crops such as sesame and sugarcane. These are higher-priced crops, and smallholders are exploring ways of direct marketing where they are less at the mercy of traders.

Various maize crop varieties are being grown. The rice varieties are HYVs, but most of the maize varieties are hybrids rather than HYVs. Some of these are relatively old (e.g., CP888), and a question is whether they can fully express an increase in crop yield to the use of more fertilizer.

With respect to their knowledge and understanding of crop fertility, they already use fertilizers of various types on cereal crops. These include urea and compound fertilizers, and they understand the importance of replenishing P and K as well as just N. The smallholders generally understand that soil fertility must be replenished with repeated cropping. But they quoted a number of reasons for not using fertilizer, including the prices of fertilizer, rice, and maize, and climate variability and uncertainty impacting crop yields.

The smallholders in these villages responded vigorously when asked about climate change. They have observed changes in the climate in recent years including irregular weather, unseasonal rainfall, droughts, higher temperatures, and less frost. These changes are having an impact on crop yields and influencing their decisions about investing in crop inputs. The uncertainty in crop yields due to climate change is an impediment to the use of more crop inputs.

With respect to water supplies for crops, the Yezin Dam water has now been diverted away from agriculture to the city of Nay Pyi Taw and other purposes (military, recreation). Also, farmers who rely on tube-wells for irrigation in the dry season are experiencing a lowering of the water table. Dryland agriculture is inherently risky, even more so under a changing climate as described above.

Some farmers recognized the financial imperatives of not having costs higher than revenue and looking for a substantial return on their investments in crop inputs. An important friction or impediment to change to the use of more fertilizer is the potential risk in economic returns (Anderson et al., 1977). If the yield outcome is uncertain, especially in a dry year, then smallholders are acting rationally to resist the use of more fertilizer unless the expected return is very large.

The sources of information used by smallholders include listening to other farmers and relying on their own experiences and observations (of plant color and vigor). Information about fertilizer types and recommended rates are provided by village shops, fertilizer company representatives, and DOA field officers, but there seemed to be problems of various sorts with each of these information sources.

They generally buy their crop inputs on credit, and the lending sources and loan conditions are worthy of further study.

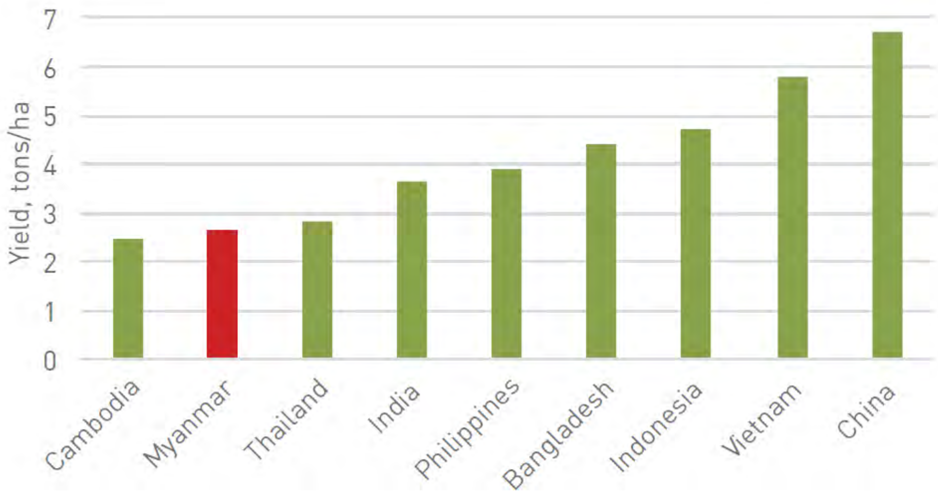
5.2 Survey Results

The survey results showed average farm sizes (2-4 ha), typical crop sequences (Appendix B), and average crop yields and prices received by farmers.

With respect to rice yields in Myanmar compared to other southeast Asian countries, the LIFT (2016) project report presented the comparison shown in Figure 6. In aggregate terms, the yield of rice in Myanmar compares relatively unfavorably with nearby countries. But the average rice yields reported for these townships (Figure 4) were higher (3.8-4.2 t/ha) than this reported average rice yield for Myanmar.

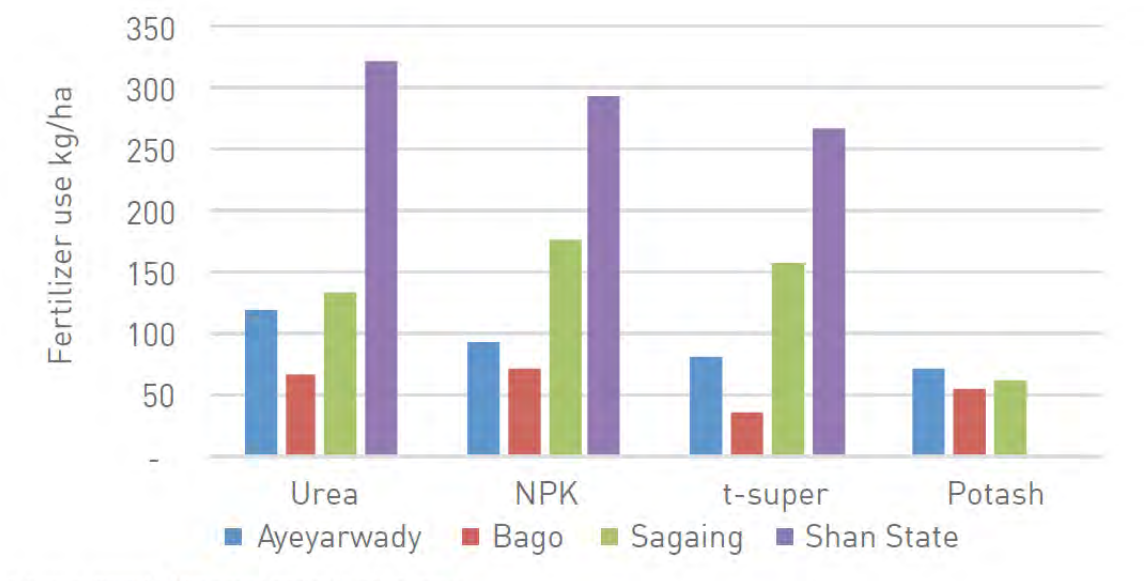
Survey results for fertilizers (Table 3) show use of compound NPK and urea on cereal crops up to 30 kg/ha of both types of fertilizer combined. This is lower than some other studies. The fertilizer application rates in the project area are less than those reported by the LIFT (2016) farm management survey results shown in Figure 7. Further study of this issue in the project area is indicated.

The rates of fertilizer application in Table 3 are also less than reported by other research. Lwin et al. (2014) reported macro data for Myanmar showing farmers using, on average, 5 kg/ha of fertilizer. This data is from similar sources to that shown in Figure 1. But Lwin et al. (2014) found from a 2013 micro household survey in Nay Pyi Taw district that average fertilizer use averaged 99 kg/ha of nutrients (125 kg/ha of urea and 69 kg/ha of NPK). Tun et al. (2015) also concluded that aggregate fertilizer statistics from international sources indicate that Myanmar farmers apply an average of 6.45 kg/ha of inorganic fertilizer, compared to a 2012 LIFT survey showing a large proportion of farmers using fertilizer for paddy, and that there are pockets of higher fertilizer use (up to 100 kg/ha according to Hnin et al., 2013).



Source: Figure 15 in the LIFT (2016) project report and USDA.

Figure 6. LIFT survey paddy yields, 2013/14, international comparison.



Source: Figure 22 in the LIFT (2016) project report and 2013/14 Myanmar agricultural survey.

Figure 7. LIFT survey application rates of various fertilizers by region.

Hence, there is evidence of limited fertilizer applications by farmers in this project area. Implications of this conclusion are that (a) further study of fertilizer management practices will be valuable (including the project field trials used for farmer field days), and (b) evaluations of other crop options and farm management practices can be useful in assessing options for improving smallholder farm profits and family livelihoods.

6. Conclusions

Myanmar smallholder farmers in these townships are very interested in improved cereal crop management. This interest encompasses soils, agronomy, climate, varieties, and economics. The evidence presented here is that fertilizer applications to cereal crops are not substantial, but further assessment of these results is warranted.

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Appendix A. Focus Group Workshop and Baseline Survey Villages and Group Sizes

Table A.1. Focus Group Workshop sample information.

Project Site Yezin (YAU)	Township Zayarthiri			Population (estimated)	
Village	Village Tract	Interview Location	Farm Group Size	Households	Farmers
Sein Sar Pin	Ma Oo Taw	KTC*	10	500	300
Shwe Baho	Kyun Yaung	KTC	4	90	25
Htan Ta Pin	Ma Oo Taw	Farmer house	6	100	35
Shwe Twin Gone	Yezin	Farmer house	5 (2 female)	254	10
Lay Thar	Zayarthiri				
Lay Thar	Kyun Yaung	Farmer house	6	400	100
Moe Te Kwin	Kyi Taung	Farmer house	5 (2 female)	213	55
Aung Thar	Mya Ga Naing	Farmer house	6 (3 female)	210	100
Thar Si	Thar Si	Farmer house	5 (1 female)	135	20
Tatkon	Tatkon				
Lat Pan Taw	Kinn Mon Tan	KTC	12	250	200
Kinn Mon Tan	Kinn Mon Tan	Farmer house	13	200	110
Ywe Su	Ywe Su	KTC	10 (2 female)	700	350
Kyarr Thae I	Kyarr Thae I	KTC	5	500	250
Shout Gone Taungoo	Shout Gone Taungoo	KTC	5	365	220
Inn Dine	Bo Ga Taw	Farmer house	15 (5 female)	340	60, but 300 laborers
Kokoh Pin Su	Sin Sate	Farmer house	10 (3 female)	100	24
Kyan Taw	Nga Phae Inn	Farmer house	17 (1 female)	107	70
Nyaung Pin Thar	Moe Kaung	Farmer house	17 (1 female)	300	70
Sate Phyu Taung	Sate Phyu Taung	Farmer house	5	360	180

* Knowledge Transfer Centre

Table A.2. Baseline survey sample information.

Date	Township	Village Tract	Village	Sample Size
2-May	Zeyarthiri	Kyauk Chet	Aisauk	8
		Thet Hnin Inn	Thet Hnin Inn	11
		Kyunyaung	Kyunyaung	11
		Kyitaung	Moon Te Kwin	12
3-May		Kyunyaung	Lay Thar	29
4-May	Tatkon	Aung Myay Yeik Thar	Aung Myay Yeik Thar	18
		Kinpondan	Kinpondan (West)	20
5-May		Anaw Ya Htar	Ywar Thit	17
			Naung Thinkhar	21
			-	4
6-May	Taungoo	Sin Sate	Kokoh Pin Su	13
			Kan Pout Gyi	8
			Zee Pin Thar	20
8-May		Bo Ka Taw	Gyo Gone	20
		Sa Par Kywe	Sa Par Kywe	20
		Total		232

Appendix B. Cropping Sequences and Patterns

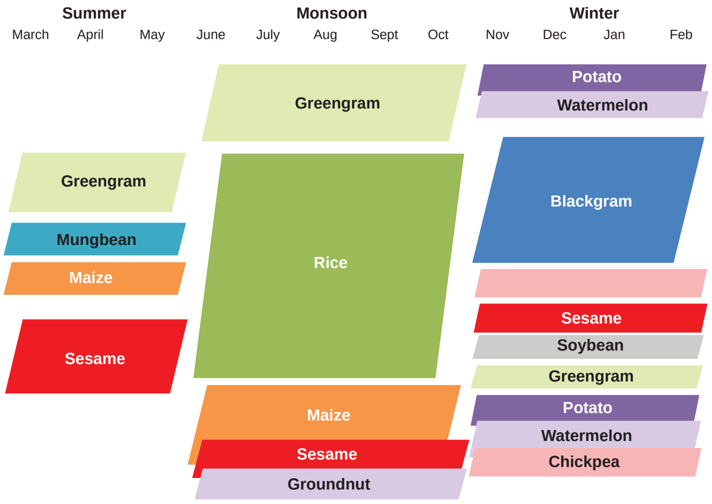

Figure B.1. Cropping sequences for Tatkone Township.

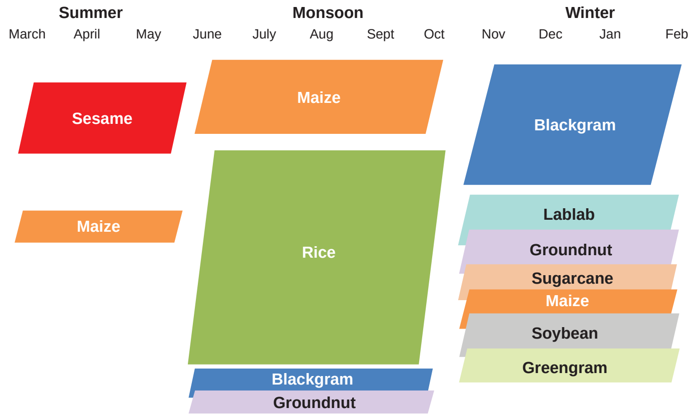

Figure B.2. Cropping sequences for Zeyarthiri Township.

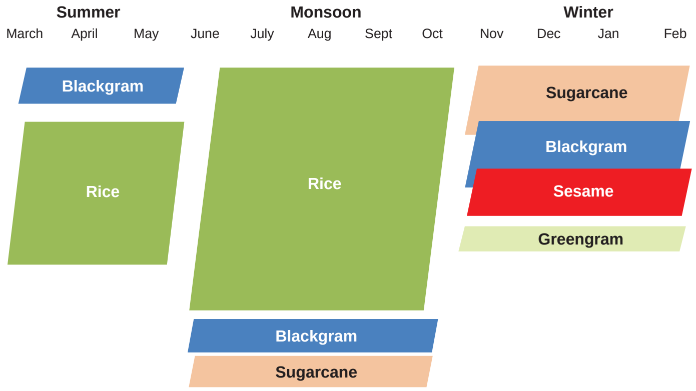

Figure B.3. Cropping sequences for Taungoo Township.

A Conceptual Framework for Delivering Improved Fertilizers to Smallholder Farmers in Africa

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Abstract

Most smallholder African farmers have access to only NP and NPK fertilizers. A host of secondary and micronutrient deficiencies have been identified throughout the continent, which when addressed, results in marked yield improvement. A challenge is to get balanced fertilizers (those that supplement available fertilizers with secondary and micronutrients) to these smallholders, who often can neither afford nor access quality soil analyses. We lay out a conceptual framework, which is being implemented to varying degrees in various African countries, to deliver improved fertilizers to smallholders. The SMaRT framework stands for Soil testing, Mapping, Recommendations development, and Technology transfer. Soil testing is done on a broad scale to identify major likely deficiencies, using complete analyses by a qualified laboratory. The major deficiencies are mapped, and crop-specific recommendations are developed through on-farm "best bet" and omission trials, considering predominant deficiencies and crop-specific nutrient demands. Once superior fertilizers have been validated, these recommendations are transferred to farmers by commercial fertilizer interests. Fertilizer regulations in many African countries need to be adjusted to accommodate new fertilizers, as regulations were often designed primarily for commodity NPK fertilizers.

Status of Fertilizer Use in Sub-Saharan Africa

Fertilizer use in sub-Saharan Africa is low, averaging 16 kg fertilizer per ha of arable land. This should not imply that the average farmer uses 16 kg/ha. The reality is that many farmers do not use any fertilizers, while commercial and smallholder farmers that do apply fertilizers use much higher rates. While several factors including accessibility, cost, and lack of output markets constrain farmer use, a major problem facing smallholders is the lack of diversity of fertilizer products to address soil- and crop-specific demands.

The main fertilizers available to smallholder farmers are what are referred to as "commodity fertilizers," such as diammonium phosphate (DAP), urea, calcium ammonium nitrate (CAN), 15:15:15 or similar NPKs, and occasionally NPKS products such as 10:20:10+6S or 23:21:0+4S. In many African countries, farmers have access to only two or three commodity fertilizers, making it difficult to address crop-specific demands or address secondary and micronutrient deficiencies. Lime products are generally not available. In many cases fertilizers are not available at the appropriate time due logistical and procurement problems, resulting in late application. As a result, fertilizer use efficiencies are less than half of what is achieved in agriculturally developed countries. Poor response and high costs discourage fertilizer use.

Relative to much of the world, African soils are poor, with most not having been enriched by recent geological activity such as glaciation, volcanic processes, mountain outwash, or acid rain, which until recently provided considerable quantities of S in industrialized countries. As a result, NPK fertilizers seldom address the suite of nutrient deficiencies present, and while usually improving yields, do not result in optimal nutrient response. Vast tracts of secondary and micronutrient deficiencies (primarily S, Zn, and B) and soil acidity constraints have been identified through various mapping initiatives, and superior response to balanced fertilizers that supplement NPKs with appropriate secondary and micronutrients have been observed in several countries. Fertilizer blending companies, primarily serving commercial farmers, now exist throughout the continent, but their products are not available to most smallholders, often impeded by cost considerations, lack of awareness and access, and subsidies on commodity fertilizers, which are persuasive in farmer purchasing decisions. A few commercially available balanced fertilizer compounds exist but are generally not targeted to soils and food crops grown by smallholders.

Delivering balanced fertilizers to smallholder farmers is a high development priority. Obtaining better fertilizer response is necessary to improve stagnant productivity (yield/ha) and for addressing human nutrition and farm income objectives. In this paper, we lay out a conceptual framework for delivering improved fertilizers to smallholder farmers at a large scale, primarily in the African context.

The Smallholder Farmer Context

Addressing smallholder farmer fertilizer requirements differs markedly from addressing those of large commercial farmers. Commercial farmers are willing to pay for, and generally have access to, full soil and plant tissue analysis, which aids in diagnosing likely deficiencies. Once getting a crop-specific recommendation for a desired yield target, they purchase in volumes that can reasonably be produced by a commercial blender – often more than 5 tons. They also have equipment that can efficiently apply fertilizers at variable rates that match recommendations.

Most smallholders' reality is very different. Most smallholders cannot access full soil analyses, and if able, are unlikely to invest in them due to the expense. Having small land holdings and often multiple crops requiring different fertilizer and lime recommendations, it then becomes impossible to access the correct fertilizer, as a blender cannot economically produce anything less than several metric tons. The fertilizers available from agro-dealers are most likely NP and NPK products of fixed nutrient ratios, so there is usually no opportunity to apply other nutrients or to adjust NPK ratios to fit the soil analysis and crops. Even if additional nutrients are available, applying them in the correct dosage poses challenges. Many micronutrients are required at less than 1 kg/ha, which farmers cannot distribute evenly. For commercial farmers, these are usually incorporated into NPK granular fertilizers to ensure even distribution. Overapplication can induce toxicities (especially for boron) and can induce other deficiencies. While some have proposed inexpensive field soil test kits for soil analysis, based on wet chemistry and more recently infra-red spectrometry, these generally measure only soil pH and macronutrients. Challenges exist in converting kit analyses into crop-specific recommendations, even for the few analyses the kits perform. Kits are also a slow extension tool, as they require individual farmer field analysis, which number in the millions. While soil test kits are still in development conceptually, yield improvements based on some kit analyses have yet to be validated.

The SMART Concept

SMART stands for Soil analysis, MApping, Recommendations development, and Technology transfer. The concept behind SMART is to get better fertilizers to farmers for a given crop and region that substantially and sustainably outperform fertilizers currently used by farmers. Sustainability is addressed by using “balanced” fertilizers, which have a balance of macro, secondary, and micronutrients that address predominant nutrient deficiencies. Lime recommendations may be part of a SMART recommendation when lime is available and required. Some aspects of the SMART concept have been implemented in various countries. Where quality soil analyses, mapping, and/or crop response data exist, they should be reviewed and collated to avoid duplication of efforts.

The goal is not to make the perfect fertilizer for every smallholder farmer and crop, but to develop fertilizers that substantially improve yields and economic returns compared to fertilizers currently available. With this target in mind, fertilizers can be produced for major crops in defined geographical areas in sufficient quantities to be commercially viable. This may mean that the fertilizers will contain nutrients that are not required for some farms, but result in an economic yield increase for the majority.

The SMART concept begins with **soil sampling**. A minimum sampling density of 25 km^2 (approximately 5 x 5 km, not necessarily on a grid) of cropped land was sufficient to identify likely nutrient deficiencies and soil acidity constraints in Rwanda and Burundi. A sampling depth of 0-20 cm is desirable, though deeper samples (20-50 cm) can provide additional information on constraints such as subsoil acidity, subsoil nutrients such as S or Cl, or soil texture impediments. Samples receive a full analysis for all essential nutrients, soil pH, organic C, total N, and soil texture from a pre-evaluated qualified laboratory, using recognized procedures. While many procedures are “recognized” (there are at least three procedures commonly employed for most nutrients), some harmonization would be desirable to facilitate interpretation of results, as interpretation is dependent on the procedure used. Some of these analyses may be performed spectrally if good spectral calibrations have been achieved.

In the **mapping** step, analytical results are mapped. Nutrient deficiency and soil acidity maps are not the same as soil classification maps, which are already available at different scales. The purpose of the mapping is to show areas that have likely nutrient and soil pH constraints, as well as toxicities when they exist, that need to be corrected. Mapping may concentrate on specific zones of production; for example, a rice marshland, an area of cocoa-intensive production, or a maize belt.

Mapping is a worthy project output in itself. As a public good, it is available to both the public sector and to fertilizer companies. Fertilizer companies can use maps to target their products, based on their best interpretation of results, for crop-specific needs. Maps are also very powerful in informing policy and agricultural research priorities. Many countries are unaware of the extent of the various nutrient and soil acidity constraints affecting yields. Maps can spark interest in the need to develop and support balanced fertilizers.

Quality of Soil Analyses Required for Mapping

While complete quality soil analyses are somewhat more expensive, it is not an area for compromise, particularly when invested as a public service. The largest expense is usually not in soil sample analysis, but in sample collection and transportation to a qualified laboratory. Poor quality soil analyses, either due to the methods themselves or to the analytical laboratory, will not provide a good guide as to which nutrient deficiencies and acidity constraints predominate, or their spatial distribution. While less accurate but faster and less expensive methods may have a role, methods of complete soil and/or leaf analyses that are well-correlated with crop response are necessary for mapping, particularly in the African context where the likelihood of response to secondary and micronutrients and the correct type of lime (either calcitic or dolomitic) is high. Spectral analysis may replace some wet soil methods for several analyses including soil pH, total N, organic C, P fixation capacity, and others where calibrations are good, and is well-calibrated for most total nutrients in plant tissue.

The **recommendation** step is concerned with developing fertilizer recommendations that address predominant constraints. A recommendation is both a fertilizer formula and an application rate. Fertilizer formulations (e.g., 12:24:12 + 6S + 0.5 Zn + 0.2 B) indicate the percentages of nutrients in a blend or compound. When multiplied by the rate of application of the fertilizer (in kg/ha), the amounts of nutrients applied per ha are calculated.

Fertilizers should be assessed within the guidelines contained in the 4R Nutrient Stewardship Framework promoted by the fertilizer industry: the right source of fertilizer, at the right rate, time, and placement. The 4R framework is implemented in the context of the crop grown, soil types, and weather, among other factors. Other good agricultural practices such as timely planting and weeding should be employed.

During the development of recommendations, several “best-bet” fertilizers may be tested. A “best bet” is not a recommendation but becomes a recommendation once its yield and economic superiority have been established through on-farm trials. A “best-bet” trial involves one or more “best-bet” alternatives, the current fertilizer, and a non-fertilized control.

In developing recommendations, a starting point is to understand nutrients removed in the harvested products. For a given yield target, estimates of nutrient extraction from both crop and stover are available for many crops. For the macronutrients N and P, one generally wants to apply sufficient N and P to offset extraction, even though a soil may have moderate available N and P, so that the developed fertilizer will be able to sustain a yield target without annual adjustment. Therefore, N and P rates are generally fixed based on crop extraction, unless for exceptional areas where high N and/or P that can sustain production for several years are observed. We have occasionally found such soils in high organic matter volcanic soils. P application may also consider the P-fixing potential of soils. For K, while extraction rates are high for many crops, return to the soil from crop residue can also be high, if crop residue is not immediately removed. Some soils can also have a high K-supplying capacity that will sustain production for decades; in such circumstances, minimal or no K may be sufficient. Most soils can provide some K, and for many crops including maize, tables have been constructed on K application based on soil analysis values and yield targets. Micronutrients, when incorporated or coated onto granular fertilizers, need only be applied at about twice the crop removal rate, to account for leaching (B) or fixation (common with Zn and Cu). Some crops are very sensitive to specific nutrient deficiencies, whereas others are sensitive to overapplication. A knowledge of specific crop demands and sensitivities helps guide best-bet formulations.

Nutrient omission trials can be run in conjunction with best-bet trials. While soil testing is often a good guide for developing best-bet formulations, it also has its limitations. Some nutrients cannot be accurately predicted with a soil test, and unexpected responses often occur. Nutrient omission trials provide more definitive data on which nutrients belong in a formula and can be used to evaluate the economic impact of each nutrient and lime on yields.

For trials to have broad applicability, these trials are best done on-farm in widely dispersed areas. On-station sites are usually avoided, as they may have been subjected to other fertility trials that leave residual effects or may have historically better management and thus not reflect on-farm realities. On-farm response data provide the economic justification for a fertilizer formulation, which informs fertilizer providers if they truly have a superior product. These trials can also provide the economic justification for changing fertilizers offered under subsidy programs. A minimum of 30 sites in a region with soil and climatic similarities usually provide sufficient statistical resolution to validate response.

Some may wish to forego trial work for various reasons. If available NPK formulations or recommendations clearly do not match crop demands, one may be able to bring to market a better product and use a season's worth of on-farm demonstrations for farmer promotions and trial data, even without soil analyses. Some specialty fertilizers such as controlled-release nutrient products may perform better than standard NPKs, regardless of soil fertility. Some fertilizer companies simply formulate based on crop demand, irrespective of soil constraints. All these approaches can bring better products to the market in many circumstances. Nevertheless, having maps of soil constraints can guide companies to produce better products, particularly in a competitive market, and are therefore a public good. Any trial work, when run in collaboration with national governments, produces data that form the economic basis for changes in national recommendations and can be a valuable contribution to subsidy programs.

Professional soil analysis interpretation is required to generate best-bet treatments. Interpretation in the context of smallholder fertilizer recommendations is not a straightforward process, and will be context-specific. Recommendations must consider the crop grown, the yield target, the current farmer application rate and/or subsidy provision (which translates into a fertilizer rate), and a crop-specific interpretation of the analytical results. It is desirable to keep the application rate within subsidy guidelines or practically affordable rates, though this is not always possible, particularly if K or S are added and are not in a current formulation such as DAP, as these added nutrients often increase fertilizer volume. Farmers can adjust rates based on yield targets or financial means. Micronutrients can be added by only slightly reducing other nutrients, such that their addition need not affect fertilizer application rates.

The interpretation of the analytical results is not a straightforward process, and different analytical laboratories have different interpretive methods. For example, some laboratories will use co-factors such as soil pH, soil texture, organic matter concentration, and different nutrient ratios (e.g., C/N ratio, ratio of K to other bases) in their interpretation of nutrient availability. Interpretive criteria differ for different crops; there is no single critical nutrient level or soil pH value that applies to all crops. Interpretation may be based on years of experience in working with farmers in a given region. In the United States, for example, different state laboratories have different interpretative criteria for the same crop, based on experience within their state. In South Africa, several blenders often compete for the business of commercial farmers, and their comparative advantage lies in part in how well they interpret analytical results to generate recommendations. In the smallholder farmer context, it should be borne in mind that one does not need to generate the “perfect” interpretation; one only needs to generate data using recognized methods on which interpretations can be derived, and best-bet formulas can be developed and tested. Best-bet formulations should provide a nutrient balance for long-term sustainability, addressing the predominant nutrient constraints, and most importantly when field-tested, show superior yields and returns on investment compared to currently used fertilizers.

Fertilizer providers and blenders should contribute their expertise in initial formulation of best-bet treatments, based on the ingredients and processes they use, as they will provide products to the market. Inexperienced blenders often have no experience with formulation and may simply rely on the customer (or project) to come up with new products. In many instances, ingredients for balanced blends may not exist within the country, particularly for micronutrients, and blenders may not be willing to invest in volume purchases of new ingredients until response has been established.

Technology transfer involves getting improved fertilizers to the market. Actions required are country-specific, and depend on a host of factors, including the subsidy environment, fertilizer regulations, which may not address new ingredients, the presence of qualified blenders, and the volumes of product required. If very large volumes are required (>5,000 t of a specific formula), fertilizers may be more economically produced as compounds rather than blends. A compound is a fertilizer in which all the ingredients are included in every fertilizer granule, whereas blends are mixtures of granular fertilizers, sometimes coated with micronutrient powders.

Fertilizer Policies and Regulations

From the beginning, it is important to understand the fertilizer regulations and the fertilizer policy of the country in which one is working, including the fertilizer subsidy environment. Some countries have regulations that only allow for certain ingredients. Others impose taxes on fertilizer sources not explicitly included. Many fertilizer regulations are crafted only for commodity fertilizers, which may make introduction of new fertilizers time-consuming. Still others have required long evaluation periods for new fertilizers, which is prohibitive for fertilizer blenders that may produce many custom formulations annually. Some have overly restrictive limits on fertilizer attributes such as contaminants or moisture contents that are outside of industry norms.

Regulations in many African countries were designed primarily for commodity fertilizers, and are understandably not designed to accommodate innovative or new fertilizer products or blends. While some countries have reasonable requirements, such as ensuring that products meet the stated nutrient concentrations, others have very prohibitive regulations that require several seasons/years of trials to prove efficacy. Some of the existing fertilizer policies seem to be a copy/paste of the pesticide registration policy, which is understandably more stringent.

In developing a facilitative regulatory and policy framework, regulatory bodies may require guidance in understanding the issues around new fertilizer products, including international norms and best practices, and their relevance to facilitating market entry of new products. Regional harmonization of national policies is ongoing through the Common Market for Eastern and Southern Africa (COMESA) and Economic Community of West African States (ECOWAS), but it is not yet clear if this will result in a facilitative environment, or when new regulations may come into effect. Harmonization of accredited labs that can be used across the region for product testing would also be beneficial.

Where implemented, fertilizer subsidies often work to discourage use of superior blends. In most countries, only commodity fertilizers are subsidized. Thus, superior balanced fertilizers must compete against these lower cost fertilizers. Since cost is a major consideration for most African smallholder farmers, they will often choose the least expensive fertilizer and forego purchase of higher cost fertilizers, even though the yield advantage of these fertilizers more than justifies cost. Lack of transparency in fertilizer procurement is common, with procurements going to companies in return for “facilitation fees” or procurements given to favored interests in spite of higher costs. Overcoming entrenched interests in subsidy programs is a major challenge in many African countries.

Farmer Awareness and Marketing

In a liberalized fertilizer environment where no fertilizer subsidies exist, companies are free to market fertilizers that meet regulatory standards. Different companies have different approaches, which may involve farmer demonstrations, distribution of fertilizer small packs to agro-dealers, extension personnel, or lead farmers, advertising through various media, including promotional materials with agro-dealers, and liaising with key agricultural personnel at district and country levels. A company may also wish to engage national and farmer organization extension services in field demonstrations. NGOs involved in projects that involve fertilizer use may also be engaged. In other countries, permissible fertilizers are tightly controlled, as well as fertilizer distribution channels. In such cases, one must engage with governments at an early stage, and work through government entities, to get new fertilizers into the market.

Digital Land Resource Mapping to Inform Location-Specific Soil Management Advice

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Abstract

Land resource information is a vital part of a nation’s knowledge infrastructure and provides a basis for planning agricultural development that is both productive and sustainable. Such information can be used for long-term strategic planning – for example, ensuring that investment in irrigation infrastructure is targeted to suitable areas or for identifying vulnerable areas most in need of soil conservation investment. Likewise, such information can be used for short-term tactical decision-making for improving soil management to overcome constraints to agricultural productivity or sustainability. Investment in land resource information, therefore, has benefits that accrue over many years – generally decades. However, the costs of establishing an agency for soil and land survey can be considerable in human resources, infrastructure, and financial terms. Survey organizations require expert surveyors, whose training may take many years, as well as infrastructure to support surveys, such as data management and analytical laboratories. Surveys are expensive to conduct as they involve staff and equipment being in the field for long periods of time, as well as the ongoing costs of laboratory analysis.

We have developed a protocol for digital land resource mapping that potentially makes more efficient use of survey resources to allow greater areas to be mapped in a given time. The protocol is based on four “pillars”: statistically based sampling strategy, simplified field methods, rapid soil analysis using mid-infrared spectroscopy (MIR), and spatial prediction of soil properties using statistical methods. Each pillar allows more efficient use of survey resources than conventional survey by allowing non-experts, possibly drawn from local organizations, to carry out much of the field work.

Digital land resource mapping produces maps showing the spatial variation of individual soil properties of direct relevance to crop growth and management. Conventional survey produces a single map of soil type, from which relevant soil properties must be inferred. Digital maps can be used by extension staff to prepare a list of potential soil problems at a location before they visit the farmers there. The soil properties at the location can also be compared to land suitability rules for a range of potential crops, so that alternative crops that are less constrained can be suggested to farmers. The status of plant nutrients in the soil is generally not mapped. However, maps of other soil properties can be used to guide fertilizer management, since they inform both the productive potential of the soil and the efficiency with which applied nutrients are used as affected by leaching, waterlogging, pH, phosphorus adsorption, and erosion.

From Site-Specific Nutrient Management or Tailor-Made Fertilizer to a Soil Clinic in Thailand

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Abstract

Site-specific nutrient management (SSNM) in Thailand was developed and transferred to farmers under the name “tailor-made fertilizer.” Fertilizer recommendations were determined by the crop models Decision Support System for Agrotechnology Transfer (DSSAT) and Phosphate Rock Decision Support System (PRDSS) for nitrogen and phosphorus requirements. Potassium requirements were calculated by a specific model. The procedure of fertilizer recommendations was simplified into three steps: (1) simplification of soil taxonomy; (2) simplification of crop modeling; and (3) NPK test kit. After empowering farmers’ success, a soil clinic was established and managed by a farmers’ group. The concept of the soil clinic was expanded by support from several funding agencies and the government. Recently, the soil clinic in Thailand was transformed to be the Agricultural Productivity Efficiency Increasing Learning Centre, which covered 882 districts around Thailand. The Asian Soil Partnership could be a facilitating function to transfer this technology among Asian countries.

Introduction

The agriculture sector has played a major role in enhancing Thailand’s production base. It has provided a secure domestic food supply and income for the nation while supporting value creation for trade and services. Most Thai farmers earn below the country’s average income. The number of farmers who are over 50 is increasing, while working on the farm appears to be less attractive to the younger generation. As a consequence, during 1998-2007, the number of farm workers decreased by 1.9% per year, which resulted in labor shortages and low productivity. On the other hand, national and international demand for food is likely to increase significantly due to rapid population growth, which, in turn, will affect food security in the future.

Formerly, fertilizer recommendations supplied to farmers were very general and often constrained by the nutrient content of particular fertilizer compounds available on local markets. Lack of basic knowledge of farmers was another factor that led to the farmer having no choice to select the appropriate fertilizer. Technology transfer from the government sector in that time seemed not effective for knowledge transfer to farmers.

Site-Specific Nutrient Management (SSNM)

A Step-Wise Approach to Fertilizer Recommendations

An SSNM research project was started in Thailand in 1997 by Professor Dr. Tasnee Attanandana and colleagues (Attanandana and Yost, 2003). Fertilizer recommendation was an output from site-specific nutrient management. Her team was intent on developing a low-cost technology with high efficiency. Soil classification was prepared in a simple way so that Thai farmers can identify their own soil. A soil test kit has been invented that allows farmers to analyze soil nutrients (NPK) by themselves. DSSAT and PRDSS models were used to generate N and P requirements, and a specific model for K requirements was developed (Phinchongsakuldit, 2003). All procedures mentioned were simplified by the following steps:

1. Simplification of Soil Taxonomy

Soil classification is sometimes difficult even for soil scientists. To teach soil classification tends to be problematic. How can farmers identify soil series in their farmlands, use some soil properties from soil taxonomy, and combine with recent soil analysis. Visual soil color, soil texture, soil pH, and a decision tree technique were developed by Boonsompopphan and colleagues (Boonsompopphan et al., 2008). Recently with the supporting technology of smart phones with GIS chipsets, some Thai farmers are able to access the soil database from the national soil information via the internet (Land Development Department, 2017).

2. Simplification of Crop Modeling Software

A Crop Simulation Model (CSM) is a mathematical or simulation model that helps estimate crop yield as a function of weather conditions, soil conditions, and choice of crop management practices. One crop simulation that has been used in many countries is DSSAT, a software application program that comprises crop simulation models for over 42 crops (as of v4.6). DSSAT is supported by database management programs for soil, weather, and crop management and experimental data, and by utilities and application programs. The crop simulation models in DSSAT simulate growth, development, and yield as a function of the soil-plant-atmosphere dynamics.

Site-specific nutrient management is one of many applications of the principles of site-specific agriculture, sometimes called “precision agriculture” (Attanandana et al., 2006). Recent research using DSSAT-CERES-Maize and PRDSS together with simplified soil test kits resulted in higher yields, greater economic return, and balanced fertilization.

3. NPK Test Kit

Real-time information is important for crop simulation. For some soil properties that are almost stable, such as soil texture or soil depth, we can use information from soil classification. On the other hand, very sensitive properties, such as soil fertility, which fluctuates with fertilizer application, could not be borrowed from soil classification. Standard soil analysis is famously used in developed countries. For developing countries like Thailand, when transportation infrastructures were under construction, farmers could not get access to standard soil analysis. So, NPK soil test kits were an alternative for farmers to evaluate the availability of nutrients in the soil. A soil test kit was invented and adapted for use in the field. This kit provided the critical site-specific information, such as the analytical results for N, P, and K from soils collected in the field (Attanandana et al., 2006).

Empowering Farmers

In the early period of training for maize in 2001, there was an indication that most of the farmers did not follow our technology on site-specific nutrient management even after training. This led the team to change the strategy to one of empowering the farmers. A Participatory Learning Forum (PLF) was used as a starting point of the soil clinic. The capability building of screened farmer leaders on rice and sugarcane was done during the first period of the project (April-August 2005). There were marked changes in the farmer leaders after only four or five months of working with them. They recorded the cost of production and tried to reduce it. Some of them expanded their thinking about better living and changed their way of working. Many good ideas were coming to them. They identified unnecessary expenses in their lives and reduced them. They realized the importance of their soils and improved the soils by incorporating the residues and green manure. The farmers tried to increase the diversity of crops in their fields and worked on other business opportunities to obtain more income. They formed a group to discuss their problems on crop production. Their appreciation and happiness to join us and the group were obvious during visits, but this is difficult to illustrate in a paper such as this. Empowering the farmers to discriminate and compare information among one another is what we called the "**soil clinic**."

Development of Soil Clinic

The soil clinic gathered farmers together focusing on soil management, crop production, and also a marketing approach in purchasing inputs and selling their products.

Optimum fertilizer application will reflect an increase in fertilizer use efficiency and economic return to farmers. In addition, optimum fertilizer application also results in mitigation of pollution caused by excess fertilizer application.

Soil clinic development was initiated with support from the Kyuma Fund. The Kyuma Fund, under the Kasetsart University Foundation, has supported the establishment of six soil clinics in four provinces since 2013. Another supporting agency is the Rotary Club of Bangkok Benjasisri, which also supported three soil clinic establishments. After the success of the soil clinics, the National Research Council of Thailand funded a pilot project for the establishment of 15 soil clinics in three provinces in 2014-2015. Since 2015, the Department of Agricultural Extension has agreed to implement the soil clinic concept as a national policy and to support up to 882 soil clinics in every district throughout the country.

In a soil clinic, designated farmer leaders analyze soil samples for member farmers, provide tailor-made fertilizer recommendations, and have fertilizer materials available for sale to them. It's an incubator unit or a micro-enterprise where farmer leaders learn to run the soil clinic as a business.

Agricultural Productivity Efficiency Increasing Learning Center

Recently, the government has rejuvenated the "soil and fertilizer management community center," which emphasized mainly soil and fertilizer management as a learning center to increase the efficiency of agricultural production in each district. A total of 882 Agricultural Productivity Efficiency Increasing Learning Centers have been set up across the country. In these learning centers, various relevant agencies have brought in research, innovation, and modern technology to introduce to local farmers, who have also been provided with knowledge on production technology, processing, and marketing in order to reduce production costs and add value to their productivity.

Asian Soil Partnership (ASP)

The Global Soil Partnership (GSP) was initiated by the Food and Agriculture Organization (FAO) of the United Nations. The objectives of the GSP link to five Pillars of Action: (1) promote sustainable management of soil resources for soil protection, conservation, and sustainable productivity; (2) encourage investment, technical cooperation, policy, education, awareness, and extension in soil; (3) promote targeted soil research and development focusing on identified gaps, priorities, and synergies with related productive, environmental, and social development actions; (4) enhance the quantity and quality of soil data and information, such as data collection (generation), analysis, validation, reporting, monitoring, and integration with other disciplines; and (5) harmonization of methods, measurements and indicators for the sustainable management and protection of soil resources (FAO, 2016). The Asian Soil Partnership (ASP) is a regional activity under the umbrella of the GSP. According to ASP, SSNM or soil clinics should be considered activities suitable for Asian collaboration with support from FAO.

Conclusion

Site-specific nutrient management is essential for appropriate fertilizer recommendations. SSNM requires a lot of input data, such as soil, plant, and climate information. Much information could be obtained on the internet or adopted with some modification. However, there are some specific varieties in local conditions, specific soil characteristics, and microclimates that need to be considered. The model from Thailand could be studied and modified to suit Myanmar conditions. The Asian Soil Partnership is an opportunity to be assisted through Asian country collaboration.

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The Role of Agribusiness in Advisory and Marketing Services in Myanmar

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Abstract

The Fertilizer Sector Improvement (FSI) project has provided training on business management and agricultural-related products and technologies to agro-input retailers in the project regions (Ayeyarwaddy, Bago, and Yangon) and in Southern Shan State since March 2016. As of August 2017, the project trained 205 agro-input retailers. The training was developed to provide retailers with a broad understanding of small business management and subject-specific knowledge in their business areas. As the interface with farmers, dealers have the potential to provide technical advice to farmers on their products for sale and the products' use. This helps farmers choose the right quantity and the right quality products for their farms.

To determine the impact of such training programs on the businesses of the agro-input retailers, FSI conducted a sample survey in the project regions and in Southern Shan. The result indicated that no retailers understood the costs analysis in the project regions before training, and only 18.5% understood it before training in Southern Shan. After training, 6.7-50% of trained retailers in the project regions enhanced their recordkeeping, and 7.4% in Southern Shan transformed from their traditional bookkeeping. The market share increased, on average, by 13.64 villages and 170.13 farmers after training in the project regions and 2.22 villages and 92.96 farmers in Southern Shan. The trained retailers are now able to calculate their net profit accurately. From 93.3% to 100% of trainees now keep inventory records in the project regions. In Shan, 92.6% keep good inventory records. About 40-64.3% in the project regions and 66.7% in Shan did not know Syngenta's "five golden rules" or systematically wear personal protective equipment (PPE) before training. Those sampled were divided into five categories based on how many farmers they shared information with: 1-10 farmers, 11-20, 21-30, 31-40, and 41-50. About 35.7-50% of trained dealers in the project regions and 33.3% in Shan shared the five golden rules with 41-50 farmers after training.

Introduction

Agriculture is the second largest source of export commodities and the most important sector for the country's economy. The sector is an important growth engine for rural development. Rice is the country's primary agricultural product, which accounts for nearly 60% of production value. In Myanmar, 70% of the country's population lives in rural areas depending on farmland and forests for their livelihoods.[1] Agriculture sector growth is the government's top priority for poverty elimination in the country. However, by March 2016,[2] Foreign Direct Investment (FDI) in the agriculture sector only accounted for 0.4% of the total FDI, with 19 foreign enterprises

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[1] https://www.export.gov/apex/article2?id=Burma-Agriculture.

[2] http://www.fao.org/fileadmin/user_upload/faoweb/docs/MM3/Statements/Myanmar.pdf.

investing an approved value of U.S. $250 million. Due to natural disasters, such as flooding, and unfavorable weather conditions, agriculture exports as a percentage of total exports have declined over the past few years.

According to the Myanmar government, the agriculture sector constitutes 41% of the country's total gross domestic product (GDP) and 11% of foreign exchange earnings.[1] Its potential for growth is higher than any other ASEAN country.[1] However, to achieve this potential, yield and product quality improvement is required. To achieve and sustain the yield, fertilizers become a critical farm input.

There are over 5,200 agro-input retailers registered with the Land Use Division of the Department of Agriculture. In his survey of retailers in the regions of Yangon, Ayeyarwady, and Bago, Ian Gregory (FSI Retailers Survey March 2015)[3] divided retailers into four categories based on the volume of annual fertilizer sales: (1) area distributors with annual sales of more than 100,000 50-kg bags; (2) large agro-dealers with annual sales of between 20,000 and 100,000 bags; (3) medium agro-dealers with annual sales of between 1,000 and 20,000 bags; and (4) small agro-dealers with less than 1,000 bags in annual sales. With the exception of the distributors, all expressed lack of finance as their biggest constraint followed by lack of product knowledge and capacity to provide advice to farmers. This paper will only deal with the role of agri-business in providing advisory and marketing services, in particular the services around soil fertility and fertilizer management.

IFDC's FSI project is funded by the United States Agency for International Develoipment (USAID). Its target areas are Yangon, Ayeyarwady and Bago, with a pilot project shared between FSI and Syngenta in Southern Shan State. The project includes a component to address fertilizer retailer capacity, such that retailers are able to begin providing advisory services and a range of higher quality products. IFDC also manages the Dry Zone Agro-input and Farm Services project funded by the Livelihoods and Food Security Trust Fund (LIFT) with activities in Pakokku, Yesagyo, Taung thar, Myingyan, Natogyi, and Mahlaing townships, designed to support service providers' and retailers in order to strengthen their business and asset base, as well as improve both public and private extension services available to the Dry Zone farmers.

This paper will focus on the role of agro-input retailers selling fertilizer in the FSI project area and trained by IFDC over the period 2015-2017.

An Analysis of the Fertilizer Market in Myanmar

Fertilizer is imported in two ways: overland by truck or by sea through the Yangon port. The majority of overland imports, consisting mainly of urea, triple superphosphate and NPK compounds from China enter through the border crossing at Muse in Shan State. Products from Thailand are imported through Myadwaddy in Kayin State and fertilizer from India through various border crossings in the northwest. Supply advantages for Myanmar include the access to Chinese urea at border prices that are below international norms, access to a wide range of products on the international market, including imports from Thailand, Malaysia, Vietnam, the Arabian Gulf and India, and well-established fertilizer importers.[3] All fertilizer in Myanmar must be registered. There are 3,567 fertilizer products registered with the Land Use

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[3] Fertilizer Sector Improvement Project. Retailer Survey. March 2015.

Division of the Department of Agriculture. This number changes year by year, as each brand of each product requires separate registration.

Myanmar imports about 85% of its chemical fertilizers from China and Thailand and produces domestically 15% of the fertilizers used. Organic fertilizers can be found in the market, but farmers prefer chemical fertilizers which offer higher yields.[3]

Myanmar has five ammonia urea plants using domestic natural gas as feedstock. However, only three are currently operating, one in northern Magway Division, one in southern Rakhine State, and one in Yangon Region. Gregory et al. reported total annual production has fluctuated between 35,300 mt urea and 208,600 mt during 2010-2014. Fluctuations are due to availability of natural gas, continuity of natural gas supply, age of plants with low energy efficiency and small design capacity. Myanmar relies on urea imports for over 70% of the urea supply with the bulk of this coming from China.[3]

The industry in Myanmar is dominated by a few importers/distributors, such as Myanmar Awba, Aventine (Capital Diamond Stars Group), Golden Lion, Golden Dragon, Shu San, Wisara, Myanmar Kaung Thuka, CP, Golden Key, Supreme Bio-Tech, JJ Pun, Marubeni, Shan Maw Myae, Malarmyine, etc.

Fertilizer Retailer Market Analysis in Myanmar

Retail shops sell more than just fertilizer, often seed, pesticides and small hardware. What they stock is personal choice to satisfy their own business needs or the needs of their customers. Farmers' needs can be influenced on a local basis and dealers are selling with very competitive prices. According to the Land Use Division (LUD) records, there were 3,093 registered retailers in 2014 and this had increased to 5,200 in 2017. There are at least two to seven shops[3] in the same vicinity selling similar products; thus, there is a need to build customer loyalty. With the increase in the number of registered shops, new shops are taking a market share and dealers must compete much more than before. Indeed, the market is mainly affected by the importers and their own marketing of their brands

Most agro-input retailers are running their business as a family-owned business. There is no financial assistance currently available for Agro-Input retailers, as there are no monetary institutions to support unsecured loans or to provide seasonal credits to agro-input retailers under the government's monetary laws in Myanmar. Likewise, there are no official financial institutions currently available to support business expansion. This would indicate that small and medium entrepreneur development is quite a tough business to sustain and there is no window for long-term growth. Fertilizer shops, referred to as dealers or retailers, are officially registered with the LUD of the Department of Agriculture.

For a dealer to achieve a competitive advantage over a rival, they need a cost advantage and/or a differentiation advantage. But dealers' lack of knowledge in products and running their businesses with traditional practices continue to be a problem. However, if dealers have more knowledge about the goods being sold and were delivering high-quality services, it would be more attractive to their farmer customers and they would stand over competitors on the other hand. This would be a win-win business solution for both dealers and their customers. Retailers are residents within the catchment of their market. Their survival depends on their reputation and the resources available to them.

Table 1. Registered Fertilizer Dealers 2016-2017 in Myanmar

Region / States	Numbers of Shops
Kachin State	182
Kayah State	37
Kayin State	86
Chin State	0
Sagaing Region	584
Tanintharyi Region	56
Bago Region	722
Magway Region	376
Mandalay Region (Mandalay 778, Naypyidaw 83)	861
Mon State	274
Rakhine State	147
Yangon Region	309
Shan States (North 141, South 482, East 20)	643
Ayeyarwady Region	923
Total	**5,200**

The Role of Retailers in Fertilizer Advisory and Market Services

FSI sees the retail outlets in townships and village tracts as the final point in the supply chain from port to farm. The Fertilizer Law requires them to be licensed if retailers sell more than 100 50-kg bags per year and the products on sale must be registered. The authority for inspection and quality control rests with the LUD of DOA but farmers and retailers can request sampling of products if they suspect adulteration. Therefore, FSI sees the retailers not just as a point of sale, but also as a functionary in quality control and farm advisory services to ensure farmers get the right product at the right time.

Domestic Urea Capacity and Production in Myanmar

1. Sale Factory (Japan Made)
2. Kyung Chaung Factory (Germany Made)
3. Kyaw Zwa Factory (Germany Made)
4. Myaungtaga Factory (China Made)
5. Kan Gyi Daunt Factory (China Made)

Total Production

2014-2015	166,017.28 mt
2015-2016	130,431.25 mt
2016-2017	82,502.15 mt

Figure 1. Domestic urea plant locations with total production volumes

IFDC started to launch the Agro-Input Retailers Training Program in the project regions in March 2016. The training program is a six-day residential training with six half days of business management and six half days of technical training covering plant protection, soil fertility, and fertilizer management. However, not all are willing to take on the role as a farm advisory service as a way of working closer with their farmers.

There are those who think their business generates good sales revenues and feel they have no need to learn from others. However, those willing to grow their businesses are joining the training. This program helps entrepreneurs define their business plans, in order to improve their chances for obtaining venture funding, and for creating concrete marketing deliverables to promote their original ideas. IFDC seeks to help small businesses at various stages of their development.

If the agro-input dealers can provide advisory services that meet with customers' expectations, it would be of mutual benefit for both farmers and retailers. For this, the FSI and Dry Zone projects have launched retailer training programs that are helping to develop the business management and technical capacity among selected retailers in target townships since March 2016. Today, FSI has trained 161 retailers (49% women), seven service contractors (all male, 5%), 11 briquette machine owners (57% women) and 30 DOA/DAR staff (60% women) completely. The Dry Zone Agro-Input and Farm Services project has trained 55 retailers (27% women) since May 2016.

The Impact of Retailer Training

In the FSI training, not only business management topics are covered but also agricultural product knowledge technology is being delivered by Syngenta crop protection trainers, who provide training on occupational health and safety when handling plant protection products. IFDC also provides training and on-farm advisory services, plant nutrition, and fertilizer management.

This paper reports the impact the FSI training is having on retailers, referred to as beneficiaries, both before and after the training, and also in comparison with dealers who have not received the FSI training. The data analysis is based on three batches, both in the project regions and in Southern Shan. A random sample of 22 retailer trainees (male 13, female 9) and non-trainees in project regions and 27 trainees (male 12, female 15) and 18 non-trainees (male 8, female10) in Southern Shan.

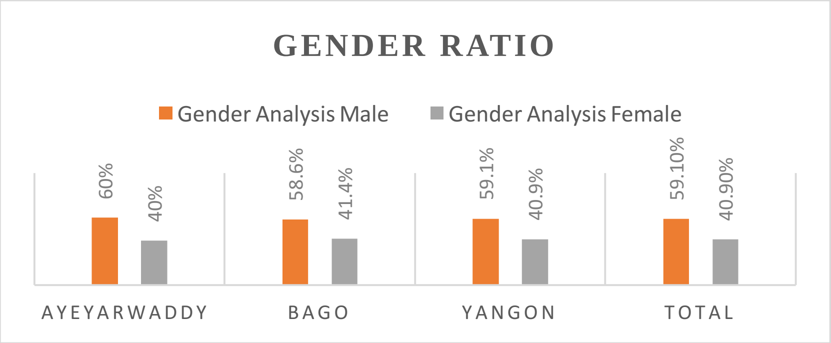

Figure 2. Gender ratio in FSI project regions.

Medium-sized businesses (1,000-20,000 bags, 50-kg) and larger were keen to attend the training and did ask for further business assistance after training. However, the small sales volume retailers declined to come to training, giving reasons like having children, working for household chores, taking care of elderly parents, etc. In FSI project regions, we did surveys for gender ratio in Ayeyarwady (female 40%, male 60%), in Bago (female 41.4%, male 58.6%), and in Yangon (40.9% female, 59.1% male), and it was the same as non-training ratio.

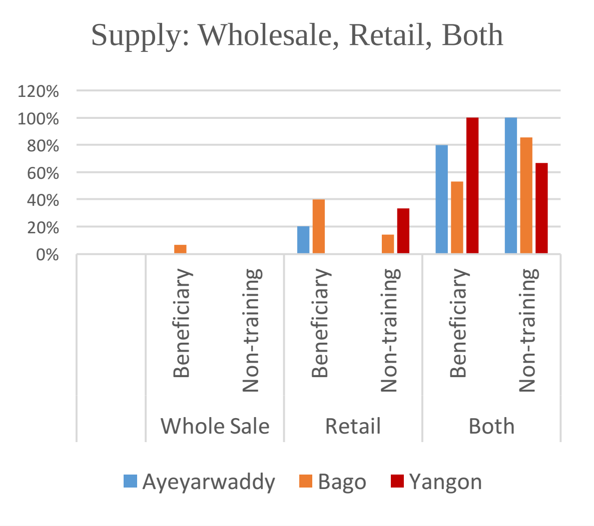

Figure 3. Supply-wholesale, retail or both.

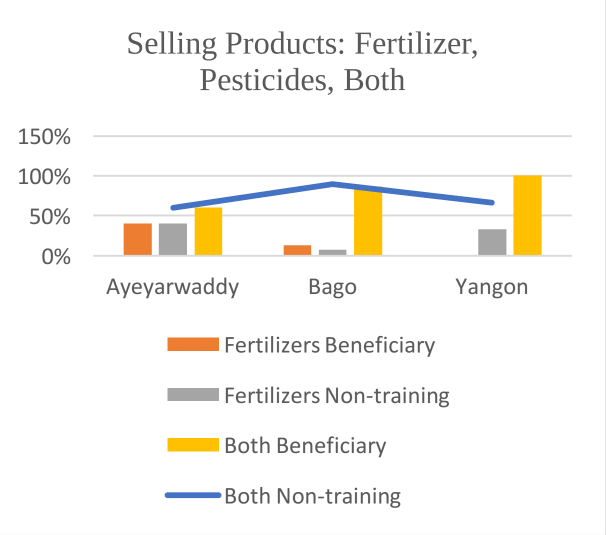

Figure 4. Selling products.

Then we studied the supply chain, such as wholesale, retail, or both, between beneficiaries and non-training retailers. No wholesale was found in both the beneficiaries and non-training groups in Ayeyarwady and in Yangon. We did not see non-training as wholesale but 6.7% of beneficiaries run wholesale in Bago.

When we analyzed the products sold, like fertilizers, pesticides or both, between the beneficiaries and non-training groups, both were selling 40% only fertilizer and 60% were selling both fertilizers and pesticides. No results were found of retailers selling only pesticides in the project regions. In Bago, 13.3% of beneficiaries and 7.1% of the non-training group sold fertilizer and 86.7% of beneficiaries and 89.7% of the non-training group sold both fertilizer and pesticide. In Yangon, 100% of beneficiaries and 66.7% of non-training group sold both fertilizer and pesticide, but 33.3% of the non-training group sold only fertilizer.

(1) Understanding of Costs Analysis

No beneficiaries understood the costs analysis in the project regions before training. Eighty percent of the non-training group in Ayeyarwady, 78.6% in Bago and 100% in Yangon did not know. Twenty percent of the non-training group in Ayeyarwady and 21.4% of non-training group in Bago confirmed they knew. However, we found none of the non-training group had an understanding of the role of fixed costs and variable costs in their businesses.

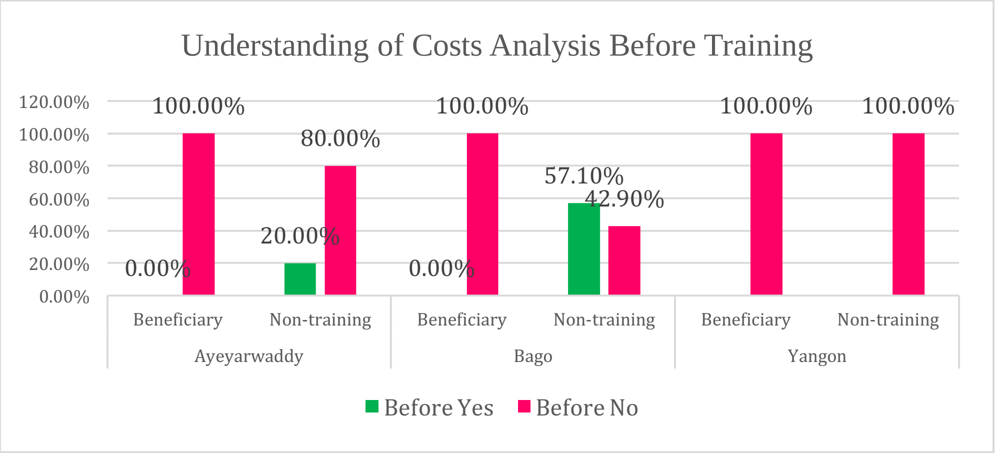

Figure 5. Understanding of costs analysis.

(2) Change the Recordkeeping After Training (Only Beneficiaries)

In the project regions, 20% of beneficiaries in Ayeyarwady, 6.7% in Bago, and 50% in Yangon have already changed their recordkeeping. Eighty percent of beneficiaries in Ayeyarwady and Bago and 50% in Yangon are still in the process of changing their recordkeeping at their shops. However, 13.3% of beneficiaries in Bago were unchanged. A beneficiary said he was working for seed production in his farmlands after returning from training.

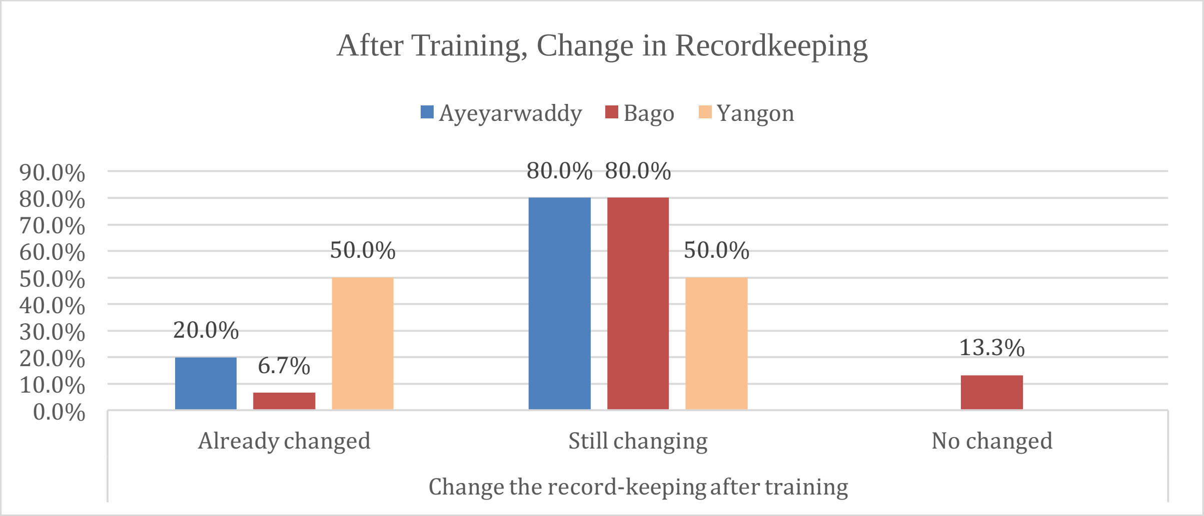

Figure 6. Change in recordkeeping after training.

(3) The Status Of Market Share

FSI sees the retail outlets in townships and villages tracts as the final point in the supply chain from port to farm. The market share increased on average by 13.64 villages and 170.13 farmers after receiving training in the project regions. After training, beneficiaries provide better quality products and services to farmers, and their market is increasing. Also, they have made the business records and can give the actual data when we conducted survey.

(4) Understanding of Net Profit

Beneficiaries calculated the net profit after deduction of all costs including fixed costs while those not trained did not. Regarding the understanding of costs analysis, 80% of the non-training group in Ayeyarwady, 78.6% in Bago, and 100% in Yangon did not know about the fixed costs. As a result, all of the control group overestimated their net profit.

(5) Managing Stocks with Records

One-hundred percent of beneficiaries in Ayeyarwady and Yangon, and 93.3% in Bago are keeping good records after the training. In contrast, we found only 40% of non-training retailers in Aywyarwaddy, 57.1% in Bago, and 33.3% in Yangon are keeping good records.

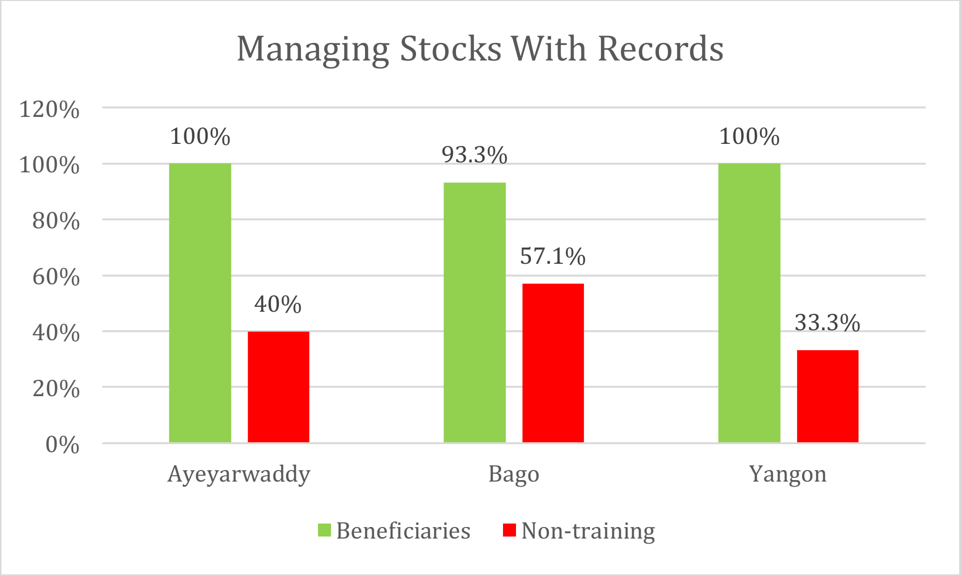

Figure 7. Keeping stocks with records in good order.

(6) Understanding of Five Golden Rules (Wearing Personal Protective Equipment)

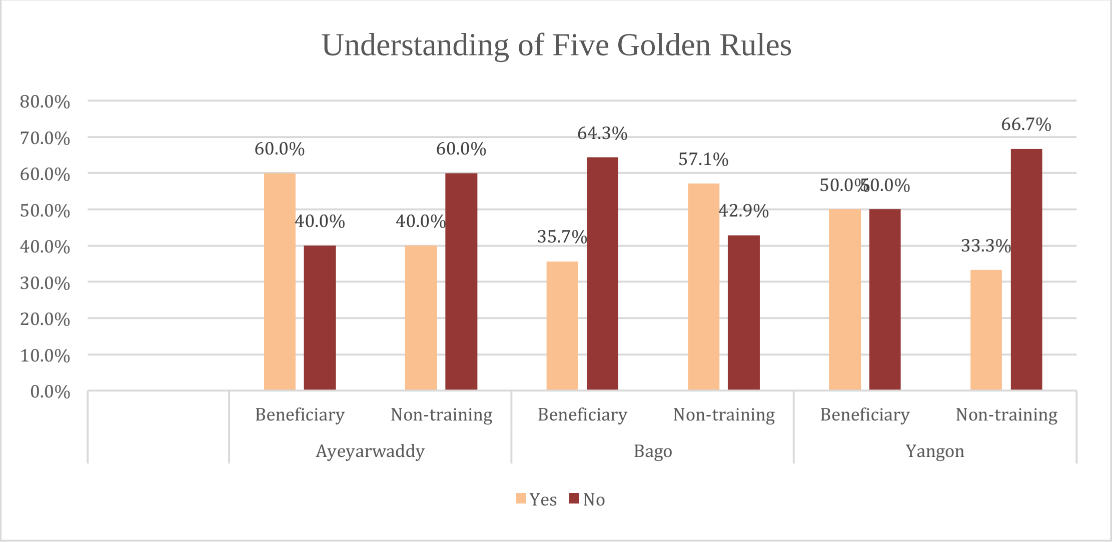

Figure 8. Understanding of five golden rules.

We asked what dealers understood about wearing Personal Protective Equipment (PPE) dress when handling pesticide-related products in the project regions. Forty percent of beneficiaries and 60% of the non-training retailers in Ayeyarwady, 64.3% of beneficiaries and 42.9% of non-training retailers in Bago and 50% of the beneficiaries and 66.7% of non-training retailers in Yangon did not know these rules before the training. After the training, the beneficiaries reported knowing all the right ways to use pesticides.

(7) Sharing Five Golden Rules with Farmers

After understanding the five golden rules, those sampled were counted in five categories as those sharing with 1-10 farmers, 11-20, 21-30, 31-40, and 41-50. Forty percent in Ayeyarwady, 35.7% in Bago, and 50% in Yangon reported they have shared the five golden rules with 41-50 farmers after training.

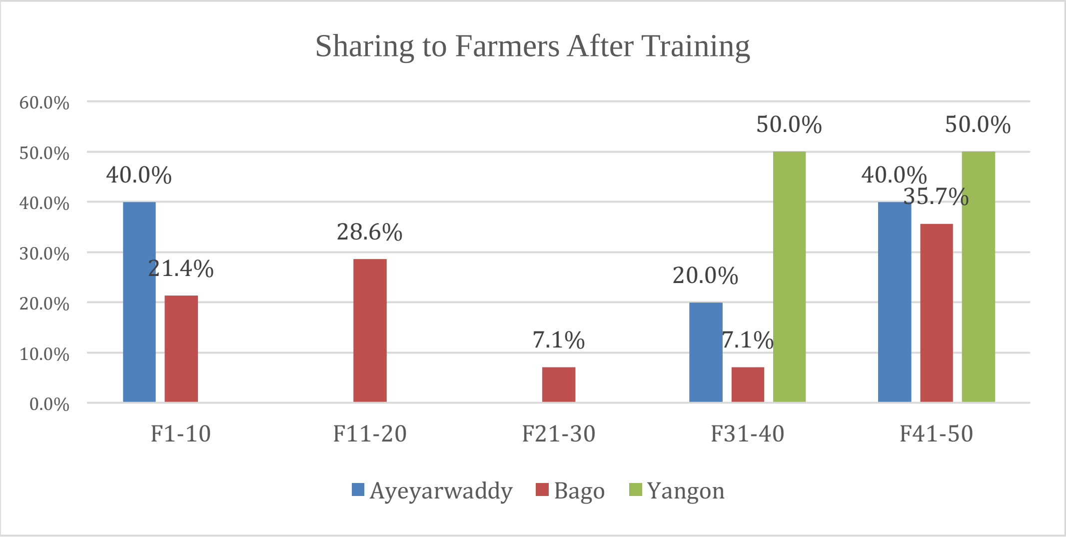

Figure 9. Sharing five golden rules to farmers after training.

Southern Shan Analysis

When we conducted the survey, 37.0% of beneficiaries and 44.4% of non-training retailers were selling fertilizer and 14.8% of beneficiaries and 5.6% of non-training reported they were selling pesticides. Both fertilizer and pesticides were sold by 48.1% of beneficiaries and 50.0% of the non-training retailers. Gender ratios are seen in the fibure below.

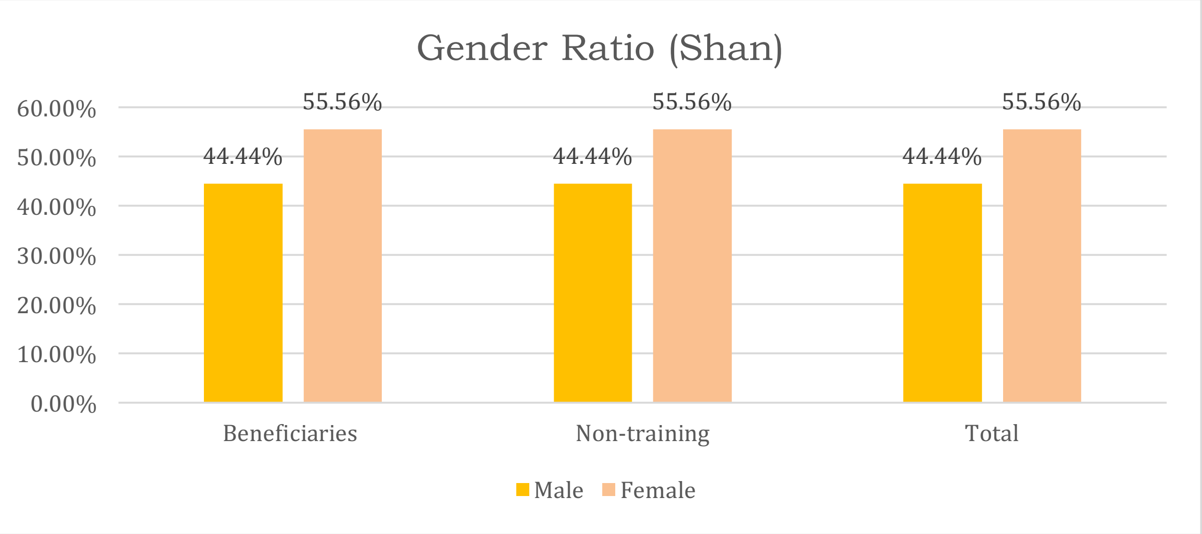

Figure 10. Shan gender ratio.

Comparing the type of business of the beneficiaries and the non-training retailers, 3.7% and 5.6% were wholesalers, 48.1% and 33.3% were retailers, and 48.1% and 61.1% reported being both wholesalers and retailers, respectively.

(1) Understanding of cost analysis

We found 18.5% of beneficiaries and 16.7% of the non-training retailers understood costs analysis. While 81.5% of beneficiaries confirmed they knew this after participating in the FSI training. On the other hand, 83.3% of the non-training retailers did not know about costs analysis and they said they would come to future trainings to learn about it.

(2) Change in Recordkeeping After Training (Only Beneficiaries)

Regarding improving recordkeeping, 7.4% of beneficiaries have already changed the basic accounting format, 88.9% are in the process of transformation, and 3.7% have not changed.

(3) The Status of Market Share

Today, agro-input shops are operating in a very competitive market, and it is gradually increasing within each of the townships. Generally, farmers have little knowledge of the best agricultural practices, and this is where the competitive edge is possible – offering technical advice on their products at the time of sale. For beneficiaries, there was an increase of 2.22 villages and 92.96 farmer customers after training in Shan. For non-training retailers, they did not have records and could not respond to the question yet. Generally, farmers are aware of product brand but have little knowledge of the best agricultural practices and can't select a suitable product for themselves. In this situation, the retailers need to know about their products, so they can advise farmers according to the right product for the right crop with the right price.

(4) Understanding of Net Profit

As mentioned above, non-training retailers did not know the fixed costs performance in their business. Only beneficiaries calculated the net profit after deduction of all costs including fixed costs. As a result, all of the control group overestimated their net profit.

(5) Managing Stocks with Records

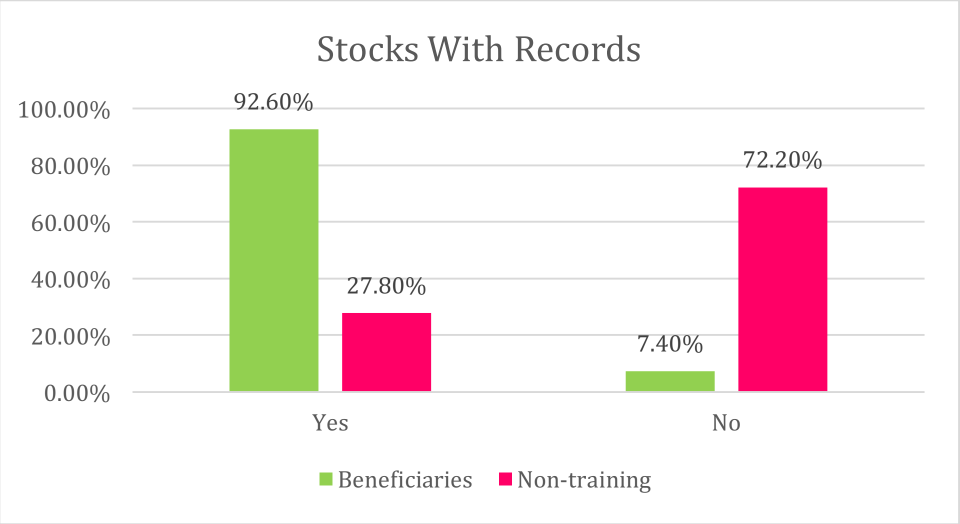

Figure 11. Stocks with records after training.

Regarding managing stocks, 92.6% of beneficiaries and 27.8% of non-training retailers keep their stock in good order using records. Non-training retailers (72.2%) did not know how to manage stocks.

(6) Understanding of Five Golden Rules

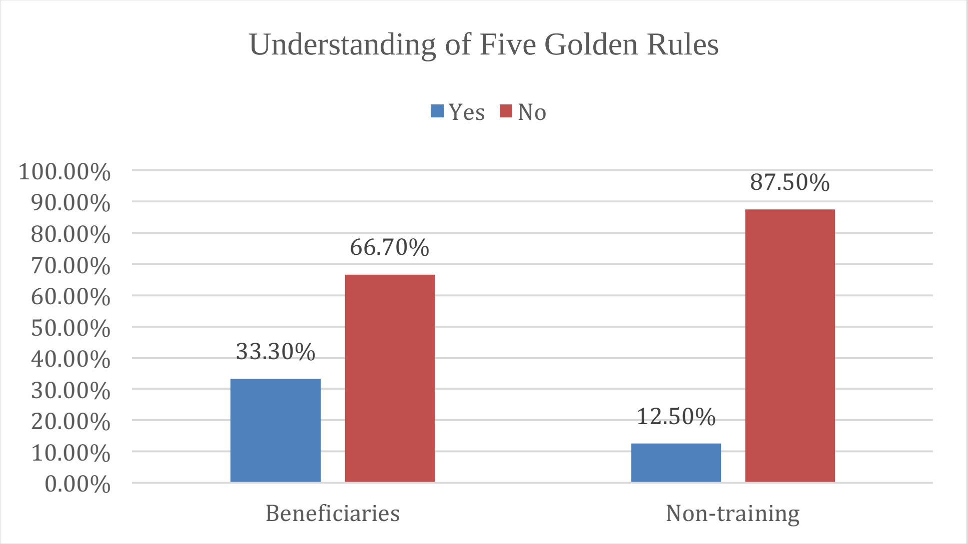

Figure 12. Understanding of five golden rules.

Before training, 66.7% of beneficiaries confirmed not knowing about the five golden rules (wearing PPE dress systematically). Apart from this, 87.5% of the non-training retailers did not know this as well.

(7) Sharing Five Golden Rules with Farmers (Only Beneficiaries)

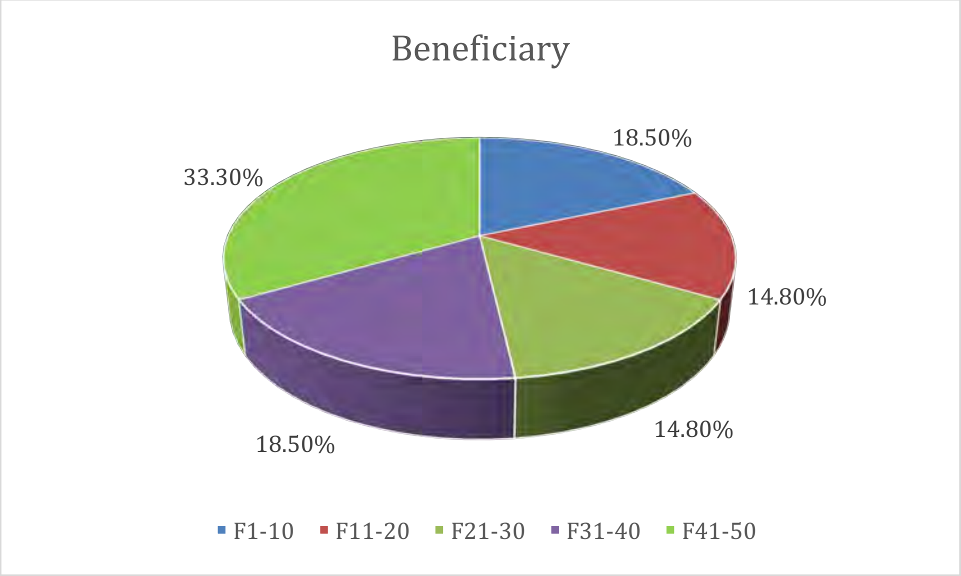

Figure 13. Sharing five golden rules after training.

After having training, 18.5% of beneficiaries shared the five golden rules with 1-10 farmers, and 14.8% of beneficiaries shared this with 11-20 farmers and with 21-30 farmers. Also, 18.5% of beneficiaries confirmed they shared this with 31-40 farmers. As shown above, 33.3% of beneficiaries shared their knowledge with 41-50 farmers.

Conclusion

This survey indicated that agro-input dealers are running under traditional practices in doing business and they did not know where or how to learn about business development before coming to the FSI retailer training. In fact, the agro-input product suppliers are the same for all shops. So, product features are the same and prices are also very competitive. Increasingly in a number of shops, they lack knowledge in differentiating between one product and another and do not know how to deliver their services. Services are an intangible product that offers prospects for a specific, superior result. It makes the customers walk away feeling good about their purchase. They realized more competition in the marketplace year over year but they are also working as usual in the daily routine, not having a business plan for long-term growth, not knowing how to sustain their business over competitors, and not understanding how to expand business as well.

In this situation, IFDC encourages retailers to offer customers a value on top of straight product purchase. Service marketing often requires more explanation as why the customer needs the products and how they works. IFDC plans to train 180 dealers in the FSI regions (Yangon, Bago and Ayeyarwady), 55 dealers in six Dry Zone townships, and 300 dealers in Southern Shan over three to five years.

If dealers can use their advisory services to add value to product sales, then they will achieve a competitive edge. They can become a one-stop shop for products and advice. After having the IFDC training, participating retailers could see the window of opportunity for their business sustainability and could begin to control the competitive market in their region. To be able to increase market share or experience business expansion, their recordkeeping systems can give them the required information needed to support them making not only informed decisions but also accurate decisions for their businesses' future growth in the competitive marketplace. Due to now knowing their fixed costs, businesses can accurately calculate their net profits for each growing season and, thus, they can be well-positioned for planning for future growing seasons. All trainees said this program has benefited their business and has helped position them better for the future.

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Sensor Technology for Soil Testing to Provide Fertilizer Recommendations for Smallholder Farmers in Myanmar

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Abstract

Fertile agricultural land is the lifeblood of every farmer. But farmers in developing countries often lack knowledge about the precious soil in which they grow their crops. Soil fertility decline is one of the most persistent causes of soil degradation worldwide. Continuous extraction of nutrients from the soil is a precursor to a downward spiral resulting in loss of soil organic matter, lower yields, and ultimately degraded, unproductive soils. Preventing soil fertility loss by adequate soil nutrient replenishment is important, and good techniques for calculating soil nutrient requirements do exist and are implemented as standard practice in many countries of the world. However, these methods are often not affordable for smallholder farmers and not aligned to local conditions. This can lead to, for example, recommendations of fertilizers that are not available or recommendations that do not sufficiently consider the local practice. Consequently, adoption rates of fertilizer recommendations are often very low and the benefits of the testing are not reflected in increases in yield.

SoilCares has developed soil scanning technology:

1. In the form of a portable, easy-to-use, rapid soil scanner that is transportable and, as such, can be taken into the field to develop on-the-spot, customized nitrogen (N), phosphorus (P), and potassium (K) fertilizer recommendations aligned to local conditions and farmer preferences.
2. As a Laboratory in a Box (LIAB), which is stationary technology but also significantly simpler than wet laboratory analysis. With this, farmers will be able to analyze soil and receive advice for not only N, P, and K fertilizers but also secondary nutrients such as calcium (Ca), sulfur (S), and magnesium (Mg), and a vast array of micronutrients, including iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn), and molybdenum (Mo).

To predict the soil status, the scanner compares its results to the unique Global Soil database. The database was developed and is being constantly updated by SoilCares' research team in the central laboratory in the Netherlands and follows a detailed, standardized procedure to ensure highly accurate results. The scanners will be introduced to the Myanmar market in the fourth quarter of 2017. With this paper, we will share our vision for the technology and consider the opportunities that exist to improve farmer yields.

Fertilizer Use by Upland Farmers in the Magway Region of the Central Dry Zone of Myanmar

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Abstract

Fertiliser use in 142 upland fields was monitored as part of a benchmarking project in the 2016 monsoon season. The fields were either sown to groundnut or sesame, the major crops in the Magway Region of the Central Dry Zone of Myanmar

Nutrient inputs were from manures, applied pre-crop during the dry season, and inorganic fertilizers, applied at planting and during crop growth. Compound fertilizers were used in 50% of the individual in-crop fertilizer applications, while gypsum (23%) and urea (19%) were the other most commonly used fertilizer types. Triple superphosphate (TSP) and potassium (K) fertilizers were used in just 5% of fertilizer applications.

The total quantities of nutrients applied varied widely between farmers and crops. The median quantities of nutrients applied to groundnut crops were 39 (N), 12 (P), 20 (K), and 18 (S) kg/ha, with 19, 7, 10, and 11 kg/ha of this being supplied by inorganic fertilizers. For sesame, the median values were 49 (N), 12 (P), 17 (K), and 10 (S) kg/ha applied in total, with 26, 6, 10 and 0 kg/ha being supplied in inorganic fertilizers.

Most farmers used split applications of fertilizers, which is sensible in an environment with sandy soils and heavy monsoonal rainfall. However, 50-55% of fields have a proportion of P inputs applied later than 25 days after sowing (DAS), which may limit crop response, while 40% of sesame fields and 35% of groundnut fields have all N and S inputs, respectively, applied by 25 DAS, which may result in nutrient losses through leaching and deficiencies later in the growing season.

We suggest research and extension are needed to improve fertilizer management by farmers, specifically targeting nutrient requirements and losses, management of manure and inorganic nutrient inputs, and matching nutrient inputs to crop requirements at different growth stages.

Introduction

There is little detailed information on fertilizer use in Myanmar. The limited data that is available is often at a country scale, such as FAO data on fertilizer use per hectare of arable land, or qualitative data collected as part of a larger survey focusing on socioeconomic issues (e.g., LIFT, 2012; Gregory, 2015), where questions on rates and timing are not included. However, more detailed data is becoming available in some areas (Thwe, 2015) as a result of focused research projects. This paper is intended to contribute to this trend by publishing selected data on nutrient management from an ACIAR-funded project (SMCN/2011/047) in the Central Dry Zone. As part of this project, a large body of information on management practices, inputs, and yields were collected on ca. 160 fields in the Magway Region. However, this paper focuses on organic and mineral nutrient inputs and the types and timing of fertilizers used.

Methods

Benchmarking groups were established in four villages in the Magway township area in May 2016, with approximately 20 farming families involved in each village. Families were selected by local Department of Agriculture (DOA) extension staff and the village head to cover a range of farm sizes and levels of productivity, and to include farmers who are not normally contacted by extension services. Each family recorded management and input data for two fields. Data collection was overseen by local DOA extension staff in each village and collated after harvest.

Data recorded included mineral fertilizer type, rate, and timing, as well as the rate and type of manure or other organic matter inputs. Samples of manure were collected from five farmers in each village and analyzed to determine the range and average concentrations of nutrients present.

The prices of fertilizers from several fertilizer suppliers were recorded, and the values of compound fertilizers were calculated, based on the price of the individual nutrients in triple superphosphate (P), urea (N), gypsum (S), and potassium chloride (K).

Results

Results are shown as box and whisker plots, with the shaded box covering the 25 to 75 percentile range, and including the median line. The whiskers show the 10 and 90 percentile values of the data.

Manure was typically applied to fields during the dry season, between January and late April. The manure was mostly cow manure, but also included organic residues from the household, and possibly groundnut hulls and sesame residue. The manure was stored in a pile for up to 12 months as it accumulated, and was exposed to weather during this time. Some farmers also used goat or chicken manure, while others also used clay soil, ash, and other organic residues such as groundnut leaf and hulls.

Seventy-eight percent of sesame fields and 87% of groundnut fields received some manure. The median quantity applied was approximately 3,000 kg/ha, with 50% of the fields receiving between 1,650 and 5,000 kg/ha (Figure 1). The median concentration of P, K and S in the 20 manure samples was 0.20, 0.20, and 0.26%, respectively (Figure 2). There was considerable variation in these values with the 90 percentile concentration being approximately three times larger than the 10 percentile but, overall, half the samples were within 0.05 percentage units of the median value.

Nutrient inputs from manure were calculated using the median values for nutrient concentrations (Figure 2) and manure application rates for each field. The N content of manure was assumed to be 0.57%, based on previous research (Win, 2008). The median value of nutrient inputs to fields from manure was 19, 6.2, 6.9, and 7.4 kg/ha for N, P, K, and S, respectively (Figure 3).

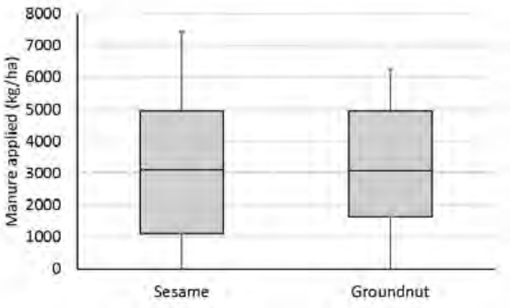


Figure 1. Manure use in sesame and groundnut crops.

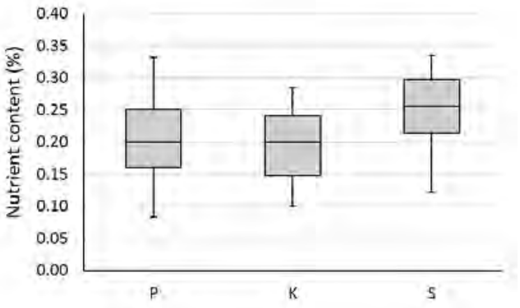


Figure 2. Nutrient content of manure samples from four villages.

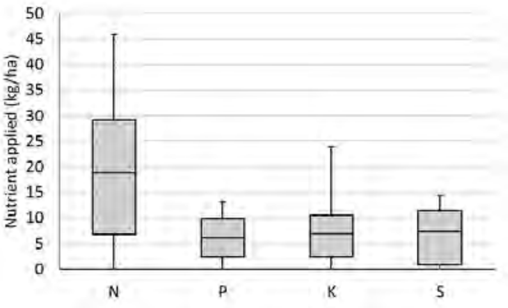


Figure 3. Nutrient inputs from manure.

Inorganic fertilizer use typically involved one to three applications, with the first at planting, then the remaining two to three applications during the 35 days after planting. Some of the later applications were mixtures of compound fertilizer and urea or gypsum, or gypsum and urea. Where two fertilizers were applied together, this was counted as two applications in Table 1.

Fertiliser use was dominated by compound fertilizers (Table 1), with 50% of the applications being one of the many compound fertilizers available from suppliers. Gypsum and urea made up the majority of the remaining applications, while triple superphosphate and potassium fertilizer use was minimal.

Table 1. Frequency of use of fertilizer types.

Fertiliser Type	% of Applications
Compound	50.2
Urea	19.2
Gypsum	23.1
TSP	2.6
Potash	2.4
Other	2.4
Total no. of applications	536

Nutrient inputs for the 80 sesame fields are shown in Figure 4. The median inputs from fertilizer were 26, 5.8, 10.2, and 0.0 kg/ha for N, P, K, and S, respectively (Figure 4a), with approximately 70% of the fields receiving no S from fertilizers. The median values for total nutrient inputs from manure and fertilizer were 49, 12, 17, and 10 kg/ha for N, P, K, and S (Figure 4b). For the median field, manure supplied approximately 50% of the total N and P inputs, 40% of the K, and 100% of the S.

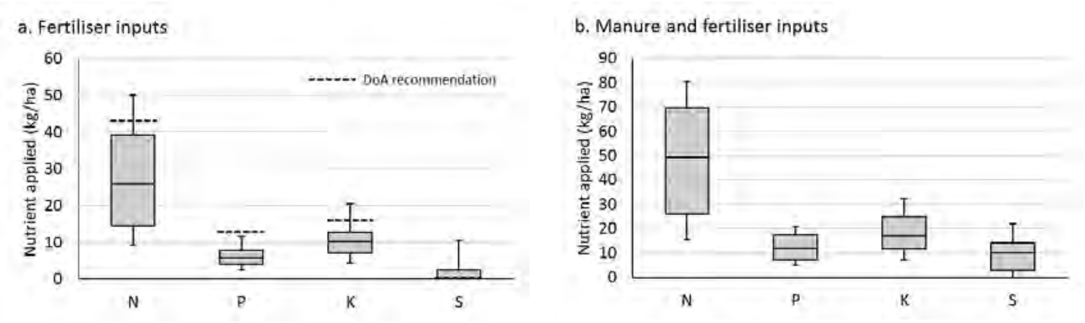


Figure 4. Nutrient inputs for sesame crops. The Department of Agriculture (DOA)-recommended fertilizer inputs are shown as dotted horizontal lines.

Nutrient inputs to the 63 groundnut fields were similar to sesame for P and K, but with more S and less N applied as fertilizer. The median quantities of nutrients from inorganic fertilizers were 19, 6.7, 10, and 11 kg/ha of N, P, K, and S, while total inputs were 39, 12, 20, and 18 kg/ha of N, P, K, and S, respectively (Figure 5). The median nutrient inputs from manure contributed 53% of total inputs for N, 43% for P, 49% for K, and 40% for S.

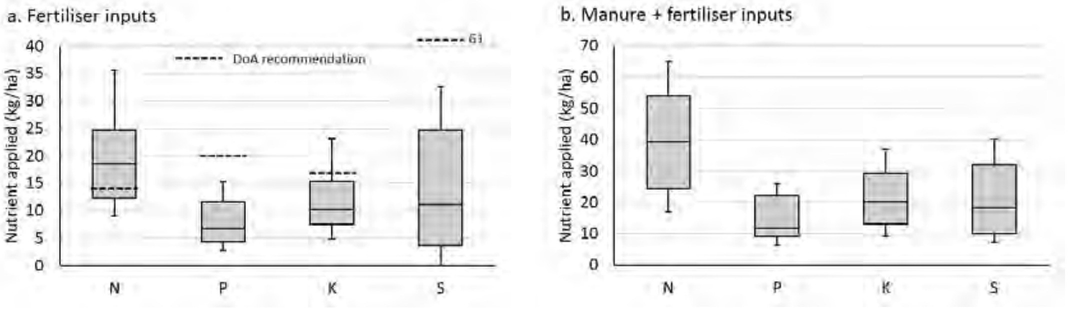
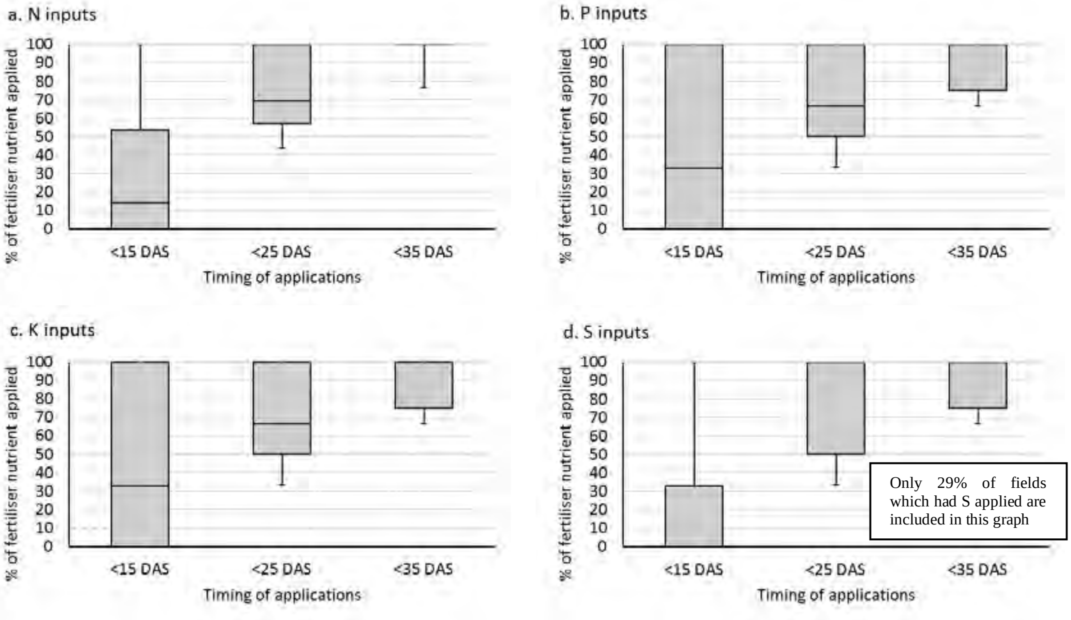


Figure 5. ***Nutrient inputs for groundnut crops. The Department of Agriculture (DOA)-recommended fertilizer inputs are shown as dotted horizontal lines.***

The timing of nutrient applications to crops, i.e., the proportion of each nutrient applied to fields before 15, 25, and 35 days after sowing (DAS), is shown in Figure 6 and Figure 7. Only fields which were fertilized with that nutrient were included, and all fertilizer applications were completed by 45 DAS.

Nitrogen application in sesame was concentrated in the early stages of crop growth, with 50% of fields having more than 70% of the N fertilizer applied by 25 DAS, and 75% having applied all N inputs by 35 DAS (Figure 6a). Phosphorus application was extremely variable at 15 DAS, with 25% of fields receiving no P fertilizer and another 25% receiving all of their P, with the median value being 33% of P applied by 15 DAS (Figure 6b). Phosphorus applications continued until much later in many fields, with 28% of fields still receiving P from compound fertilizers after 35 DAS. The timing of S applications only includes the 29% of fields that had S fertilizers applied. Half of these fields had all S inputs applied before 25 DAS (Figure 6d).



Only 29% of fields which had S applied are included in this graph

Figure 6. ***Timing of nutrient inputs from inorganic fertilizers for sesame crops. DAS = days after sowing.***

The timing of nutrient applications to groundnut crops was similar to sesame crops, although there was slightly less P applied early, with the median value of only 25% of P fertilizer having been applied by 15 DAS. Also, only 10% of fields had received all of their P inputs by this time, and 25% had received no P inputs (Figure 7b). Relatively little S was applied early (<15 DAS) in most fields, but 85% of S inputs were then applied before 35 DAS in the median field (Figure 7d).

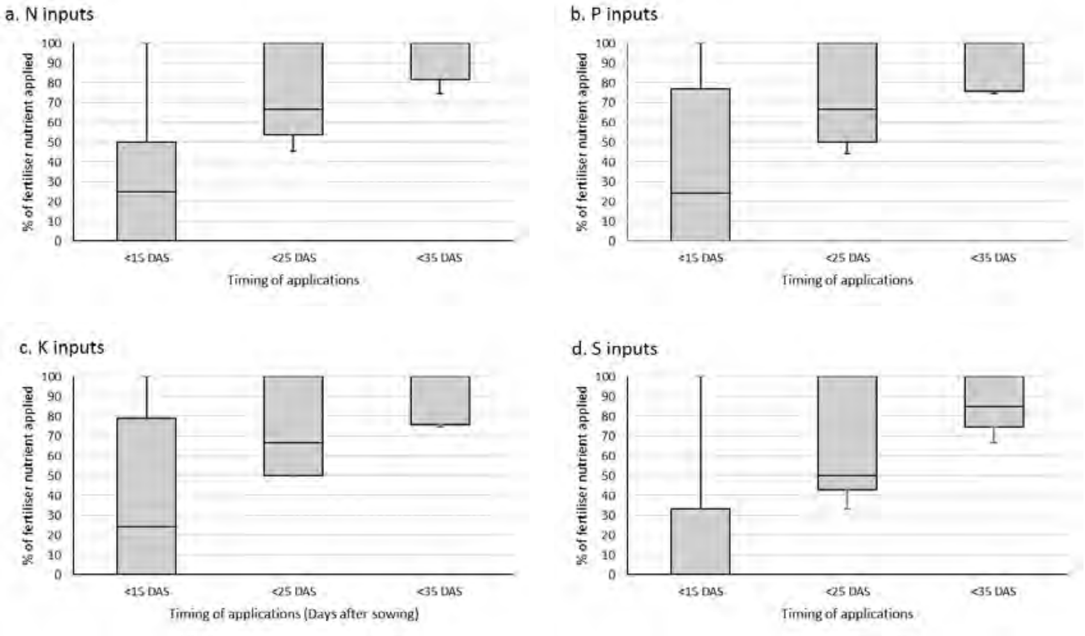


Figure 7. Timing of nutrient inputs from inorganic fertilizers for groundnut crops. DAS = days after sowing.

The price and calculated value of a number of compound fertilizers are shown in Table 2. Most of the compound fertilizers are priced between 1.4 and 2 times the value of the nutrients that they contain, with the nutrient costs calculated from TSP, urea, gypsum, and KCl fertilizer prices in July 2016.

Table 2. Value and cost of compound fertilizers.

Fertiliser	Price	Value	Price/Value
	Myanmar Kyat		
15:15:15:7	37,500	23,863	1.6
16:16:8:13	35,500	25,910	1.4
10:10:5:0	17,000	10,913	1.6
15:9:8:6	20,000	17,795	1.1
15:15:15:0	38,000	19,313	2.0

Value of fertilizers is based on average prices for 50-kg bags of TSP – 20,000 MMK, Urea – 20,700 MMK, Gypsum – 11,700 MMK, KCl – 23,500 MMK.

Discussion

The data show that both manure and inorganic fertilizers are important for groundnut and sesame nutrition, with manure supplying ca. 50% of nutrient inputs.

Manure is a low-cost fertilizer if the farmer has their own supply, and it has sustainability benefits in the recycling of nutrients and organic matter to fields following removal of crop residues for feeding to draught animals. The slow release of nutrients from manure may also be important for sustained nutrient supply during crop growth, given the high potential for leaching in sandy soils and heavy monsoon rainfall (Sitthaphanit et al., 2009).

Inorganic fertilizers supply the remaining 50% of the nutrient inputs in these systems, with a large proportion applied as compound fertilizers. While compound fertilizers are convenient farmers in supplying several nutrients at once, they may not contain the correct mixture of nutrients for a given crop growth stage. In particular, although N, P, and K are generally present, many compound fertilizers have low S content and will not supply the crop requirements for this nutrient. This issue may be of particular importance in sesame crops where there is very little use of gypsum. Sulfur is a critical element for sesame and oilseed crops in general (Singh, 1999).

In addition to the potential problems with compound fertilizers, the higher prices charged for many formulations/brands compared to the value of the nutrients contained (Table 2) suggest that farmers should be carefully looking at which types and brands they use. Increasing the use of single element fertilizers, such as TSP, urea, potash, and gypsum, would reduce fertilizer costs and allow the strategic application of specific nutrients.

The rates of nutrients applied to crops, along with the Myanmar Department of Agriculture recommendations, are shown in Figures 4a and 5a. The median quantities in these figures are all less than the recommended quantities. The only exceptions are manure rates, which are generally higher than the DOA-recommended 1,500-3,000 kg/ha, and N applied to groundnut, which is approximately 5 kg/ha, or 30% higher.

The timing of P application to crops varied substantially, from 10-25% of fields where all P is applied at sowing, to 50% of fields where one-third of the P is applied after 25 DAS (Figure 6b and 7b). Phosphorus is normally recommended to be applied at sowing so that it is close to the roots and immediately available to the developing seedling (Bolland and Gilkes, 1998). However, in similarly sandy soils in monsoonal Thailand, Sitthaphanit et al. (2009) found that split application of P maintained soil solution levels in the 0-30 cm layer at a higher concentration compared to a single basal application, and reduced leaching losses. While we don’t suggest the best timing for P applications, the diverse timing of applications by the Magway farmers shows that there will be a proportion of farmers who could change the timing of their P applications to improve fertilizer management.

Nitrogen and S applications occurred from sowing through to more than 35 DAS across the 143 fields. However, this broad range hides details which may contribute to low yields in many fields. In sesame, more than 70% of the N was applied by 25 DAS in the median field, and 100% was applied in 75% of fields by 35 DAS. Sitthaphanit et al. (2009) found that the split application of fertilizers, i.e., at planting, 30 and 50 DAS, increased yields and nutrient uptake compared to the recommended practice of applying most fertilizer at sowing, and topdressing 75% of the N at 30 DAS. This result suggests that the current practice of applying most of N before 30 DAS may be limiting yields. The visual symptoms of N deficiency seen by the authors in many flowering sesame crops support this theory, suggesting that more N may be needed, and/or that a greater proportion should be applied at later growth stages. The DOA recommendation of applying two-thirds of the N inputs at sowing, and one-third at approximately 35 DAS may also need to be revised, based on this information.

Similar observations apply to S in groundnut, where all the S inputs were applied to 25% of fields by 25 DAS, and 85% were applied to half of the fields by 35 DAS. Sulfate will leach readily in sandy soils under high rainfall conditions, so split applications with later timing should produce similar results to that seen with N in Sitthaphanit et al. (2009). Again, visual symptoms of S deficiency in many groundnut crops seen by the authors suggest that more S may be needed, and at later growth stages. The DOA recommendation of applying approximately 300 kg/ha of gypsum (60 kg/ha S) at 30-35 DAS is likely to be intended to supply calcium at the critical pegging stage as this nutrient is important in pod and seed development (Walker, 1975). However, the application of this much S is likely to be sufficient for crop uptake for the rest of the season.

The situation with S is more extreme in sesame, where 70% of fields received no S fertilizer at all. Half of the remaining fields had received all S inputs by 25 DAS, increasing the potential for loss by leaching. Sulfur is a critical nutrient in oilseed crops (Singh, 1999), so this low level of inputs, especially with early applications potentially lost to leaching, could be a major limitation to sesame productivity in this area. This information suggests that the DOA recommendation of not supplying S to sesame crops should be revised.

We suggest an increased focus on research and extension is needed to improve fertilizer management by farmers, targeting the nutrient requirements of groundnut and sesame, and particularly the timing of split applications of fertilizer to reduce leaching losses and to match crop uptake patterns. The limitations of using compound fertilizers extensively, and the advantages of using alternative, i.e., single nutrient, products for supplying nutrients, should also be a high priority for extension to farmers and fertilizer suppliers.

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Session 3.
Environmental Impacts and the Role of Fertilizers in Promoting Crop Resilience

Role of Nuclear and Isotopic Techniques in Climate Change Adaptation and Mitigation

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Abstract

Agriculture needs to produce more to feed the growing population. However, the frequent occurrence of extreme weather events and an increased unpredictability of weather patterns are having major detrimental effects on agriculture and food security. Nuclear and isotopic techniques can offer unique roles and tools for measuring the impact of climate change. They can make important contributions in improving water and fertilizer use efficiencies, tackling environmental challenges such as land degradation, soil erosion, and pollution as well as deteriorating water quality, which can help agriculture to adapt and improve the resilience of food production systems.

Introduction

Climate change and the expansion and intensification of agricultural systems in response to the ever-increasing demand for food have major impacts on the deterioration of soil and water resources, affecting crop production, food security, and sustainable development. Land degradation, salinity, flooding, water scarcity, and pollution are worldwide threats affecting billion of hectares globally. Currently, some 6-7 million ha of land are lost annually through soil erosion, while desertification affects about one-sixth of the world’s population and one-quarter of the world’s land (Bullock, 2005). Similarly, salinization affects some 20 million ha of irrigated land; it is one of the main causes of soil degradation threatening some of the most productive lands (FAO, 2011) in the world, affecting 11% of global irrigated land. Agricultural pollution is a major issue and has negative impacts on human health, biodiversity, and fisheries due to overuse and misuse of agro-chemicals (organic and inorganic fertilizers, pesticides, and sediments). It is the main source of pollution in rivers and streams the United States of America (U.S. EPA, 2016) and also is responsible for a large share of surface water and groundwater pollution in China (Mateo-Sagasta and Burke, 2010).

Materials and Methods

Nuclear and isotopic techniques can make an important contribution to tackling serious agricultural and environmental challenges, such as desertification, soil erosion, pollution, and deteriorating water quality (Zapata et al., 2015).

Results and Discussion

To ensure sustainable agricultural management, there is a need to quantify the magnitude of soil erosion and determine the sources of erosion. This can be measured using fallout radionuclides (FRNs) and compound-specific stable isotopes (CSSIs) (Gibbs, 2008; Upadhayay et al., 2017). The FRNs used in erosion studies are caesium-137 (^{137}Cs), an artificial radionuclide developed during nuclear weapon testing in the 1950s and 1960s, while lead-210 (^{210}Pb) is a geogenic radioisotope and beryllium-7 (^{7}Be) is a cosmogenic radioisotope (Mabit et al., 2008; IAEA, 2014). Once these radionuclides, either anthropogenic or naturally occurring, fall on the soil surface through rainfall or dry deposition, they are strongly fixed by soil particles and not taken up by plants. During erosion and deposition processes, these FRNs move with soil particles and can be used to trace the origin of soil over a large area and over a short period of time. Due to their different half-lives, they are used to assess medium- and short-term soil erosion and deposition processes (Mabit et al., 2008).

On the other hand, the CSSI technique is used to identify sources of soils in sediments (fingerprints), apportioning their relative contribution from different land uses. The CSSI technique is based on the measurement of carbon-13 (δ^{13}C) natural abundance signatures of specific organic compounds, such as natural fatty acids (FAs), in the soil. When coupled with an isotopic mixing model, the contribution of different sources of erosion to downstream sediments can be determined. Such an integrated approach helps to identify critical areas of soil loss and the source of eroded soil and thereby determine areas prone to soil degradation and sedimentation, so that management practices can be devised with targeted appropriate soil conservation measures, thus providing effective guidelines for area-wide sustainable management of land and water resources in agroecosystems (FAO/IAEA, 2008).

Low soil fertility and nutrient mining exacerbate existing food insecurity and vulnerability problems and are serious threats to the production of major world food crops. It is estimated that millions of hectares of land are devastated by drought, salinity, and nutrient deficiencies brought about by long-term nutrient mining and climate change and variability. There is, therefore, a need to increase the resilience of current food production systems to soils with low fertility and to the impacts of climate change and variability. Nitrogen (N) is an important nutrient for global agricultural production that can be derived from applied N fertilizers, soil organic matter, and biological nitrogen fixation (BNF) by legumes. To maximize its use, the nitrogen-15 (^{15}N) isotopic technique can be used to quantify fertilizer N use efficiency (Ladha et al., 2005), estimate N fixed through BNF (Chalk, 1985; Chalk and Ladha, 1999) to sustain yields, and improve soil fertility. Similarly, carbon-13 (^{13}C) can be used to assess plant C and N changes under a conservation agriculture system. Using these technologies, it is possible to bring about solutions and hope to farmers in areas that are vulnerable to soil fertility and environmental stressors.

The nitrogen-15 isotopic technique can also be used to trace the sources and extent of nitrous oxide greenhouse gas emissions. More than 24% of greenhouse gases are emitted by agricultural practices, and they continue to increase due to inappropriate changes in land use, excessive use of chemical fertilizer, increasing numbers of ruminants, and deforestation. Of these gases, nitrous oxide is 300 times more powerful than carbon dioxide in causing global warming (IPCC, 2007) and stays in the atmosphere for more than 120 years. Microbial processes in the soil convert nitrogen fertilizers and animal manure into nitrous oxide, which is then emitted into the atmosphere. By knowing the origin and amount of the emission – information pivotal in global efforts to reduce these gases, it is then possible to develop sustainable climate-smart agricultural practices to minimize this emission.

Agriculture is also the major cause of water quality and environmental issues, mainly from crop and livestock activities contributing to extensive diffuse pollution from nitrate, phosphorus, pesticides, soil sediment, salt, and pathogens. Often the contribution from these multiple sources is not well known, especially in developing countries. Stable isotopes have the potential to characterize and quantify sources and transport of pollutants in agroecosystems. Depending on the origin of the polluting source, the isotopic signature of each element could be unique, which can be applied to fingerprint the source. The stable isotope composition of hydrogen (H) and oxygen (O) can be used to assess the hydrological cycle in agroecosystems and evaluate evaporative losses and mixing of different water sources (Skrzypek et al., 2015). Similarly, the stable isotope composition of N and O in NO_3- carries a signature of the N source and can be used as a proxy for proportional contribution (Kendall and McDonnell, 1998). The stable isotope composition of oxygen in phosphate can also be used to understand the biogeochemical cycle and dynamics of phosphorus in the environment. Under particular circumstances (e.g., short residence time), the stable isotope composition of O in phosphate is retained and can pinpoint the source of pollution/contamination in the agroecosystem (Pistocchi et al., 2017).

Conclusion

A brief summary is provided on the use of nuclear and isotopic techniques, which can play important and unique roles in providing useful information and tools for defining and alleviating constraints to intensify and diversify farming systems while ensuring sustainable use and management of land and water resources. The knowledge provided by the techniques can also help to improve the response to extreme events related to agricultural production by resource-poor farmers and enhance their resilience toward the impact of climate change through climate-smart agricultural practices.

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Methane Emissions as Affected by Rice Genotypes under Different Water Management

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Abstract

Rice is one of the most important food crops in the world. However, rice paddy fields are considered one of the major sources of anthropogenic methane (CH_4) emissions. The objectives of this study were to (1) investigate the effect of different irrigation water management and different rice cultivars on methane emissions and (2) develop an effective environmentally friendly water management technology. A field experiment was conducted with two rice varieties (Shwethweyin and Yadanatoe) under two water regimes – continuous flooding (CF) and alternate wetting and drying (AWD) irrigation – at the Water Utilization Research Section, Department of Agricultural Research, Yezin, Naypyitaw, Myanmar. Gas samples for methane emissions measurements were collected using the closed-chamber method. The experiment assessed growth and yield of two varieties, Shwethweyin and Yadanartoe. Methane emissions showed an increasing trend with rice growth and peaked at panicle initiation to flowering stage. AWD irrigation reduced methane emission by 60-70% compared to continuous flooding while saving irrigation water by 25-30%, without significant yield loss as compared to farmer practices. Methane emission from the Yadanartoe rice genotype was higher than short duration of Shwethweyin rice. Results suggest that AWD irrigation mitigates methane emissions while saving water without any yield penalty compared to continuous flooding.

Key Words

CH_4 flux, water management, rice yield

Introduction

Rice is the major staple food in Asia, most of which is produced on irrigated lowland fields usually with high water requirements. Since irrigation water is becoming an increasingly scarce resource, alternative irrigation systems are needed. Besides high water consumption, the paddy rice production system is known for its contribution to global warming, because of the potential emissions of methane (CH_4) through the anaerobic soil condition in the flooded rice field.

Global warming is one of the severest challenges for humanity in this century. Carbon dioxide (CO_2) and CH_4 are the most important greenhouse gases (GHGs) for agriculture. CH_4 emission from paddy fields accounts for 11% of global CH_4 emissions (IPCC, 2014).

Methane is produced by methanogenic bacteria in the anaerobic layer of paddy soils and oxidized by methanotropic bacteria in the surface layer of submerged paddy soils. There are great spatial and temporal variations in methane emissions depending on soil, climate, temperature, water depth, and rice variety (biomass and growth duration).

Bouman (2001) mentioned that alternatives to continuous flooding have been developed with different objectives, such as to reduce the volume of water used and increase water use efficiency and to reduce toxicity effects of organic compounds and inorganic ions. Water management is often considered a good strategy to mitigate CH_4 emission from rice fields. Literature shows that AWD irrigation is one of the most effective options in decreasing CH_4 emissions from paddy fields. However, studies on CH_4 emissions measurements are at the preliminary stage in Myanmar. Therefore, it is needed to understand effects on CH_4 emissions by different irrigation management techniques and rice varieties. Therefore, this study was conducted to (1) investigate the effect of different irrigation and water management techniques and different rice cultivars on methane emissions and (2) develop an effective, environmental friendly water management technology.

Materials and Methods

Site Description

The experiment was established in the 2016-17 dry season at the Water Utilization Research Section of the Department of Agricultural Research, which is located in Yezin, Nay Pyi Taw, Myanmar (19° 38' N, 96° 50' E). The paddy field soil is a sandy loam soil and the soil properties of the experimental site (0-15 cm depth) are as follows: pH (7.1), organic matter (1.7%), available N (55.7 mg/kg), available P (15.0 mg/kg), and available K (83.9 mg/kg). Two water treatments were used – continuous flooding and alternate wetting and drying (AWD) irrigation. Two rice varieties, i.e., Shwethweyin and Yadanartoe, were grown under each water regime.

Collection and Analysis of Gas Samples

Three glass chambers were placed in one plot (1,128 ft^2). These glass chambers were placed randomly in the plot with a distance of 7 m. Six glass chambers were used to collect gas samples from each water treatment regime (two varieties). A total of 12 glass chambers were used in the study. Each glass chamber was equipped with a thermometer to record air temperature during gas sampling time.

A gas sample for CH_4 was collected from the chamber using a microliter syringe from 7 a.m. to 4 p.m. once a week. Samples were stored in the 50 mL pre-evacuated glass bottle. Air temperature was recorded during each gas sampling time. Air temperature was used for CH_4 flux calculation. Gas samples were measured for CH_4 concentration with a gas chromatograph (GC 2010 plus series, Japan), following a method of Li et al. (2012). The CH_4 flux was calculated based on linear changes in CH_4 concentration against chamber closure time using the following equation.

$$\text{Flux } CH_4 \text{ (mg m}^{-2}\text{ h}^{-1}) = \Delta c/\Delta t \text{ x } V/A \text{ x } p \text{ x } 273/273+T$$

Where, $\mathbf{\Delta c/\Delta t}$ is the concentration change over time (ppm-CH_4/min), **V** is chamber volume (m^3)**, A** is chamber area (m^2)**, p** is gas density (0.717 kg m^{-3} for CH_4), and **T** is the mean air temperature inside the chamber (°C).

Water Management

Flush irrigation was applied at a depth of 1 cm at sowing. Water depth was measured using a field water tube. During one week before and after the peak of the flowering stage, alternate wetting and drying (AWD_{25}) was suspended and water depth was maintained at 3-5 cm. Irrigation was applied again when the water level reached a 25-cm depth in the soil.

Plant Sampling and Analysis

Yield and yield component characteristics in the 2017 dry season were collected at three random positions in each plot using a 2 m x 3 m frame. The rice was threshed, and the grains were weighed and adjusted to 14% moisture content. Some of the parameters, such as yield, productive tillers, leaf area, leaf area index, SPAD meter reading, and harvest index, were collect from this experiment. CropStat (version 7.2) was used for statistical analysis, and treatment means were compared using the least significant difference (LSD) test at a 5% level of significance (Gomez and Gomez, 1984).

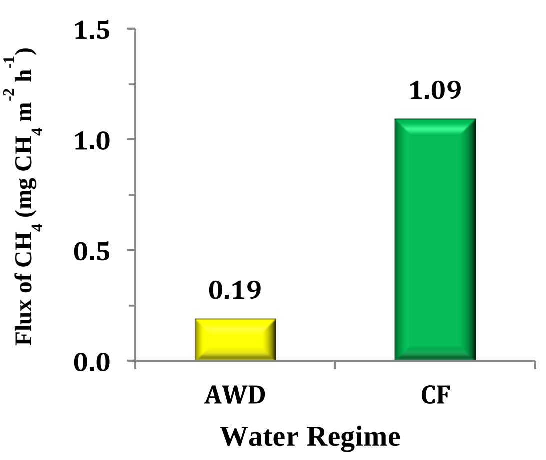
During the 10 days before harvest, no irrigation water was applied in any of the experimental plots to enable the rice plants to mature and soil to harden for harvesting.

Field Management

Missing hills were replanted within seven days after transplanting. Recommended fertilizer application was based on a fixed-time approach. Total fertilizer rates of 86.56 N kg/ha, 28.22 P_2O_5 kg/ha, and 37.64 K_2O kg/ha were applied. Potassium and phosphorus were applied basally at transplanting. N was applied in three split doses at early tillering, panicle initiation stage, and flowering stage. Occasional manual weeding was performed as required to keep the field area clean.

Results and Discussion

Results indicate that the implementation of AWD irrigation decreases the CH_4 emission rate by about 60-70% (Figure 1). These results are in line with previous studies, where the CH_4 emission from a flooded paddy field was 74% higher than a non-flooded paddy field (Lo et al., 2016). In this study, among the different varieties, CH_4 emission from the Yadanartoe rice variety was greater than for short-duration Shwethweyin (Figure 2).



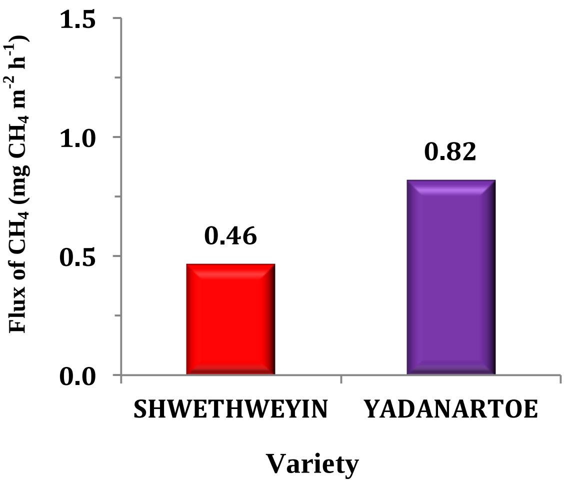
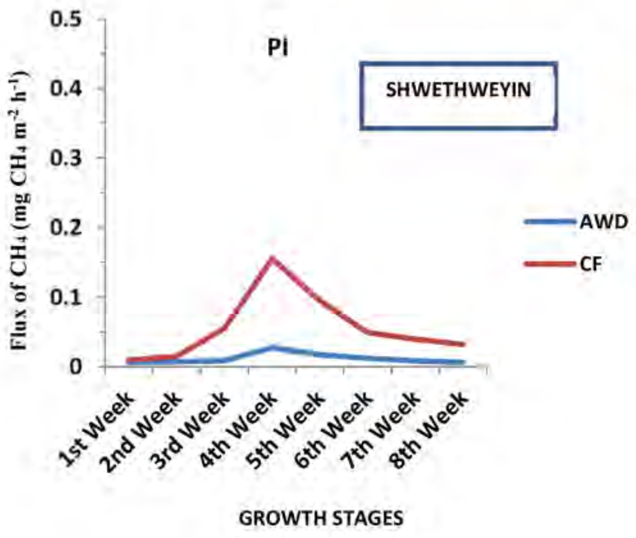


Figure 1. Methane flux in different water regimes.

Figure 2. Methane flux in different varieties.

Significant CH_4 fluxes were observed from one week to two weeks after rice transplanting. Thereafter, CH_4 emission rates showed an increasing trend and peaked at panicle initiation stage in Shwethweyin (Figure 3) and at flowering stage in Yadanartoe (Figure 4) under both irrigation regimes. The peak of the fluxes might be attributed to vigorous growth of rice roots, high air temperature, and the interaction of soil and water. Moreover, results mentioned that, when air temperature increased from time to time, within a day CH_4 emission increased significantly (Figure 5). All of the results agree with the Wassmann et al. (2000) report: increasing the temperature during the middle of the cropping season leads to highest emission during the reproductive stages.



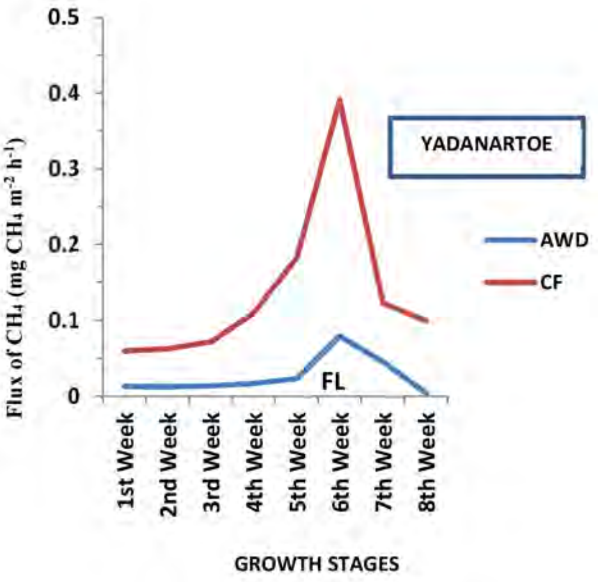


Figure 3. Observed and simulated CH_4 emission at growth stages.

Figure 4. Observed and simulated CH_4 emission at growth stages.

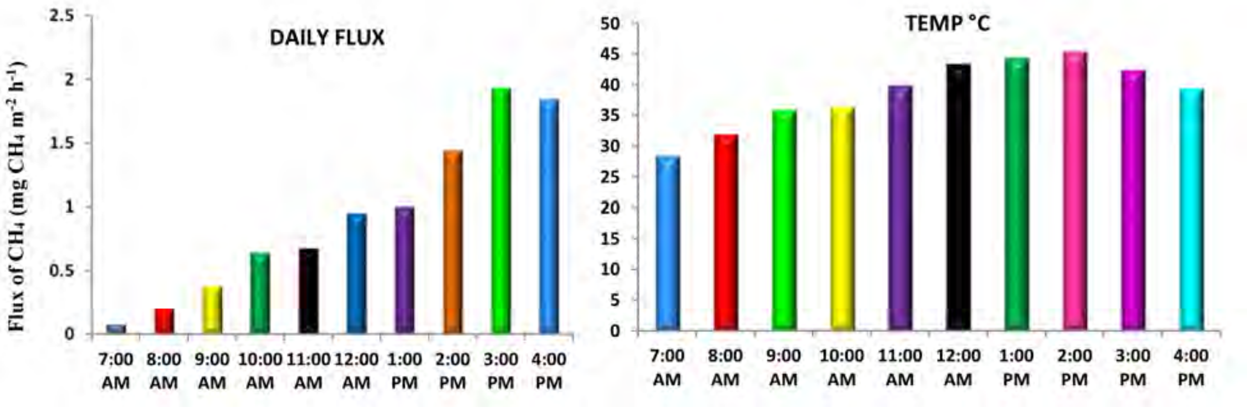


Figure 5. Methane flux for paddy field at different temperatures (°C).

Table 1 shows means of effective tillers, leaf area, leaf area index, and SPAD meter reading. There were no significant effects of water regimes on effective tillers, leaf area, leaf area index, and SPAD meter reading. No significant differences were observed in physiological traits, such as plant biomass weight, harvest index, water use efficiency, and yield on the influence of water regimes (Table 2). Results showed that total water use of farmer practice was significantly greater than AWD treatment, which saved water 25-30%.

Based on the findings, the practice of AWD would be an appropriate water-saving technique in terms of irrigation frequency and water productivity for pumping irrigated areas and Central Dry Zone areas.

Table 1. Means of effective tiller, leaf area, leaf area index, and SPAD reading as influenced by water regime.

No.	Character	Water Regime		F-test
		Continuous Flooding	Alternate Wetting and Drying	
1.	Effective Tillers	20.54	20.88	ns
2.	Leaf Area (cm^2)	2,354.55	2,194.34	ns
3.	Leaf Area Index	5.70	5.21	ns
4.	SPAD Meter Reading	39.82	39.22	ns

Table 2. Means of biomass weight, yield, harvest index, and water use efficiency as influenced by water regime.

No.	Character	Water Regime		F-test
		Continuous Flooding	Alternate Wetting and Drying	
1.	Biomass Weight (g)	59.46	63.88	ns
2.	Yield (bsk/ac)	121.54	119.78	ns
3.	Harvest Index	0.45	0.42	ns
4.	Water Use Efficiency (g/L)	1.09	1.40	ns
5.	Total Water Use (mm)	584.2	447.07	1%

Conclusion

Water-saving irrigation using the alternate wetting and drying technique not only saves irrigation water but also reduces methane emission without significant yield loss as compared to farmer practice. Methane emission from the farmer practice field was 60-70% higher than the water-saving paddy field. The conventional water irrigation method of the paddy field could contribute significantly to methane emission. Moreover, the amount of methane emission from the long duration rice genotype was higher than short-life rice genotypes. Compare to previous findings, methane emission from the paddy field in the pre-monsoon season was higher than that of monsoon rice because of high temperatures this season. In conclusion, further study on the combined impacts of different soil type and fertilizer materials on CH_4, CO_2 and N_2O emission as potential greenhouse gas) mitigation strategies is needed.

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Efficient Fertilizer and Water Management in Rice Cultivation for Food Security and Mitigating Greenhouse Gas Emissions

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Abstract

Increasing nitrogen fertilizer application has increased crop productivity and met the food demands of growing populations, but its use efficiency is very low. More than 50% of applied nitrogen is not utilized by crops, posing huge economic costs and environmental concerns. Therefore, fertilizer management should consider optimum source, rates, time, and methods of application (the “4Rs” of nutrient stewardship) to increase use efficiency, crop yield, soil health, and farm profits and to reduce negative environmental effects. Fertilizer deep placement (FDP) is one of the best currently applicable management techniques to achieve these multiple benefits. Multi-location experiments were conducted in Bangladesh to determine the effects of urea deep placement (UDP) and multi-nutrient fertilizer briquette (NPK) deep placement versus broadcast prilled urea (PU) on rice yields, nitrogen use efficiency, and nitrogen losses, including floodwater ammonium, ammonia volatilization, and nitrous oxide emissions. Deep placement of both urea and NPK briquettes in the dry (*Boro*) season increased grain yields. Across the years, the average observed yield increase was 30% compared to broadcast PU. Deep placement significantly reduced nitrogen losses compared to broadcast PU. Broadcast PU resulted in higher amounts of ammonium in floodwater and ammonia volatilization, both of which were negligible in deep-placed treatments. Moreover, UDP reduced nitrous oxide emissions by 70% as compared to broadcast PU. In Bangladesh, fertilizer briquettes are produced by micro-enterprises and applied manually in fields. This approach is effective in small-scale farming where household labor is sufficient for cultivation but requires modifications to work in larger scale farming systems where labor availability is an issue. Another issue relates to the non-availability of fertilizer briquettes throughout the country. Therefore, for large-scale dissemination in other rice-growing countries in Asia, including China and India where greater N use efficiency gains can be realized, government and/or private sector actors must work together to promote wide-scale adoption by farmers through industrial-level briquette production and mechanized on-farm application.

Introduction

Rice is the staple food of more than half of the world's population. More than 90% of the world's rice is grown in Asia, where one-half of the world's population and 80% of the world's poor are concentrated. In Bangladesh, one of the most climate-vulnerable nations (Climate Home, 2013), farmers intensively cultivate rice on 80% of agricultural lands. With the increasing population growth rate, it is estimated that the demand for rice will be 56% higher by 2050 than in 2001. Therefore, rice productivity should be increased to meet the food demand of a growing population, taking into account the dwindling amount of land area available for farming. This requires judicious use of agricultural inputs, including quality seeds and fertilizers, and water management, among other good agricultural practices.

Fertilizer use has played a crucial role in meeting the food demand of a growing world population. Among the fertilizers, nitrogen (N) fertilizer is the main driving force to produce large rice yields under irrigated and favorable rainfed conditions. However, N fertilizers are being used excessively in most countries in Asia, leading to imbalanced use of nutrients. Farmers usually apply urea as a broadcast method. Much research conducted across countries reported that more than 50% of applied nitrogen is not utilized by crops and lost to the environment as reactive forms (ammonia, nitrate, nitrogen oxides) through volatilization or surface water runoff, contributing to greenhouse gas emissions and other environmental problems, such as eutrophication and groundwater pollution (Savant and Stangel, 1990). The excessive use of fertilizers poses a huge environmental cost in addition to reduced farm profitability. Because of the rising costs of production, along with increasing input costs (including fertilizers), the quest for food security, and the need to mitigate environmental impacts, there is a need for more efficient and balanced use of plant nutrients. Thus, immediately applicable N use efficiency-enhancing measures are of paramount importance.

Over the past years, many research and development groups, including the International Fertilizer Development Center (IFDC), have worked on improving N use efficiency (NUE) through urea deep placement (UDP), urease inhibitors, and slow and controlled N fertilizers, such as polymer- and sulfur-coated fertilizers. Research conducted across different countries showed that fertilizer deep placement (FDP) could be one the best management techniques to achieve the multiple benefits of increasing grain yield, farm profits, and NUE while reducing negative environmental effects – in short, more yield with less fertilizer (IFDC, 2013). UDP in lowland rice fields, particularly under continuous flooding irrigation condition, has been widely recognized as an effective management practice that reduces fertilizer (urea) use by 25-40% and increases yield by an average of 15-20% (Savant and Stangel, 1990; Huda et al., 2016). Research conducted in Bangladesh has shown that UDP is equally effective under alternative wetting and drying (AWD) irrigation. Moreover, deep placement of compound fertilizer (NPK) briquettes was recently introduced in Bangladesh, supplying all three major nutrients in a compound briquette (Miah et al., 2016). Since many farmers do not practice balanced fertilization, deep placement of compound fertilizer briquettes offers the potential for higher yields and improves fertilizer use efficiency because of balanced use of nutrients and reduced nutrient losses.

The majority of the farmers in Bangladesh are small landholders (<2 ha). Therefore, FDP technology is being disseminated by the Government of Bangladesh, in partnership with IFDC, by developing micro-enterprise briquette producers. Each local entrepreneur who owns a briquetting machine – many of whom are fertilizer dealers – produces fertilizer briquettes amounting to approximately 1 mt per day. Farmers access fertilizer briquettes through retailer networks. Results across different districts in Bangladesh demonstrated the multiple benefits of FDP. FDP was found to reduce fertilizer use and increase crop productivity, leading to increased farm profits, while reducing the government fertilizer subsidy burden. FDP was also found to protect the environment by reducing nitrogen losses, including runoff, ammonia volatilization, and greenhouse gas nitrous oxide (Gaihre et al., 2015; IFDC, 2013; Rochette et al., 2013).

In this paper, we present a case in Bangladesh, where FDP technology is widely disseminated, discussing both the benefits of FDP and the challenges to broader adoption. We present these findings not only to illustrate the findings in Bangladesh, but to suggest that FDP – if spurred to greater scale by innovative actors in larger markets – can be an important part of the solution in terms of NUE gains in the near term.

Methods

Study Sites and Fertilizer Treatments

Field experiments were conducted in Bangladesh during 2012-2015 to compare the effects of FDP on grain yields, NUE, and nitrogen losses under two water regimes – continuous standing water (CSW) and AWD. Treatments included broadcast PU, UDP, and compound fertilizer deep placement (NPK). Grain yields and total aboveground nitrogen uptake were recorded at harvest.

Quantification of Nitrogen Losses

Nitrogen losses including floodwater ammonium (NH_4), ammonia (NH_3) volatilization, and nitrous oxide (N_2O) emission were measured from on-station trials conducted at Bangladesh Agricultural University (BAU) and Bangladesh Rice Research Institute (BRRI). NH_3 volatilization was measured using dynamic closed-chamber and acid-trap methods. Similarly, N_2O emissions were measured with the static automated closed-chamber technique (Gaihre et al., 2014).

Results

Grain Yields and Nitrogen Use Efficiency

Deep placement of urea briquettes and NPK briquettes increased grain yield by up to 30% compared to broadcast PU in the dry (*Boro*) season (Table 1). Moreover, deep placement doubled the agronomic efficiency and nitrogen recovery over broadcast PU – giving higher yields with less N. These results are consistent with previous studies conducted across different districts in Bangladesh (Huda et al., 2016; Miah et al., 2016).

Table 1. Grain yield and nitrogen use efficiency (NUE) in different fertilizer treatments during dry (Boro) seasons at Bangladesh Agricultural University.

N Source	N Rate	Grain Yield (t/ha)[ǂ]	Agronomic Efficiency (AE_N)	Recovery Efficiency (RE_N)
Boro 2013				
PU	78	4.57b	19.7c	32b
UB	78	6.66a	46.5a	67a
NPK	78	6.41a	43.3a	65a
Boro 2014				
PU	104	4.87b	28.06c	39c
UB	78	6.31a	55.93a	82a
NPK	78	4.95b	37.09b	59b
Boro 2015				
PU	104	4.73b	23.1b	29b
UB	78	6.41a	52.4a	78a
NPK	78	6.40a	50.4a	65a

Within a column and season, means followed by the same letters are not significantly different at 5% probability level by Tukeys's honest significant difference (HSD) test.

[ǂ] Grain yield is at 14% moisture content.

AE_N= agronomic efficiency (kg grain/kg N); RE_N= recovery efficiency (increased N uptake/applied N, expressed in percentage).

Floodwater Ammonium, Ammonia Volatilization, and Nitrous Oxide Emissions

Figure 1 shows that broadcast PU produced significant amounts of ammonium in floodwater, which is prone to runoff and volatilization losses. On the other hand, floodwater ammonium in deep placed treatments was similar with control (N0) plot. Deep placement of fertilizer briquettes at 7-10 cm depth ensures retention of ammonium nitrogen in the soil, thereby reducing floodwater ammonium and surface runoff loss. In addition to surface runoff, the negligible amount of floodwater ammonium in deep placement ensures a reduction in volatilization loss (Figure 2a).

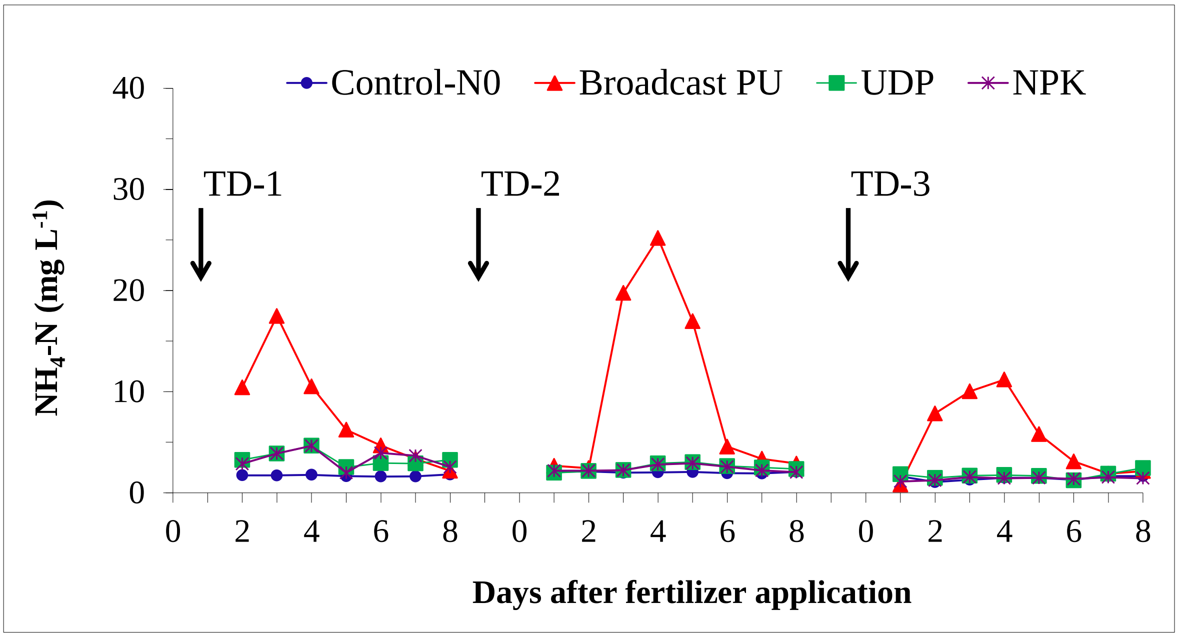

Figure 1. ***Dynamics of floodwater ammonium (NH_4-N) under control (N0), broadcast PU, urea deep placement (UDP), and NPK deep placement (NPK) treatments (104 kg N/ha) at Bangladesh Rice Research Institute (BRRI) during dry season (Boro) 2012. TD-1, TD-2, and TD-3 represent first, second, and third topdressing of urea fertilizer, respectively. Deep placement was done at a time during the first topdressing of urea.***

FDP not only has potential to reduce nitrogen losses as surface runoff and ammonia volatilization but also to reduce greenhouse gas nitrous oxide emissions. Figure 2b shows the cumulative nitrous oxide emissions measured continuously throughout the 2014 dry (*Boro*) season at the BAU site. UDP reduced emissions by 70% as compared to broadcast PU. Gaihre et al. (2015) reported the effects of UDP on nitrous oxide and nitric oxide across different rice-growing seasons in Bangladesh.

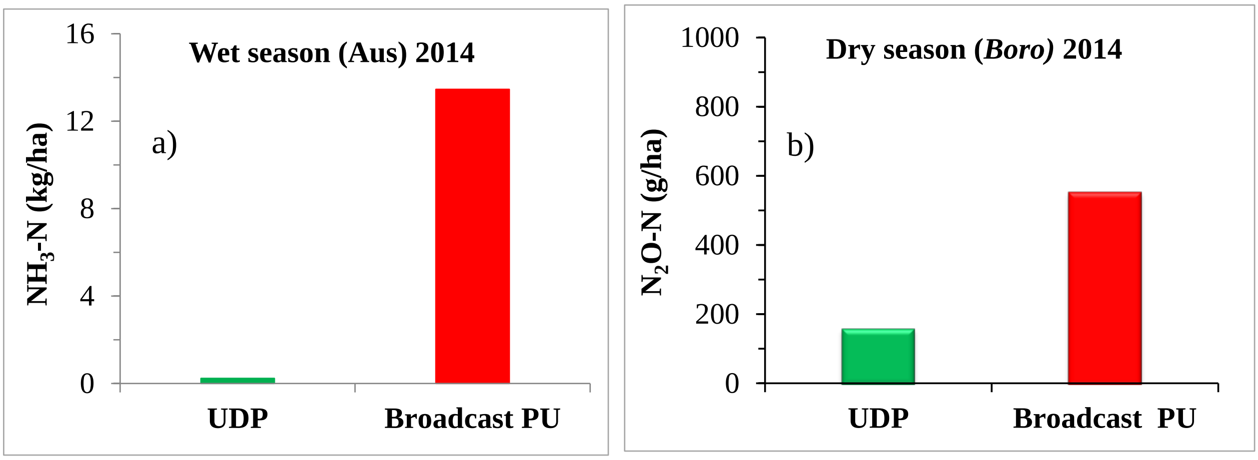

Figure 2. ***Nitrogen loss as (a) nitrous oxide (N_2O-N) emissions and (b) ammonia (NH_3) volatilization from urea deep placement (UDP) and broadcast prilled urea (PU) at Bangladesh Agricultural University (BAU).***

Conclusion

Deep placement of urea and NPK briquettes with ~30% less fertilizer compared to broadcast prilled urea significantly increased grain yields and nitrogen use efficiency compared to broadcast prilled urea. Moreover, deep placement significantly reduced floodwater ammonium nitrogen, ammonia volatilization, and nitrous oxide emissions. FDP increases yields and farm profitability (Miah et al., 2016) while reducing fertilizer use and environmental hazards, generating agronomic, economic, and environmental benefits.

Some of the challenges for wider dissemination of FDP are availability of the fertilizer briquettes and labor for deep placement. Overcoming these challenges will require government and private sector initiatives to make fertilizer briquettes more widely available while developing efficient mechanized on-farm deep-placement solutions. This will have immediate impacts, particularly for large producers and consumers of N fertilizer, such as China and India. Some research conducted in China has shown higher economic returns and use efficiency from FDP trials but emphasized the need for mechanization for broader dissemination (Liu et al., 2015).

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The Role of Mineral Fertilizers in Climate-Resilient Agriculture: Focus on Myanmar

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Abstract

The use of mineral fertilizers has permitted at least 50% of global food production. However, use of fertilizers could have negative environmental consequences contributing to climate change. Climate change is thought to be partly responsible for increases in abiotic and biotic perturbations that negatively impact crop production. Impacts of climate change, such as an increase in incidences of flooding, drought, salinity, and crop disease, are noted for Myanmar. However, appropriate use of existing nitrogen (N) fertilizers, development of new N fertilizers with improved uptake efficiency, and the balancing of fertilizer composition to include secondary and micronutrients can mitigate both the contribution of fertilizer to climate change and the impact of climate change in agriculture. This paper addresses the role of fertilizers in a changing climate where drought, salinity, pests, and incidences of diseases are heightened. Strategies to enhance fertilizer use efficiency toward engendering a climate-resilient production system are discussed for rice, the predominant crop in Myanmar.

1. Introduction

Agricultural production in most Asian countries has experienced significant advancement in the last decades. In Myanmar, agricultural crop production is dominated by rice, occupying more than 60% of the country’s arable land, mostly in lowland production systems. Rice production in Myanmar over the years has been characterized by episodes of high and low production cycles, increasing from about 21 million (M) tonnes (t) in 2000 to about 33 Mt in 2010, before declining to about 26 Mt in 2014. This trend is related to changes in cultivated land area (hectares) and rice yield per hectare. Fertilizer use has been identified as being important for increasing and sustaining rice production in Myanmar (Naing et al., 2008). However, fertilizer use in Myanmar has historically been relatively low (Ricepedia, data accessed August 2017). Between 2005 and 2013, fertilizer use on rice increased from 6,520 t to 16,830 t. A study conducted during 2000 and 2001 indicated that low rates of fertilizer application, particularly N and, to a lesser degree, P and K, is a major contributing factor to low yield in rice (Naing et al., 2008). Notably, fertilizer use in 2014 increased sharply to between 1.2 and 1.4 Mt (Gregory et al., 2014; FAO, data accessed August 2017). Whether this increase will be sustained remains to be seen. However, there is no question that rice production is crucial to food security in Myanmar and the region and that poor management of rice cropping systems can significantly affect the environment.

A national report indicates that about 15% of Myanmar’s arable land under rice cultivation is challenged by weather-related environmental factors including flooding, drought, and salinity (Myanmar RSDS, 2015). Individually or combined, these weather-related events result in considerable yield losses in rice. For example, between 2006 and 2011, record-breaking flood events in different parts of the country caused extensive damage to rice crops, with more than 50% crop and over 1.7 Mt of rice grain losses. Similarly, various drought incidences across the country in 2010 destroyed agricultural yields of various crops, including rice, peas, sugarcane, and tomato. Also, incidences of salinity impacting rice productivity in the Delta region of Myanmar have been reported. Salinity increases attributed to sea level rise and seawater encroachment are expected to intensify due to double cropping of rice in monsoon and summer seasons. However, desalinization efforts to mitigate the impact are being undertaken (Climate Change Alliance, data accessed August 2017; SeinnSeinn et al., 2015).

Nitrogen (N)-based fertilizers, especially urea, account for most of the fertilizer consumed in Myanmar (FAO, data accessed 2017; Gregory et al., 2014) and, by implication, in rice production. However, use of urea is associated with N losses that often exceed 50% of the applied fertilizer (Angle et al., 2017) and potentially contribute to climatic changes that could exacerbate some of the above-mentioned weather events. Taken together, the negative effects of environmental stressors on crop yield, still inadequate levels of infrastructure such as irrigation to mitigate effects from drought, and the huge nutrient losses associated with N fertilizer use in lowland rice production are real or potential factors contributing to hinder growth in rice production in Myanmar. Moreover, high nutrient losses under conditions of low fertilizer use have the potential to significantly impact crop productivity. The objective of this paper is, therefore, to highlight fertilizer and fertilization strategies for sustaining and increasing agricultural crop production in Myanmar in the face of climate change challenges.

Globally, mineral fertilizers have driven much of the improvement in agricultural yields and are responsible for feeding nearly half of the world's human population (Erisman et al., 2009). Accordingly, fertilizer use in Myanmar was identified as a major contributing factor influencing rice production (Naing et al., 2008), a dominant crop with production in lowland systems occupying more than 82% of the total sown area of 7.6 M ha (Myanmar RSDS, 2015). Furthermore, the introduction of fast-growing, high-yielding rice varieties in Myanmar has increased the need for N fertilizer in order to cope with the heightened crop physiological demands associated with improved crop varieties. Consequently, in Myanmar, rice yield increases to 7 t/ha have been reported with NPK application, from less than 3 t/ha in non-fertilized controls, dependent on the rice variety (Matsuda, 2011).

As previously noted, N-based fertilizers account for the majority of fertilizers used in rice production in Myanmar. However, serious N losses can occur in lowland production systems exposed to continuous flooding or alternate wetting and drying (Angle et al., 2017). Notably, of the 19.2 teragram global N-fertilizer input applied to rice, N losses range between 10% and 50% as volatilized ammonia (NH_3), 6% and 50% as leached nitrate (NO_3^-), and <1% as emitted nitrous oxide (N_2O). Globally, only an estimated 36% of the applied N is actually utilized by the rice plant (Coskun et al., 2017). Specifically for Myanmar, total fertilizer (NPK) use efficiency for rice is approximately 27% (Matsuda, 2011). Loss of N from fertilizer contributes to undesirable environmental impacts, such as greenhouse gas (GHG; e.g., N_2O) production and pollution of surface and underground waters (Angle et al., 2017). Production of GHG from N fertilizers directly contributes to climate change; a unit of N_2O is 300 times more potent in trapping heat than the same unit of CO_2, another GHG (Coskun et al., 2017). Climate change is a primary environmental factor that is disruptive to agricultural production in different parts of the globe (Angle et al., 2017), due in part to related severe weather events, including drought, salinity, and flooding. In addition, high N fertilizer use leading to increased plant biomass also leads to high uptake of other essential nutrients by plants, resulting in nutrient mining and eventually to lower yields over time (Jones et al., 2013), in addition to soil and water pollution of NO_3 runoff. Current evidence indicates that appropriately managing N fertilizers, using improved N fertilizers with enhanced N uptake, and balancing the nutrient composition of mineral fertilizers hold strong promise for mitigating N loss and adapting plants to climate change-related incidences, including drought, salinity, and pests and diseases, while improving plant biomass and grain production and, hence, carbon sequestration (Angle et al., 2017; Bindraban et al., 2015; Dimkpa and Bindraban, 2016). There is, therefore, a continuous need to re-examine the role of N fertilizers, in particular, and fertilization strategies, in general, in order to maximize fertilizer benefits and provide resilience to agricultural production systems against a changing climate. Given the recognition by several reports, including those from Myanmar's Ministry of Agriculture and IPCC (summarized by Slagle, 2014), that climate change and associated weather events are significant factors in slowing national development due to attendant losses in the agriculture sector, Myanmar is a good example of countries in dire need of climate-resilient agricultural strategies, such as those that fertilizers engender.

2.1 Fertilizer Functionality under a Changing Climate

Flooding, drought, salinity, reduced nutrient immobility, and increased pest and disease incidences are among the main environmental outcomes of climate change that directly affect crop production. For example, a national crop production decline of 10%, on average, occurs as a result of drought, according to a recent global analysis of extreme weather effects on crop production (Lesk et al., 2016). Drought, salinity, and nutrient immobility are interlinked. Soil salinity levels increase during extended drought periods as less water becomes available in soil to dilute salt. When soil salinity levels are high, water in the root is pulled into the soil through osmosis, depriving the plant of moisture. At the same time, nutrients in soil are increasingly immobilized as water becomes less available, which affects their uptake by plants. In the presence of high sodium (Na), plant-essential metal ions are outcompeted for root binding sites.

Because drought and salinity inhibit plant growth, they indirectly reduce the amount of carbon captured by plants, due to reducing plant leaf area or leaf number available for photosynthesis. Thus, drought and salinity indirectly contribute to increasing the level of CO_2 in the atmosphere. Drying soils also influence the state of N, as mobility and plant accumulation of most nutrients are limited by a low soil solution phase (Dimkpa et al., 2017). Under such conditions, N becomes more prone to atmospheric emission due to several factors, including improvement in soil aeration, enhanced nitrification, and less plant biomass as a sink for N. Emission of N into the atmosphere contributes up to 1.6% of the atmospheric GHG, N_2O (Angle et al., 2017). On the other hand, excessive salinization in soil and corresponding plant accumulation of Na and Cl cause osmotic stress in plants, further reducing available plant water and inhibiting uptake of nutrients. Ultimately, increased salt uptake induces reactive oxygen species production that hampers plant growth (Ashraf et al., 2014).

It has been speculated that due to their large populations, short generation time, and ease of multiplication and dissemination, disease pathogens will likely be among the first organisms to be influenced by climate change. Increase in pest and disease incidences occur with warmer temperatures, as rising temperatures increase pest breeding seasons and reproductive rates and pest overwintering mortality reduces. These scenarios lead, ultimately, to potentially new pest and disease invasions into new areas (Eastburn et al., 2010; Gornall et al., 2010; Pimentel, 1993). Rice production is affected by many pests and diseases that are likely to be influenced by climate change. For example, in Bangladesh, a neighboring country to Myanmar, sheath blight caused by *Rhizoctonia solani*, which was a minor disease in the early 1970s, has now become a destructive disease of rice. Similarly, leaf roller (*Cnaphalocrocis medinalis*, *Marasmia exigua*) that was not hitherto a prominent rice pest has increased in incidence since the 1980s (Haq et al., 2010). In Myanmar, notably, less than 15% of surveyed rice fields in 2000-2001 were found to be disease-free; sheath blight, bacterial leaf blight, and sheath rot were found to be prevalent (Naing et al., 2008). The interplay among crop abiotic and biotic factors related to climate change clearly has far-reaching consequences for human food security under a changing climate and warrants the development of strategies to improve the resilience of agriculture.

In response to low N fertilizer use efficiency and associated N losses and, climate change-related events, such as drought and disease infestation, novel fertilizers and fertilization strategies are being designed in order to mitigate N losses necessary for reducing N_2O and NO emissions, NO_3 leaching or runoff to water bodies, and the effects of abiotic and biotic stressors on plants (Servin et al., 2015; Angle et al., 2017). The extent of N fertilizer involvement in climate change depends to a large degree on the type of N. However, fertilization using even the most basic N fertilizer, namely urea, together with secondary and/or micronutrient supplementation, can also play a role in enhancing N uptake and mitigating N loss. In addition, micronutrients function in mitigating the impact of abiotic and biotic stressors in plants (Dimkpa and Bindraban, 2016; Elmer and White, 2016). As illustrated in Figure 1, the choice of appropriate N fertilizer and its mode, timing, and rate of application contribute to enhance crop resilience to climate change by reducing N loss. Figure 1 also highlights two technical approaches to improving N fertilizer efficiency: producing intrinsically efficient N fertilizer products and balancing crop nutrition to stimulate the use of N. Here, although the choice of an approach is directly related to its ability to modulate N uptake efficiency to reduce losses, other significant agronomic benefits accrue, as already noted, due to balancing the nutrition in fertilizer formulations (Dimkpa and Bindraban, 2016). That said, obvious increases in the purchase price of improved efficiency fertilizers versus basic fertilizers may be counteracted by using lower rates of the former and by the difference in yields obtained, not to mention the reduction in societal costs associated with negative environmental effects of fertilizers. While each of these individual fertilization approaches has demonstrated applicability for enhancing N use efficiency and/or mitigating abiotic and biotic stressors (Dimkpa and Bindraban, 2016; Angle et al., 2017), integrating them into a systems approach is likely to allow for better maximization of the benefits. Below the ramifications of fertilizer improvement strategies are discussed in more detail, together with evidence of their impact on N use efficiency and abiotic and biotic stress mitigation in rice. Although not possible with rice, examples with other grain crops are provided.

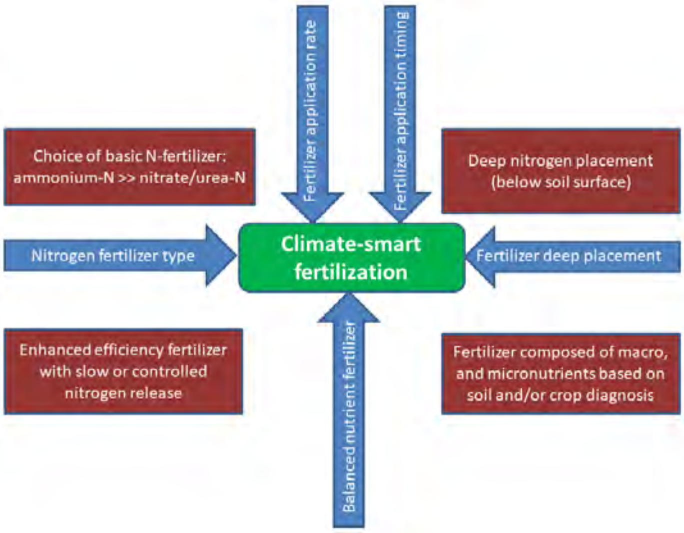

Figure 1. Strategies for maximizing the ecological benefits of fertilizers based on choice, application method, use of improved N fertilizers, and balanced nutrient composition of fertilizers.

3. Adapting Nitrogen Fertilizers for Agricultural Resilience to Climate Change

3.1 Nitrogen Fertilizer Management

Nitrogen loss to the atmosphere from mineral N fertilizers occurs at different degrees, dependent on fertilizer type. A meta-analysis indicated that the greatest N loss is from urea-based N fertilizer, with losses between 10% and 64% (average 18%) from NH_3 volatilization (Pan et al., 2016) and up to 28% from N_2O emission (Wang et al., 2016), dependent on N application rate. Based on comparative N_2O emission studies, Rashti et al. (2015) concluded that substituting urea with nitrate could reduce N loss significantly in upland cropping systems. In contrast, N loss from NH_4^+-based N fertilizers is relatively lower than from NO_3^--based fertilizers; NH_4^+ can be rapidly bound up in soil upon fertilizer application and only later converted to NO_3^- by nitrifying bacteria. In contrast, NO_3^- is prone to rapid denitrification or leaching, contributing much more quickly to the pool of N volatilized, leached, or lost through surface water runoff. Thus, the choice of N fertilizer can play a significant role in the contribution of fertilizers to GHG production. However, where N fertilizer choices are limited, the most available N fertilizer, typically urea, can be managed for improved efficiency by placement strategies. Several IFDC studies on subsurface placement of urea (urea deep placement; UDP) have demonstrated that urea savings of 25-44% are possible, relative to recommended broadcast application of urea in lowland rice, due to negligible NH_3 volatilization loss (Savant and Stangel, 1990; Kapoor et al., 2008; Bandaogo et al., 2015; Gaihre et al., 2015; Huda et al., 2016; Islam et al., 2016; Miah et al., 2016). Notably, although NH_3 is not a GHG, its loss to the atmosphere directly contributes a major reactive N that potentially pollutes the atmosphere. Moreover, NH_3 can subsequently be converted to NO and N_2O, which are GHGs.

Although N fertilizer management practices, such as using the right rates, right application method (e.g., deep placement versus surface broadcasting), or simply preferring one type of N fertilizer over another (e.g., non-urea vs. urea), already can mitigate some of the environmental problems associated with fertilizers (Pan et al., 2016; Angle et al., 2017), it is also clear that improving existing N fertilizer products represents an important step in redirecting fertilizer's role in climate change (Angle et al., 2017). The contribution of improved N fertilizers in mitigating climate change can be evaluated by how much less GHG they contribute to the environment by lowering N_2O and NO emissions and by how much GHG (CO_2) they cause plants to remove from the atmosphere through improving shoot growth for more carbon capture, relative to existing unimproved N fertilizers. For instance, by using several controlled-release N fertilizers, N_2O/NO emission reductions of 13-68% are attainable, compared to urea, dependent on the individual controlled-release technology (Angle et al., 2017). Similarly, photosynthetic rates, and hence, CO_2 removal, could be enhanced by more than 50% of the rate by regular N fertilizer using controlled-release products (Zhao et al., 2013).

3.2 Improved Efficiency N Fertilizers

To better synchronize N availability with crop N demand and reduce N loss, controlled- or slow-release N fertilizers have been produced (e.g., Chien et al., 2009; Timilsena et al., 2014; Ruijter and Corré, 2015). Such improvements essentially involve modifications using chemical, biological, and nanotechnological approaches to coat or encapsulate N with slow-release agents. The functioning of slow-release fertilizers involves two general mechanisms. First is regulating the rate of urea hydrolysis by urease, which reduces the rate of NH_4^+ formation. During the process, loss of N as NH_3 and N_2O is controlled. Second is the reduction of nitrification of NH_4^+ to NO_3, during which N_2O emission and NO_3 leaching and/or runoff rates are controlled. Thus, the aim of both mechanisms, ultimately, is to keep N in the soil much longer as NH_4^+ for synchronized and enhanced uptake by crops (Figure 2).

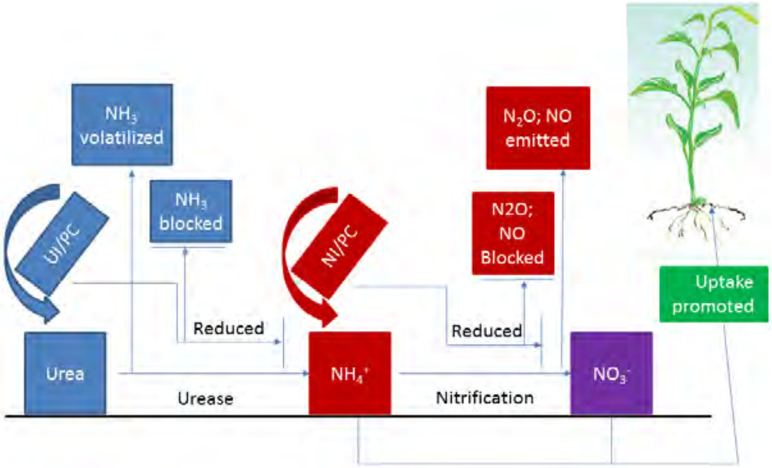

Figure 2. ***Simplified schematic of pathways for N transformation and losses, with N source as urea or ammonium. The introduction of urease inhibitor (UI), polymer coatings (PC), or nitrification inhibitors (NI) reduce N transformation rates, and thus losses, at each point. Reduction in N loss implies increased N uptake by plants. Losses via nitrate leaching or runoff are not indicated.***

To these ends, urease inhibitors, polymers, and/or chemical nitrification inhibitors are being used. With urea-based fertilizers requiring conversion by urease to NH_4^+, chemical urease inhibitors (e.g., N-[n-Butyl] thiophosphoric triamide [NBPT], phenylphosphorodiamidate [PPD/PPDA], hydroquinone) are added to slow urease activity, thereby reducing NH_4^+ production and, thus, loss of NH_3. With NH_4^+-based fertilizers, nitrification inhibitors, including nitrapyrin, dicyandiamide, 3, 4-dimethylpyrazol phosphate (DMPP), and thiosulfate, are blended with the fertilizer to reduce the nitrification rate and associated N_2O, NO, and NO_3^- losses. Alternatively, these fertilizers could be coated with polymers of either chemical or biological origin that permit diffusion through their semi-permeable or impermeable membranes, thereby controlling the release of N at rates that vary with polymer composition, polymer thickness, temperature, and soil moisture level. Examples of commonly used polymers or coating agents include dicyandiamide, polyolefin, aldehydes (e.g., formaldehyde), humic acid, zinc oxide, sulfur, polyurethane, lignin, neem, gum arabic, and starch (Abalos et al., 2014; Azeem et al., 2014). Studies by IFDC on rice using different improved efficiency N fertilizers show that high N loss via NH_3 volatilization from conventional urea can be mitigated by using improved efficiency N fertilizers (Figure 3). Notably, by lowering N transformation rates, improved efficiency N fertilizers are able to both reduce N loss to the atmosphere and its runoff loss in soil. Hence, compared to urea (check treatment), more NO_3 is retained in the soil by improved fertilizers (Figure 4). Accordingly, N application rates for crop production could be reduced without compromising yield (Kottegoda et al., 2017; Zhou et al., 2017).

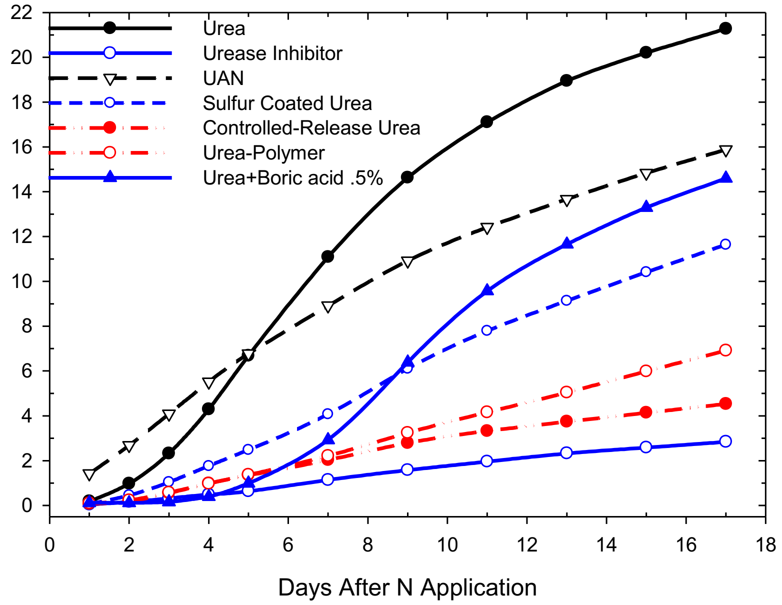

Figure 3. ***Temporal volatilization of NH_3 during rice growth from conventional urea fertilizer and its mitigation by improved N fertilizer products. UAN: urea ammonium nitrate.***

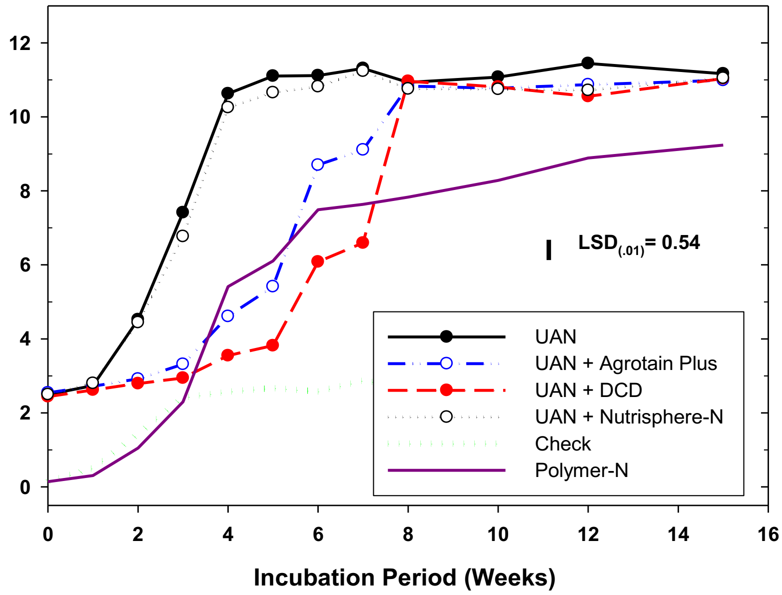

Figure 4. Effect of enhanced efficiency fertilizers on soil nitrate content. UAN: urea ammonium nitrate.

Whereas use of urease inhibitors, nitrification inhibitors, bulk polymer coatings, or sulfur has become standard practice for improving N fertilizers, use of nanotechnology, the design and production of materials at the nano-scale (1-100 nanometer dimensions), has more recently started to emerge in fertilizer development. Here, nanofilms, nanopolymers, or nano-scale additives of other nutrients, such as zinc and phosphorus, are used to modify N fertilizers to slow the release of N. Several studies report these "nanofertilizers" of N as being better able to control urea hydrolysis, and to increase crop yield and N use efficiency, than their conventional counterparts (Dimkpa and Bindraban, 2017; Kottegoda et al., 2017; Zhou et al., 2017). Dependent on the type of nano formulation, controlled N release could result in up to 35% less N release and an 86% reduction in N_2O emission. In some case, these findings are accompanied by significant crop N uptake and yield improvements (Kottegoda et al., 2011, 2017; Pereira et al., 2015; Kundu et al., 2016; Zhou et al., 2017). Notably, Kottegoda et al. (2017) demonstrated in rice that such effects are possible with up to 50% less N fertilizer application using nanohydroxyapatite-improved urea ("nano-urea") compared to conventional urea granules (Figure 5). Similarly, Zhou et al. (2017) reported N fertilizer improvement by formulating nanoclay, sodium humate (a urease inhibitor), and urea. They demonstrated strong reduction in urea hydrolysis and improvement in rice productivity by the nano-urea (Figure 6), wherein a grain yield increase of 11% was realized using 20% less fertilizer, compared to conventional urea. In addition to permitting less introduction of new reactive N into the agricultural system, these findings suggest cost-saving benefits on initial fertilizer investments using nanotechnology, contingent upon accounting for the cost of nano-enabling the urea, compared to other non-nanotechnology-based improvement methods. Unfortunately, many of the studies reporting N use improvement by means of nanotechnology have a major flaw, which the effects were compared with ordinary urea in most cases, instead of urea or other N fertilizers improved by methods other than nanotechnology.

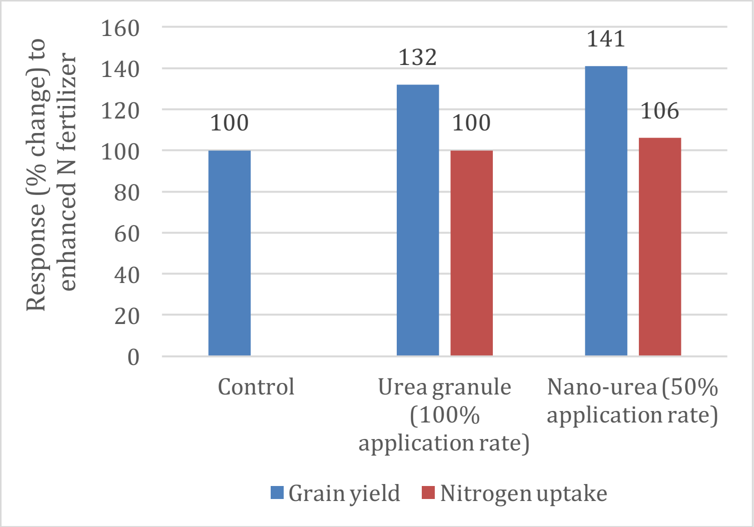

Figure 5. ***Effect of improved urea (nano-urea) on rice grain yield and N uptake. Nitrogen uptake comparisons are between urea and nano-urea only. Data are modified from Kottegoda et al. (2017) with permission.***

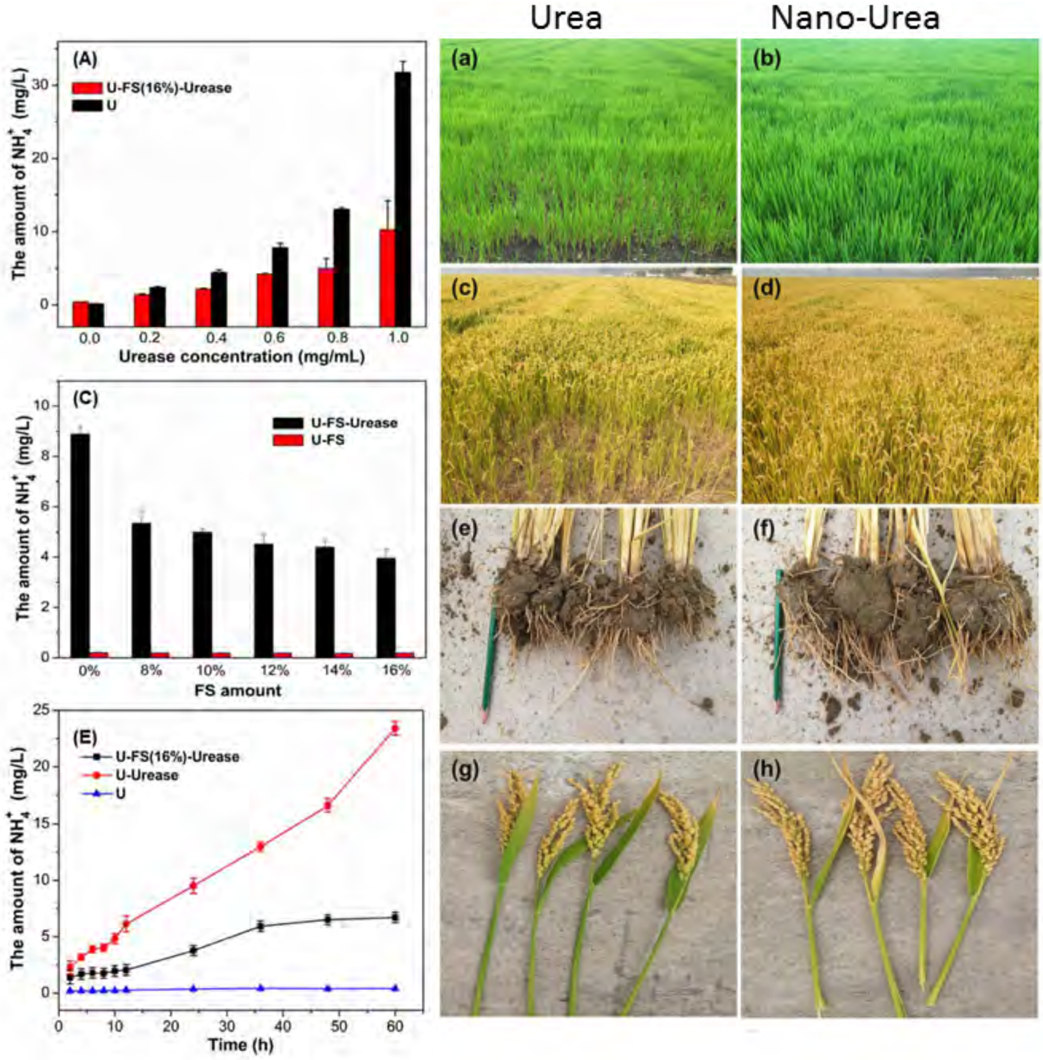

Figure 6. ***Effects of "nano" on ammonium production by urea hydrolysis and rice performance under urea fertilization. Left panel (upper row) shows reduction of urea hydrolysis rate in nano urea (red bar) compared to conventional urea (black bar) as a function of urease concentration; middle row shows reduction of urea hydrolysis rate in nano urea with (black bar) and without (red bar) urease treatment, as a function of "nano" concentration; and lower row shows the time course of the reduction of urea hydrolysis in nano urea (black line) and conventional urea, each in the presence of urease, and compared with conventional urea without urease treatment. Middle and right panels are photographic images of field-grown rice plants treated with urea (middle panel) or nano-urea (right panel). Vegetative, root, and ear developments are shown in the upper, middle, and lower rows, respectively. These data culminated in an 11% grain yield increase by using nano-urea (see Zhou et al. [2017] for more detail).***

3.3 Role of Sulfur in Promoting N Use and Mitigating N Losses

The role of sulfur as a nutrient in fertilizers for stimulating crop production is well studied. Sulfur, once converted to sulfate, adds to the completeness of crop nutrition, with the potential to enhance biomass production, as consistently demonstrated in IFDC's work in East Africa for different soils and crops. However, S is also relevant for mitigating fertilizer-induced environmental pollution. The previous section indicates that S is used as a coating agent to improve urea fertilizers by slowing N release. Beginning with the work of Billings et al. (1967) at the Tennessee Valley Authority about half a century ago, IFDC and others have been using S as a coating material for urea improvement. Mechanistically, S forms an impermeable layer over urea that slowly decomposes as a result of microbial, chemical, and physical processes. As shown in Figure 3, the use of S coating in urea can reduce NH_3 volatilization loss by as much as 45%, 18 days after fertilizer application. Similarly, Khariri et al. (2016) reported a lowering (by 15%) of N_2O emission in rice soils by S-coated urea, compared to uncoated urea. With respect to effects on plant performance, a rice yield increase of 10% was obtained upon treatment with S-coated urea, compared to uncoated urea (Kiran et al., 2010). Likewise, Shivay et al. (2016) reports 12% more rice grain yield by S-coated urea compared to uncoated urea, concomitant with N uptake increase of 21% by the plant. In another grain crop, S-coating induced significant lowering of N_2O emission compared to uncoated urea and resulted in significantly more shoot and root biomass production in maize (Dheri et al., 2015). This dual benefit can be viewed in terms of S simultaneously contributing to lowering two GHGs: reducing N_2O emission and permitting more CO_2 capture by plant, thereby increasing plant growth. In wheat, sulfur-induced N recovery of up to 70% from soil under high N treatment with otherwise greater potential for losses has also been noted (Salvagiotti et al., 2009).

4. Micronutrient Fortification for Climate-Resilient Crop Production

The second fertilizer improvement strategy to be addressed in this paper concerns the balancing of nutrients in fertilizer products. This has serious ramifications other than just improving N use because of its role in engendering crop resilience to climate-induced abiotic and biotic stressors and its benefits for crop and human nutrition. Ample evidence demonstrates that the inclusion of micronutrients in N(PK) fertilizers can markedly increase the resilience of plants to climate change effects, such as drought, salinity, and disease. Notably, even in the absence of environmental stressors, these nutrients are known to enhance crop performance, productivity, and nutritional quality, regardless of the N status of the soil (Dimkpa and Bindraban, 2016). Prominent among the micronutrients in this regard are Zn, Cu, and B and, to a lesser extent, Fe and Mn. Despite the benefits, these micronutrients are hardly included in the national fertilizer recommendations in many countries, including Myanmar. In particular, the need for Zn inclusion in fertilizers is warranted by the fact that Zn deficiency is a growing global human health problem that agronomic fertilization has the potential to address. Notably, Myanmar has been identified as one of the countries with a high population percentage having low Zn dietary intake (Wessells and Brown, 2012).

Regarding their role under abiotic stress, micronutrients mitigate drought effects in plants by several mechanisms, including increasing water use efficiency, maintaining membrane stability which otherwise causes tissue flaccidity by drought-induced wilting, and detoxifying toxic free radicals that accumulate in plants during water scarcity. All of these actions are related to micronutrients' multiple roles in stimulating several enzymes and plant processes related to abiotic stressors, water interactions, or nutrient uptake (Karim and Rahman, 2015; Dimkpa and Bindraban, 2016). For example, Zn activates enzymes that regulate plant response to water stress, and both Cu and B are involved in cell wall strengthening and functioning. Notably, under drought stress, plants produce increased quantities of abscisic acid (ABA) to optimize stomatal closure and conserve scarce water. Interestingly, Zn fertilization has been shown to increase ABA production in plants (Zengin, 2006); hence, it is a potential strategy for fertilizer induction of tolerance to drought stress in plants.

Conversely, micronutrients such as Zn and Fe modulate salinity effects on plants by reducing osmosis-induced Na accumulation. This is possibly due to competition for binding sites at the cellular interface between Na and metallic micronutrients. Concomitant with that is the enhancement of K uptake relative to Na, and the regulation of antioxidative enzymes and metabolites ostensibly protecting the plant from salinity stress (Soliman et al., 2015; Saeidnejad et al., 2016). Mechanistically, increased K uptake facilitates osmotic pressure, drawing water into the plant to dilute excess Na effects. As such, K fertilization could be an appropriate strategy in rice production systems (Zain et al., 2014), especially where alternate wetting and drying is practiced, whereby plants may become exposed to elevated salt levels due to precipitation during the drying regime. As demonstrated below, the above-discussed cellular-level effects of micronutrients under drought or salinity stress often translate to agronomic and nutritional benefits in different crops. Therefore, micronutrients have strong promise in climate-sensitive agriculture as smart fertilizers for facilitating quality crop production in drought- and salinity-prone agroecosystems and could prove immensely beneficial for countries such as Myanmar, given its history of drought and salinity and the need for agricultural resilience against diseases.

4.1 Micronutrients Impact under Drought Stress

Crop trials involving different species have consistently shown micronutrient fertilization as capable of increasing drought tolerance (reviewed by Karim and Rahman, 2015). Conversely, drought-induced reduction in grain yield also is more pronounced with micronutrient deficiency, especially Zn (Dimkpa et al., 2017). Although studies conducted specifically in rice systems for drought evaluation of micronutrients appear to be scarce, fertilization of drought-stressed plants with micronutrients has led to significant mitigation of drought effects on vegetative and reproductive development in other crops. For instance, under drought, average wheat grain yield decreased by 25%; however, the addition of Zn increased wheat yield by 16%, thus lowering the loss in yield due to water shortage from 25% to 13% (Bagci et al., 2007). Similarly, Karim et al. (2012) demonstrated application of Zn, B, and Mn under drought stress to increase wheat grain yield by 15%, 19% and 13% concomitantly with increased grain accumulation of Zn (29%), B (17%), and Mn (52%), respectively, relative to untreated plants. In other studies, yield of wheat was reduced 30% by drought but was improved by between 13% and 18% upon B application, dependent on application time (Abdel-Motagally and El-Zohri, 2016).

IFDC's recent studies have contributed to unraveling the influence of micronutrients on crop yield and N uptake under drought and non-drought conditions alike. For example, drought stress reduced biomass production, grain yield, and N uptake in soybean to 48%, 47%, and 52%, respectively (Dimkpa et al., 2017). However, under drought stress, a micronutrient formulation of Zn, B, and Cu administered to plants as oxide or salt mitigated the effect of drought by enhancing biomass production, grain yield, and N uptake, relative to drought-stressed plants not exposed to the formulation (Figure 7).

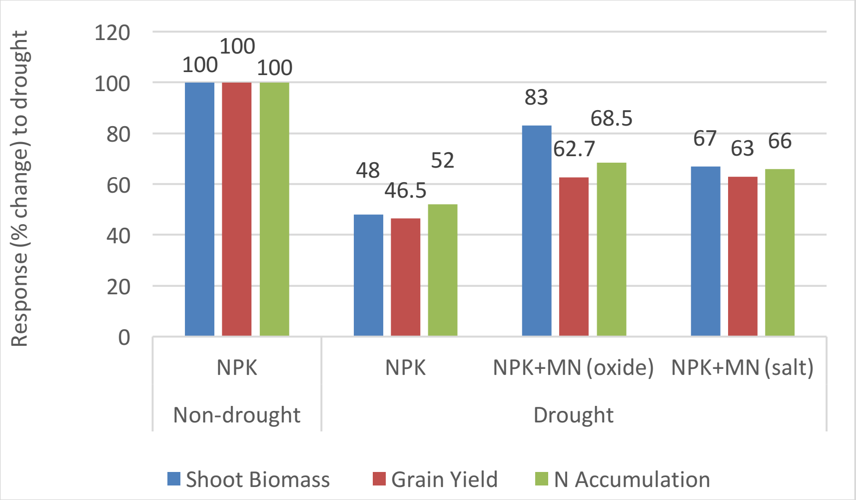

Figure 7. Response of soybean under drought stress to a micronutrient (MN) formulation of Zn, B, and Cu as oxide powders or salts. Data are modified from Dimkpa et al. (2017).

Under non-drought condition, Zn application raised rice grain yield, grain Zn, and shoot N contents by 8%, 18%, and 8%, respectively, in flooded growth condition (Ranjha et al., 2001). Similarly, rice growth, grain production, N accumulation, and soil N retention were improved 13-25%, 19-34%, 34-39%, and 25-36%, respectively, upon Zn fertilization using different methods, including soil and foliar (Ghoneim, 2016). Viewed from a nitrogen management perspective, these findings suggest Zn as capable of both increasing the accumulation of N in plants and leaving residual N in soil in a more stable form, thereby potentially reducing N losses.

4.2 Micronutrients Impact under Salinity Stress

As noted, salinity in rice production systems is of concern in Myanmar; more than 27,000 ha of the total land used for rice farming is salinity prone (RSDS, 2015), which is likely to increase, as previously indicated. Notably, fertilization of salinity-stressed crops with different micronutrients has been shown to alleviate salinity-induced loss in productivity. For example, treatment with B or Zn decreased Na and Cl uptake but increased K uptake in rice challenged by salinity stress. This resulted in improved vegetative growth and paddy yield increases of between of 80% and 163% over the control for B and between 41% and 56% for Zn, compared to the controls, across different cultivars or micronutrient treatment rates (Mehmood et al., 2009; Ashraf et al., 2014). Likewise, rice response under salt stress was improved by Zn application, generating significant increases in grain yield and K uptake, while depressing Na and Cl uptake (Jan et al., 2016).

4.3 Micronutrients Impact under Biotic Stress

Rising temperatures and changes in rainfall pattern are among climate change indicators influencing the development of plant pest and disease epidemics. In Myanmar, insect pest incidences are generally low. However, due to abnormally high rainfall, it is likely that insect pest prevalence will increase, as found in 2002 for rice ball midge. In the case of rice diseases, incidences are more widespread in Myanmar. Dependent on the disease agent and year, incidences ranged between <5% and 65% (Naing et al., 2008). Notably, fertilization of rice with certain nutrients helps to control pests due to their effect on modulating sugar and amino acid production, increasing the production of allelochemicals, and thickening cell walls, which retards stem borers (IRRI, downloaded August 2017) Similarly, balanced crop nutrition plays a role in plant disease tolerance. Although studies that have directly assessed the role of nutrition in suppressing diseases under "climate-change" conditions are lacking, rice disease-causing pathogens have been shown to be controllable by nutrition-based treatment strategies (Rodrigues and Datnoff, 2005). Mechanistically, Zn activates signals for the cellular activities of proteins involved in disease resistance in cereals (Shirasu et al., 1999), and Zn-efficient cereal crop varieties are known to be more resistant to plant disease than Zn-inefficient varieties (Grewal et al., 1996). Copper is a cofactor for important proteins, including plastocyanins, peroxidases, and multi-Cu oxidases, which are involved in plant response to pathogenic infections (Evans et al., 2007). Studies have found some of these enzymes, as well as pathogenesis-related protein genes, to be activated by Cu application under pathogen attack (Elmer et al., 2017). However, other micronutrients, including Zn, Mn, and B, have also shown ability to suppress plant diseases (Servin et al., 2015; Elmer and White, 2016; Elmer et al., 2017). Interestingly, these micronutrients not only directly inhibit pathogen growth, but also engender considerable systemic resistance in the plant against upcoming diseases. Diseases affecting eggplant, watermelon, tomato, and other crops have been systemically controlled or mitigated using micronutrients, leading to substantial increases in crop yields (Servin et al., 2015; Elmer and White, 2016; Elmer et al., 2017). Notably, micronutrient effects on diseases seem to be more effective with early exposure to the micronutrients, prior to disease onset (Imada et al., 2016; Elmer et al., 2017). These findings clearly highlight the importance of a disease treatment window with nutrition, which may be relevant for the seasonal cultivation of rice in Myanmar. The literature on this subject indicates that a balanced nutrition fertilization regimen can be pursued both for decimating pathogen populations and for priming crops, as it were, for future resistance to pathogen attack. Elmer et al. (2017) discusses how sufficient Cu availability could induce host defenses that then prevent or minimize infection, delay the onset of symptoms, and reduce the severity of disease when they do establish. Particularly for rice, high N application increases susceptibility to pests and diseases (IRRI, 2015; Mukherjee et al., 2005). Thus, it is possible that lowering N application rate and offsetting with a suite of yield-enhancing and disease-preventing micronutrients may help with the control of diseases while allowing for uptake of sufficient N even at low application rates. Alternatively, fertilizing the plants with such micronutrients before a second split N application may help with priming the crop against susceptibility that may be induced by the additional N or by climatic factors, such as drought.

5. Perspectives

In comparison with other South Asian farmers, Myanmar farmers have a lower adaptive capacity to confront the high impacts of climate change (SeinnSeinn et al., 2015). Hence, they are in need of strategies to sustain production in the face of climate change events associated with the region. While fertilizer misuse – under- and overuse – has serious consequences in agro-environmental systems, appropriate use of fertilizers is one strategy that can be applied to sustain production. Data from studies on improved N agronomic management, use of improved N-fertilizers, and balanced crop nutrition all demonstrate enhanced use efficiency of N, with potential to mitigate both GHG emissions and the adverse abiotic and biotic challenges brought about by climate change. Thus, for countries such as Myanmar, the above-described positive impacts of fertilization will be favorable for addressing multiple climate change-related challenges, such as drought, salinity, and pest and disease. Moreover, increased CO_2 as a result of climate change is reported to lower the nutrient quality of crops including rice (Loladze, 2014; Myers et al., 2014; Nakandalage et al., 2016), which could pose a serious human health threat for the predominantly rice-consuming population, in addition to weakening the physiological ability to thrive under a changing climate. These warrant deliberate strategies of developing improved N fertilizers capable of enhancing N use efficiency, which in turn contributes to increased biomass production and lowering of CO_2 levels, and promoting balanced fertilization in order to harness the power of micronutrients in enhancing N use efficiency and to replenish diminished nutrients, both for crop adaptation and human health improvement. Quite surprisingly, although drought is a potentially major challenge limiting rice production, there is a notable lack of research demonstrating the alleviating effects of micronutrients on this crop under drought stress. Therefore, a range of studies to evaluate the impacts of different micronutrients and their mixtures, as well as different application methods, including soil and foliar, on rice growing under drought challenge should be conducted. Obviously, for Myanmar, where at least 15% of the land devoted to rice production is affected by drought, the significance of a strategic micronutrient fertilization regime to mitigate the effects of drought cannot be overstated. A recent article on new fertilizers suggests that Myanmar is already pursuing the inclusion of nutrients other than NPK in the national fertilizer recommendations (Dimkpa and Bindraban, 2017). Several products are reported to be under consideration as new fertilizers that include nutrients advantageous for enhancing crop N use and improving the nutritional quality of crop produce in the face of climate change threats to the environment and humans.

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Session 4.
Fertilizer Quality Assessment

Fertilizer Quality Assessment in the Myanmar Dry Zone

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Abstract

The Dry Zone Agro-Input and Farm Services project, which is funded by the Livelihoods and Food Security Trust Fund (LIFT) consortium and implemented by IFDC, carried out a fertilizer quality assessment in the Dry Zone of Myanmar. The four fertilizers of highest commercialization in Myanmar's Dry Zone – NPK 15:15:15, NPK 10:10:5, NPK 15:7:8, and NPK 16:16:8 – presented out-of-compliance shortages (OOCS) with frequencies of 9%, 19%, and 23% of the samples for total N, P_2O_5, and K_2O, respectively. The OOCS severities relative to the fertilizer bag label specification were -1.5%, -4.7%, and -3.2% for total N, P_2O_5, and K_2O, respectively. The rest of the fertilizers, of lower commercialization, presented OOCS with frequencies ranging between 11% and 15% and OOCS severities ranging between 2.7% and 4.1%. Based on the relatively low OOCS severities of the macronutrients in fertilizers of high and low commercialization, the nutrient content problems in the Dry Zone are not as dramatic as reported anecdotally, but they still require attention. With no evidence of adulteration found and very mild granule degradation, nutrient shortages likely originate in the manufacture of the imported products. Port inspections should be more rigorous.

Granule integrity, moisture content, and other physical properties of fertilizers were found to be good, with the exception of caking found in 12% of the samples. Storage facilities are hot and humid, but the good quality of the impermeable bags preserves the fertilizers from moisture absorption and granule degradation. The caking can be explained by bags stacked too high and the absent use of pallets. Fourteen percent of the 50-kg bags weighed presented weight shortages of more than 0.5 kg.

Fertilizer quality assessments such as this should be carried out in all Myanmar agricultural areas, including formal and informal fertilizer markets. Then, the findings of the studies should be used as a foundation for the development of a Myanmar Fertilizer Quality Regulatory Framework, which will protect farmers against fertilizers of substandard quality.

Introduction

Myanmar has an open and competitive, non-subsidized fertilizer market dependent on imports for more than 80 percent of the total market demand estimated at between 1.2 and 1.4 million product tons per annum; however, fertilizer use in Myanmar is still low by Southeast Asian standards and very low by world standards. Together with the use of improved seed, fertilizer use and adoption of modern technologies by farmers are key to raising agricultural productivity (Gregory et al., 2014).

The Myanmar government and the country's private sector envision Myanmar becoming an agriculture-based economy larger than Vietnam and rivaling Thailand by upscaling production of rice and other crops, such as pulses and beans, sesame, groundnuts, rubber, maize, cotton, oil palm, and other perennial and annual crops. One of the essential conditions for these projections to become reality is the establishment of a culture of good fertilizer quality in the country through the development of a fertilizer regulatory framework and its implementation.

This fertilizer quality assessment was conducted by the Dry Zone Agro-Input and Farm Services project, funded by the LIFT Fund consortium and implemented by IFDC. The objective of the assessment was to make a diagnostic of the Dry Zone fertilizer quality condition and to identify the critical factors, such as characteristics of the distribution chain and characteristics of the fertilizer products themselves, that play important roles in fertilizer quality in Dry Zone markets. The study was conducted using a scientifically based methodology that has been tested and improved across 12 developing countries in West and East Africa (Sanabria et al., 2013).

Information generated by this type of study conducted in all agricultural areas of the country would be indispensable to support the development of a Myanmar Fertilizer Quality Regulatory System.

Methodology for Data and Sample Collection

The fertilizer quality assessment was restricted to six townships (Pakokku and Yesagyo in Magway region and Maghlaing, Myingyan, Nahtogyi, and Taungtha in Mandalay region) located inside the Myanmar Dry Zone. Before conducting the field survey to collect samples and data from fertilizer markets, six IFDC staff members and six Department of Agriculture (DOA) staff members were trained for two days in theoretical and practical components of the scientifically based methodology designed to inspect fertilizer quality in fertilizer markets. In teams of three people, the 12 trained IFDC and DOA staff members took turns conducting the fertilizer quality inspection in markets of each township. It was very important that each inspection team working in the townships included a DOA member; as government representatives, the DOA staff members confer authority to the inspection team to collect data and fertilizer samples from the fertilizer dealerships.

The methodology consisted of two sampling steps: the first was the random selection of a sample of fertilizer dealers, and the second was the random selection of fertilizer samples and data collection in each dealer shop selected in the first step.

Sampling of Fertilizer Dealers

A list of 144 fertilizer dealers provided by the DOA was the basis to define a conceptual population of fertilizer dealers in the Dry Zone. The fertilizer dealer sample size was determined based on the sampling capability of one inspection team depending on the net number of sampling days – discounting travel time – and the number of dealers that the sampling team was able to visit in a day. The random process for selecting the sample of dealers was weighted by the number of dealers in each township and the number of shops in each dealer category: retailer and wholesaler. This means that the subsample of dealers from a township had a size proportional to the total number of dealers in the township, and the representation of wholesalers and retailers was proportional to their presence in the townships.

The random sample of dealers included 33 fertilizer dealers, equivalent to 22.9% of the population. A list of the dealers in the sample was prepared for each of the six townships; a number of additional dealers selected at random were added to make substitutions when a dealer in the sample list was not found or when the dealer did not have any fertilizers.

The inspection teams collected fertilizer samples and collected data about characteristics of markets, dealers, storage conditions, and fertilizer products following procedures specified by international standards. Data collected about these characteristics were used to explain fertilizer quality problems (Sanabria et al., 2013).

Chemical Analysis of Fertilizers

Two DOA laboratories, one in Yangon and the other in Mandalay, that provide soil, plant tissue, and fertilizer analysis services were evaluated about their capabilities to analyze fertilizers. After satisfactory analysis of macro- and micronutrients in blind samples given to the labs, the Yangon laboratory received 30 duplicate samples from the 82 samples collected in the Dry Zone. All 82 samples were analyzed at the IFDC laboratory in the USA.

Nutrients determined were total nitrogen (N), available phosphorus (P_2O_5), and soluble potassium (K_2O). Samples included fertilizers that contain sulfur (SO_4^{-2}), calcium (CaO), magnesium (MgO), iron (Fe), and zinc (Zn). Analysis of cadmium (Cd) was performed in a group of fertilizers containing P_2O_5, based on concerns about the natural content of Cd in phosphate deposits and the potential of this heavy metal accumulation in soils as fertilizers are applied season after season.

Physical Analysis of Fertilizers

The physical properties evaluated in the samples collected were: granule integrity through quantification of fine particles and dust, granule segregation, color, moisture content, critical relative humidity, caking, presence of fillers, and presence of impurities. The definition of physical properties was developed by Rutland (1993), and the assessment methodologies used in fertilizer markets was explained by Sanabria (2016).

Data Analysis and Interpretation

Nutrient Content Compliance

The 82 samples collected in the Dry Zone were classified as fertilizers of high commercialization and fertilizers of lower commercialization. The group of lower commercialization was also classified as granulated, liquid, and powder fertilizers. Fertilizers in the high commercialization group and fertilizers inside each subgroup of the lower commercialization group were pooled to assess shortages of total N, P_2O_5, and K_2O.

Due to the absence of a Myanmar Fertilizer Quality Regulatory System, the macronutrient shortage tolerance limit (TL) of 1.1% from the European Union (EU) was used (European Parliament, 2003). This TL was developed accounting for all the random variability involved in the process of adding nutrients to fertilizers in the manufacture of fertilizers and the random variability involved in the determination of nutrient content in the chemical analysis of fertilizers. A nutrient shortage is defined as follows:

$$\text{Shortage}_{(\text{nutrient})} = \text{Nutrient Content}_{(\text{laboratory})} - \text{Nutrient Content}_{(\text{label})}$$

A nutrient shortage is out of compliance when the $\text{Shortage}_{(\text{nutrient})} < \text{TL}_{(\text{nutrient})}$.

The macronutrient European OOCS TL of -1.1% will be used for determination and interpretation of nutrient shortages in this study.

The magnitude of an OOCS is expressed by combining the frequency and the severity of the OOCS. The frequency is obtained from the cumulative frequency associated with the shortage values out of compliance in the cumulative frequency distribution function (CFDF), and the severity is calculated as the mean of the nutrient shortage values out of compliance ± one deviation standard. For example, the frequency of OOCS for total N in Figure 2A is 9%, and the OOCS severity for total N is -1.5±0.29%.

The CFDF was used with quantitative continuous variables, such as the nutrient content of fertilizers and the fertilizer bag weight shortage (BWS). In addition, the frequency distribution function (FDF) is used in categorical variables, such as the ones associated with the market and dealer characteristics as well as with the fertilizer physical properties.

Bag Weight Verification

Prior to sampling each fertilizer product in a shop or warehouse, a bag was randomly selected to be weighed to verify the weight declared on the fertilizer label. The weight reported on the label and the weight obtained from the scale were recorded in two separate columns on the survey questionnaire, and the difference between the two values was used for the development of the weight CFDF. The CFDF graphs show the BWS in the abscissa and the cumulative frequency (percent) in the ordinate. The BWS is out of compliance when it is lower than 1% of the weight declared on the fertilizer label. The dominant bag weight found in the Myanmar Dry Zone is 50 kg; therefore, in most cases, the BWS tolerance limit is -0.5 kg.

Evaluation of Fertilizer Physical Properties, Characterization of Markets and Dealers, and Qualitative Storage and Packing Conditions

Given the categorical nature of some of the fertilizer physical property variables, such as caking or moisture content, as well as the characteristics of markets, dealers, and some of the storage and packing characteristics, the frequencies associated with the different categories of these discrete variables were obtained directly from the FDF.

Factors Influencing Fertilizer Quality

The factors that have the potential to affect the chemical and physical properties of fertilizers can be classified as internal and external factors. Some of the internal factors are themselves fertilizer characteristics, such as physical properties that are expected to influence the fertilizers' nutrient content compliance, or factors related to the environment (storage) where fertilizers are located. External factors, such as characteristics of markets and dealers, have an indirect effect on fertilizer quality; the potential effect of these types of factors on fertilizer quality is associated with behaviors of dealers and consumers based on their knowledge about fertilizers and the location of the markets and shops. Internal factors have a high likelihood of influencing the physical and chemical properties of fertilizers, while external factors have a potential effect on fertilizer quality; a potential effect means that such impact may or may not occur.

Relationships tested were the effects of physical properties, storage conditions, and market and dealer characteristics on nutrient content compliance. The effects of storage and bag conditions on fertilizer physical properties were also tested. All these relationships were evaluated with logistic regression models (Stokes et al., 2009).

Results

Distribution of Fertilizer Samples

Eighty-two fertilizer samples were collected from six townships in the Myanmar Dry Zone. Figure 1 depicts the relative importance of various fertilizers in the fertilizer markets of the Myanmar Dry Zone; the likelihood of finding the first four products listed in the figure in every store visited was high, while the likelihood of finding the rest of the fertilizers in every shop was low. Urea is underrepresented in the figure because its sampling was purposely reduced to a minimum due to the very rare nitrogen content shortages of this fertilizer. Only one sample was collected from each of 23 additional fertilizers not shown in Figure 1A. The NPK 15:15:15 product in various forms, some of them containing secondary and/or micronutrients, is the fertilizer of highest commercialization in the area, followed by NPK 10:10:5, NPK 15:7:8, NPK 16:16:8, NPK 0:21:0, and NPK 13:13:21. Eighty-two percent of the fertilizer samples were from granulated fertilizers, 10% from powder fertilizers, and 8% from liquid fertilizers (Figure 1B). The following bulk blends were found in markets of the Dry Zone: NPK 11:20:20, NPK 16:16:8, NPK 20:10:10, NPK 20:10:5, and NPK 20:12:12.

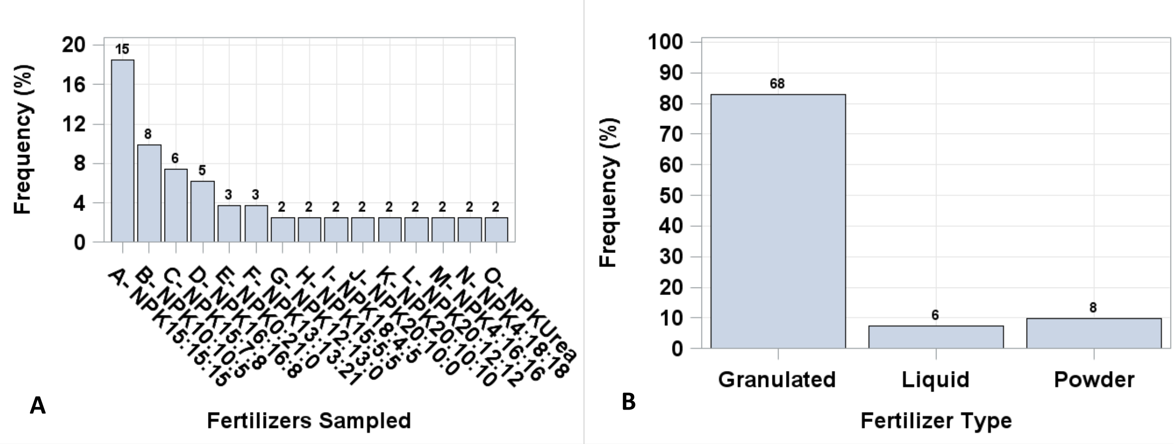

Figure 1. Frequency distribution of fertilizer samples collected (A), and frequency distribution of fertilizer types sampled (B) in the Myanmar Dry Zone.

Nutrient Content Compliance of Fertilizer

Granulated Products of High Commercialization

The granulated fertilizers of highest commercialization in the Myanmar Dry Zone were NPK 15:15:15, NPK 10:10:5, NPK 15:7:8, and NPK 16:16:8 (Figure 1A). Results from chemical analysis of these four products were pooled for the analysis of frequency used for the assessment of nutrient content compliance. Since Myanmar does not have a Fertilizer Quality Regulatory System, the EU TLs are used here as a reference for establishing the OOCS of each macronutrient content. The EU TLs for total N, P_2O_5, and K_2O content in solid granulated fertilizers is -1.1%.

Two samples, or 9% of the samples (Figure 2A), present OOCS for total N content. The total N OOCS severity is -1.5±0.29%. P_2O_5 OOCS takes place with a frequency of 19% and an OOCS severity of -4.7±3.3%. (Figure 2B). K_2O OOCS occurs with a frequency of 13% and an OOCS severity of -3.2±3.7% (Figure 2C). The total N shortages are very mild, while the P_2O_5 and K_2O shortages are more serious.

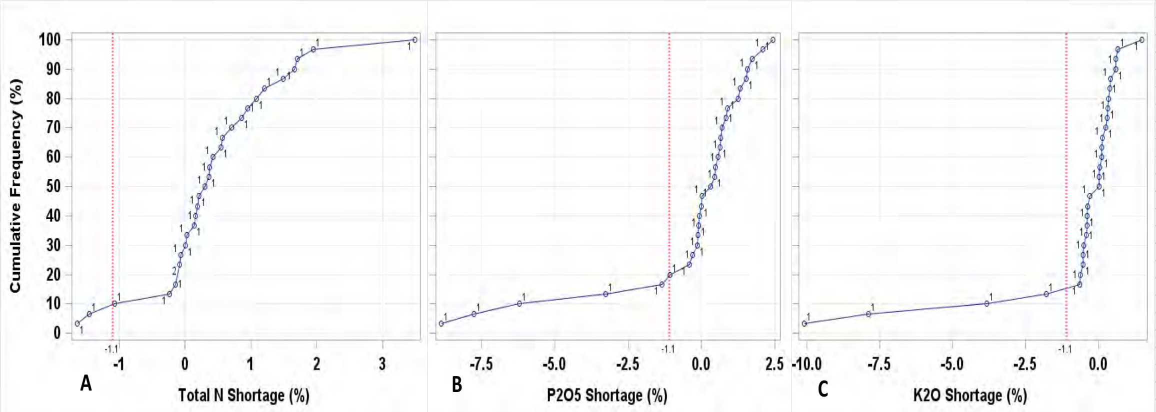

Figure 2. Cumulative frequency distribution function of total N (A), P_2O_5 (B), and K_2O (C) content shortages found for the fertilizers of highest commercialization in fertilizer markets of the Myanmar Dry Zone using the Indian and European Union tolerance limits.

Fertilizer products with three or fewer samples were classified as granulated, liquid, or powder and pooled within these three classes to conduct the analysis of frequency for nutrient content compliance. Interpretation of the nutrient content OOC will continue using only the EU TL.

Among the granulated fertilizers, the total N OOCS happened in 12% of the samples with an OOCS severity of 4.13±3.8% (Figure 3A), the P_2O_5 OOCS occurs in 15% of the samples with an OOCS severity of 3.13±4.1% (Figure 3B), and the K_2O OOCS takes place in 11% of the samples with a severity of 2.7±3.9% (Figure 3C). Among the liquid fertilizers, none is in OOCS for total N content (Figure 3A), two of the five samples present OOCS for P_2O content (Figure 3B), and one of the five samples shows OOCS for K_2O content (Figure 3C). Among the powder fertilizers, one of the seven samples presents OOCS for total N (Figure 3A), one sample presents OOCS for P_2O (Figure 3B), and none of the samples present OOCS for K_2O content (Figure 3C).

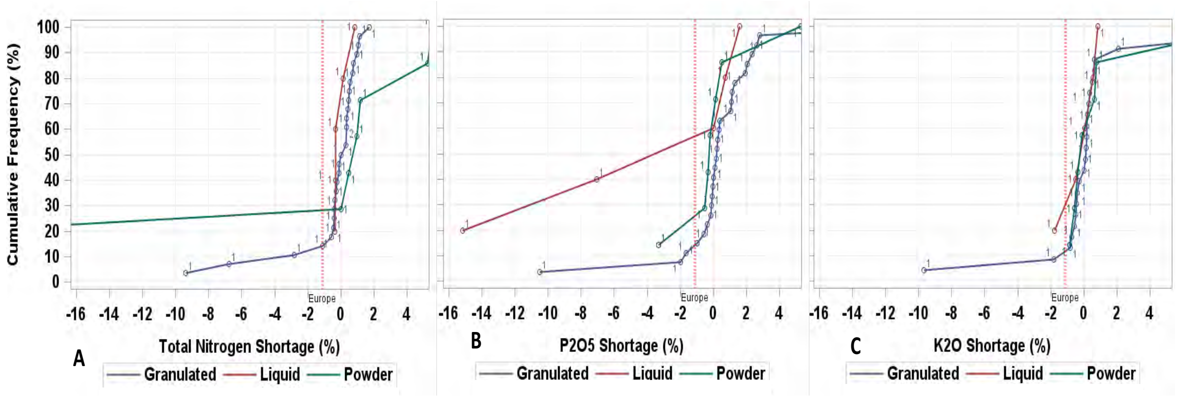

Figure 3. Cumulative frequency distribution functions for the nutrient content shortages of the three physical presentations of fertilizers of lower commercialization in the Dry Zone.

There were enough samples from fertilizers containing sulfur to develop the CFDF. From the 18 fertilizers that claim sulfur content in the form of sulfate (SO_4^{2-}), nine of them, or 50% of the samples, had sulfur shortages below the 0.36% EU TL.

Bag Weight Verification

Most of the international regulations suggest 1% as the TL for weight shortage, meaning that in the predominant 50-kg bags used in Myanmar, the maximum weight shortage is 0.5 kg. Eighteen percent of 50-kg bags sampled in Myanmar presented weight shortages higher than 0.5 kg.

Underweight bags result from lack of control in filling and weighing the bags during manufacture or rebagging. In some cases, it is possible that the underweight bags are the result of a deliberate act. The random error committed during the filling of the bags can be estimated from the weighted mean of frequencies associated with overweight 50-kg bags. The random error calculated this way is 4.0%. After subtracting the random error, it is estimated that 14% of the bags sampled are intentionally underweight.

Effect of Country of Origin on Nutrient Content of Fertilizers

The fertilizers' country of origin does not have a major effect on the nutrient content compliance of fertilizers (Figure 4). All of the countries of origin for the products sampled have the majority of the sample points at the right of the TL line for the three macronutrients. At the left of the TL line, there are just a few OOCS points for each macronutrient from China, Thailand, Vietnam, and Russia. China and Thailand have a few points more than the other countries in the "out-of-compliance area" across the three macronutrients. This is not evidence of lower fertilizer quality associated with these countries but is due mainly to the fact that these two countries have the largest sample size; by far, the largest proportion of samples from China and Thailand are in the compliance area.

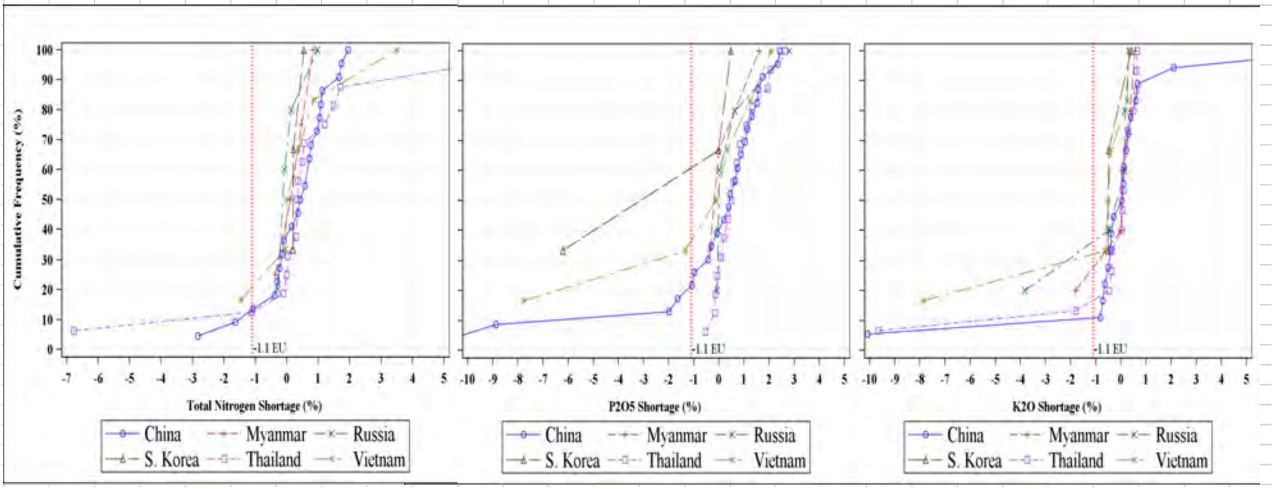

Figure 4. *Cumulative frequency distribution function of nutrient shortages from samples of fertilizers imported from five countries or manufactured in Myanmar.*

Cadmium Content in Phosphate Fertilizers

Cd is considered a toxic heavy metal and occurs naturally in soils and in the phosphate rock deposits used to manufacture fertilizers. Its accumulation in soil and uptake by crops have raised concerns and prompted considerable research and legislation to understand the problem and magnitude of the risks and to protect the public against the potential health problems associated with exposure to this heavy metal (Roberts, 2014). Forty-three of the fertilizers containing phosphorus that were collected in the Dry Zone were analyzed for cadmium. Sixteen of the samples contain Cd at levels lower than the analytical method detection limit; the rest of the fertilizers have Cd contents ranging between 0.011 and 0.83 mg Cd/kg P_2O_5. Even the maximum Cd content found in fertilizers of the Dry Zone is far below the 20 mg/kg P_2O_5 TL suggested by the EU (Roberts, 2014).

Storage and Packing Conditions

Physical properties of fertilizers in terms of moisture content, caking susceptibility, and integrity of the granules are highly affected by the temperature and relative humidity (RH) of the storage areas. In general, high temperature and high RH during the storage period are detrimental to the fertilizers' physical properties. Temperature in appropriate storage facilities should not exceed 30°C, and the relative humidity must be low enough to protect fertilizers from absorbing moisture from the environment. Absorption of moisture from the environment by fertilizers depends on the particular critical relative humidity (CRH) of each fertilizer. The CRH of any particular fertilizer depends on the hygroscopic characteristics of the constituent materials of the fertilizer. Figure 5, which has been constructed with RHs measured at temperatures between 28° and 32°C, shows that the CRH for NPK 15:15:15 is 43% and CRH for urea is 73%. This means that the NPK 15:15:15 and urea fertilizers at a storage temperature of 30°C start absorbing moisture from the air when the room RH is 43% and 73%, respectively. Other common NPK fertilizers in the Myanmar Dry Zone, such as NPK 10:10:5, NPK 15:7:8, and NPK 16:16:8, are expected to have a CRH similar to the NPK 15:15:15.

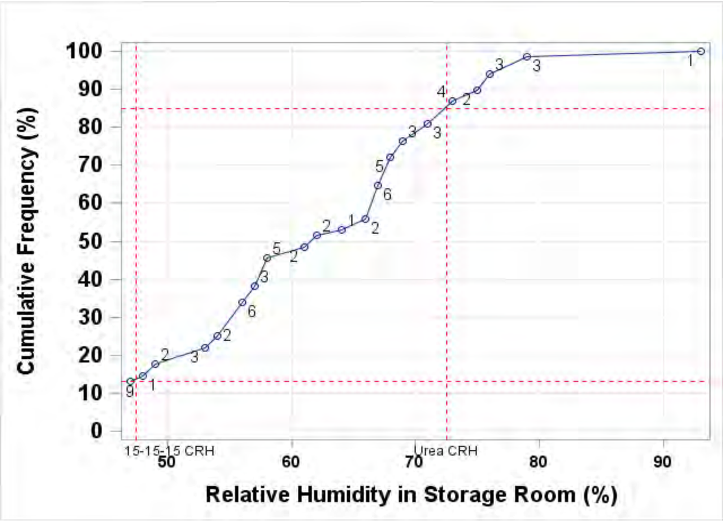

Figure 5. Cumulative frequency distribution function of the relative humidity in storage rooms and identification of critical relative humidity for 15:15:15 and urea in the fertilizer markets of the Myanmar Dry Zone.

The average temperature in the storage facilities inspected in the Myanmar Dry Zone is 32°C, and 80% of them are expected to reach temperatures of 30°C or higher during the afternoon. Fifty percent of the storage facilities are able to reduce the temperature inside only by 2°C with respect to the temperature outside; reductions of 4°C take place in just 32% of the storage rooms visited. The average RH in the storage rooms inspected was 58%, significantly higher than the CRH for NPK 15:15:15 and similar NPK fertilizers. Only 28% of the storage facilities inspected are able to reduce the inside RH by 2% with respect to the RH outside. Higher inside RH reductions, such as reductions of 4%, occur only in 12% of the storage facilities in the Myanmar Dry Zone.

The high temperatures and RH common in the fertilizer markets of the Myanmar Dry Zone are the result of inadequate ventilation and poor air circulation in the storage areas. Fifty-five percent of the storage rooms inspected had no ventilation or deficient ventilation, and the majority of them had poor air circulation. The poor ventilation and circulation are due to the absent use of pallets in 88% of storage rooms and none of the rooms having at least half a meter of free space between the walls or roof and the bag stacks as well as free space between stacks of different fertilizer lots.

Physical Properties of Fertilizers

Adequate moisture content was found in 98% of the fertilizer samples observed. The highly frequent cases of low or adequate moisture of the fertilizers commercialized in the Myanmar Dry Zone can be attributed mainly to the good bagging conditions, despite the very frequent storage conditions with high RH and the very limited capability of the storage facilities to reduce the RH with respect to the outdoors. Twelve percent of the bags inspected showed some caking, ranging from low-degree caking to high-degree caking. This degree and frequency of caking can be explained by a combination of factors that contribute to the fusion of fertilizer particles that end in caking. Pressure is exerted on bags located at the bottom of medium to high bag stacks, which are prevalent in 82% of the storage rooms. This, in conjunction with the low use of pallets and moisture reaching fertilizer granules in the few cases of torn bags and loose seams, can lead to caking. Another factor that may have contributed to the 12% caking may be thin inner layers of bags that allow penetration of water vapor inside the fertilizer bags. The dominant adequate moisture content, identified through the high flowability of dry granulated fertilizers, is mainly the result of the good quality bags used in the Myanmar Dry Zone.

The particle size distribution in the five most commercialized fertilizers in the Myanmar Dry Zone is dominated by the regular granule size (2-4 mm); the average presence of fines (1.9 mm-1 mm) is 2%, 1%, 0.5%, and 0.5% in NPK 10:10:5, NPK 15:7:8, NPK 15:15:15, and NPK 16:16:8, respectively, and negligible in NPK 13:13:21. Dust particles (< 1 mm) were present, with an average of 0.5% in NPK 10:10:5 and 4% in NPK 15:7:8. Three of the five fertilizers have close to zero granular degradation, and the other two fertilizers have granular degradation at non-concerning levels. Such a low level of granule degradation must be explained mainly by the manufacture of the products with an adequate granule hardiness that withstands the impact, crushing, and abrasion forces that act together and accumulate during the dominant manual handling of individual fertilizer bags practiced in the Myanmar Dry Zone. Another contributing factor to the low granule degradation in the Dry Zone is the good quality of the bags, which minimizes contact of fertilizer granules with environmental moisture.

The bulk blend fertilizers found in the area of this study were NPK 11:20:20, NPK 16:16:8, NPK 20:10:10, NPK 20:10:5, and NPK 20:12:12. No particle segregation was present in NPK 20:10:10, NPK 20:10:5, or NPK 20:12:12; in these three fertilizers, the granules of the three main constituents were symmetrically distributed in the three left columns of the sieve box, and the proportion of three types of granules was about the same in the three columns. This distribution of the granules indicates that the three components of the fertilizers have about equal proportion of granule sizes that range between 4 mm and 1.4 mm. The NPK 11:20:20 and NPK 16:16:8 fertilizers showed mild granule segregation, with urea (2.6-4.0 mm) showing a slightly higher proportion of particles than the other two components of the blend. The granule segregation analyzed by the particle distribution of the different components of the blend with the sieve boxes is usually corroborated by the chemical analysis; the blend components with higher proportion of particular size ranges are expected to show larger nutrient content than specified in the label, while the nutrients contained in particle sizes of low proportion show nutrient shortages. None of the samples collected from the five bulk blends found in the Dry Zone markets had OOCS for any of the three macronutrients.

Adulteration of Fertilizers

The presence of fillers or foreign materials that can be used to dilute the nutrient content of granulated fertilizers were not found in fertilizers packed in original bags or in rebagged fertilizers. Impurities that could indicate tampering of fertilizer bags were not found either. Fertilizer quality inspectors were asked to record any evidence of adulteration found in each of the fertilizer bags inspected. There was not one record related to adulteration of granular fertilizers.

Effect of External Factors and Fertilizer Physical Properties on Fertilizer Quality

From all the external factors tested for possible effect on nutrient content compliance, only the type of buyer showed evidence of having a significant effect on the nitrogen shortages of granulated fertilizers (Table 1). The probability from the chi-square distribution (Pr>ChiSq) equal to 0.058 indicates a significant effect of the type of fertilizer buyer on the nitrogen content shortages. The odds ratio for the type of buyer indicates that the occurrence of OOCS of total N in a fertilizer shop has 4.831 times higher odds when the shop buyers are small-scale farmers only than when the shop buyers are a combination of small-scale farmers, commercial farmers, and fertilizer retailers. This estimated odds ratio is significant because the 0.95 confidence interval (0.95 CI) does not contain zero.

Other relationships, such as the effect of physical properties on the shortage of macronutrient content and the effect of storage conditions and bag characteristics on fertilizer physical properties, were tested, but none of them helped to identify additional significant factors affecting fertilizer quality. Low variability of the physical properties (most of the samples were found within good physical categories that help to preserve good fertilizer quality) led to non-significant relationships in the logistic models.

Table 1. Significance test and odds ratio estimation from a logistic model predicting the effect of fertilizer dealer characteristics on nitrogen content shortages in the Myanmar Dry Zone.

Effect	DF	Wald Chi-Sq	PR > ChiSq	Odds Ratio Label	Odds Ratio Estimate	0.95 CI	
Owner Training	1	0.064	0.801				
Business Status	2	1.588	0.452				
Type of Buyer	1	3.604	0.058	Buyers: SS Frm only vs SS Frm+Com Frm/Ret	4.831	0.95	24.564
Owner Knowledge	1	2.513	0.113				

Evaluation of Laboratories for Chemical Analysis of Fertilizers

The staff working at the two DOA laboratories evaluated in Yangon and Mandalay demonstrated the scientific knowledge, experience, and administrative capability to perform fertilizer chemical analysis. The two laboratories performed well in the analysis of the blind samples, but the Mandalay lab has no capability to analyze micronutrients.

The equipment available in the two laboratories is antiquated and allows very limited automation; for this reason, the two labs have a turnaround of no more than 10 to 20 fertilizer samples a day. For the two labs to be capable of analyzing a large number of samples within the implementation of a Myanmar Fertilizer Quality Regulatory System, their equipment must be updated.

Conclusions

- The four fertilizers of highest commercialization in the Dry Zone – NPK 15:15:15, NPK 10:10:5, NPK 15:7:8, and NPK 16:16:8 – presented very mild OOCS for total N, but the OOCS for P_2O_5 and K_2O occurred in 19% and 23% of the samples, respectively, with -4.7% and -3.2% average shortage of P_2O_5 and K_2O, respectively.
- Among the fertilizers of lower commercialization in the Dry Zone, the macronutrient OOCS had a frequency ranging between 11% and 15%, and the severity of the shortages ranged between -2.7% and -4.1%.
- Based on the relative low OOCS severities of the macronutrients, the nutrient content problems in the Dry Zone are not as dramatic as reported anecdotally but

still require attention. Without evidence of adulteration and very mild granule degradation, the shortages likely originate in the manufacture of the imported products. Port inspections should be more rigorous.

- Macronutrient shortages do not show a difference among countries of origin. The majority of samples from different countries show nutrient contents in compliance. China and Thailand have some nutrient shortages out of compliance, but this is not enough evidence to indicate that products from these two countries are lower quality than those imported from other countries.
- The five bulk blends, each with only one or two samples, did not show nutrient shortages or granule segregation. These characteristics of the blends manufactured in recently established blending plants in Myanmar suggest the use of input fertilizers with uniform granule size and appropriate technology/equipment to manufacture this type of fertilizer.
- Fourteen percent of the bags showed weight shortages greater than 0.5 kg.
- Cadmium content in the fertilizers traded in Myanmar is not a concern; the maximum Cd concentration found in phosphoric fertilizers is well below the tolerance limit contained in international standards.
- High bag stacks and absent use of pallets produced caking in 12% of the samples. The good quality of the bags protects fertilizers from moisture absorption, granule degradation, and higher caking despite the hot and humid storage conditions.
- Appropriate granule hardness of imported products is a factor to explain minimum granule degradation despite manual and individual handling of the fertilizer bags.
- Of all the external factors evaluated, the only factor that had a significant relationship with nutrient shortages out of compliance was the type of buyer. When dealers sell fertilizers only to small-scale farmers, the odds of N shortages out of compliance are 4.8 times higher than when the dealer sells to a combination of small-scale farmers, commercial farmers, and fertilizer retailers.

Recommendations

- Updating the country regulatory framework, coupled with regional harmonization of regulations and standards, could contribute to making it more difficult for poor-quality fertilizer to be traded in Myanmar.
- Dealing with quality problems linked to the manufacturing process will require more stringent inspection arrangements at the points of entrance to the country. Regular training of inspectors to update their skills and knowledge should be emphasized in quality assurance plans. Laboratories located in the port inspection points able to provide nutrient content results quickly are required.
- There is a chance that informal markets or informal fertilizer dealers distribute fertilizers with quality characteristics lower than the ones found in the formal markets sampled in this study. Such informal distribution points must be identified and included in future sampling for assessment of fertilizer quality in the Dry Zone.

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Nitrogen Content and Fertilizer Quality in Central Myanmar

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Abstract

Nitrogen (N) fertilizer quality in local markets and factors influencing its quality control were assessed in Pyinmana, Tatkone, and Taungoo townships of Central Myanmar. This study found that N-based commercial fertilizers in local markets are generally adequate, as only 6% of total inspected fertilizers, primarily nitrogen-phosphorus-potassium (NPK) compound fertilizers, were deficient in N content. All urea, ammonium sulfate (AS), and diammonium phosphate (DAP) samples contained the required levels of N. There was excellent agreement between the Yangon laboratory and the University of Melbourne laboratory for N fertilizer analysis. According to a survey of fertilizer inspectors and dealers, the main factors influencing the quality of fertilizers were weak control of fertilizer imports at borders, insufficient and under-resourced fertilizer inspectors, delays in providing up-to-date information on fertilizer products, limited knowledge of fertilizer dealers, and slow turnaround times from analytical laboratories.

1. Background

Fertilizer is an important agricultural input that can increase agricultural productivity and profitability when used at the proper time and in an appropriate nutrient balance. In Myanmar, the application of mineral fertilizers for the first high-yielding variety (IR8) was adopted in 1978 when the government encouraged fertilizer use by subsidizing fertilizer prices (Soe et al., 2015). At that time, the government of Myanmar encouraged farmers to apply urea fertilizers because the country had natural gas as a major raw material for urea production. Most farmers now use N fertilizers because they noticed a clear plant growth response and it is cheaper than other major nutrient fertilizers that contain phosphorus or potassium. According to the Myanmar Department of Agriculture (DOA) Land Use Division (LUD) database (2017), the imported and domestically produced N fertilizers, such as urea and ammonium sulfate (AS), in 2016 were almost half of total fertilizer use in the country, indicating N fertilizers are being used by most of the farmers that use fertilizer. Thus, N fertilizer has been recognized as a key fertilizer in fertilizer marketing.

Farmers are the main decisionmakers on the use of mineral fertilizers and they need reliable information on fertilizer quality. However, farmers and a majority of those involved in the fertilizer industry, such as sellers, distributors and end-users, are not well trained on fertilizer specifications, labeling requirements, plant nutrient deficiencies, adulteration, and other issues such as misbranding in Myanmar.

Fertilizer quality issues, such as low-quality fertilizer through cross-border trade (Global Agriculture and Food Security Program, 2016) and improperly labeled bags, are often found in local markets. Most dealers do not have any means to check the quality of fertilizer. According to LUD fertilizer quality inspection data in the domestic market (LUD, 2017), 211 and 651 fertilizer samples in 2014-2015 and in 2015-2016, respectively, were different from the label specification. This can cause substantial losses to famers who usually have to purchase fertilizers (and other inputs) with a loan before planting. The application of below-specification fertilizer by farmers is a major constraint along the fertilizer supply chain. The sale of urea N fertilizers that are well below the correct content of 46% has been a problem in Uganda (Bold et al., 2015), where it can be expected that there is minimal regulation and lack of control of the importation of fertilizers. Similar conditions apply in Myanmar, and it has been speculated that fertilizers deficient in N are responsible for smaller than expected responses of crops to fertilizer.

Although quality assurance is crucial to maximize the profitability of fertilizer end-users, there is a lack of regular assessment in fertilizer quality control programs in the laboratories of LUD, which is responsible for the regulation of fertilizer in Myanmar. This is because of limited capacity. Despite the importance of fertilizer quality along the fertilizer supply chain, there are limited studies of fertilizer quality, particularly in central Myanmar, encompassing the Central Dry Zone and upper Bago District. Although it is one of the main agricultural regions, producing rice, maize, grain legumes, sesame, sunflower, and sugarcane, grown in rotation or as intercrops, the yields of these major crops are limited by low soil fertility and suboptimal agricultural management. Therefore, an evaluation of the quality of fertilizer inputs is essential, especially for N fertilizer. An assessment of fertilizer analysis capacity and performance of institutional laboratories is also valuable.

This study was conducted to assess the state of fertilizer quality and quality control in central Myanmar. The performance of the laboratory analysis of N in fertilizers by the only laboratory responsible for fertilizer quality assurance in Myanmar was also assessed.

2. Materials and Methods

This study focused on commercial inorganic fertilizer quality in Pyinmana (19^{o}74’43”N, 96^{o}21’78”E), Tatkone (20^{o}09’81”N, 96^{o}19’41”E), and Taungoo (18^{o}09’81”N, 96^{o}19’40”E) townships. The study area is one of the largest agricultural production areas of central Myanmar where rice, maize, legumes, and various kinds of vegetables are grown. These townships are some of the major fertilizer marketing centers in the Mandalay and Bago regions. In this study, commercial fertilizer samples available in local markets were collected and tested for conformity with bag labels. In January 2017, a total of 233 commercial fertilizer samples were taken from fertilizer wholesalers, retailers, and local distributors chosen at random from the surveyed townships. Seventy-five dealers and 10 fertilizer inspectors from DOA were interviewed using a questionnaire. Extensive data were collected from each of the dealers interviewed to capture their perceptions of fertilizer quality, sales in 2016, and dealer training requirements. Interviews were held with the owner of the shop, who makes the decisions on bulk fertilizer purchasing and selling activities. The field investigations of fertilizer physical characteristics, such as caking, impurity, and granular degradation, involved site visits to fertilizer dealer shops and warehouse locations.

In this study, a commercial N fertilizer is considered deficient in quality if the analysis is below the guaranteed percentage by an amount exceeding the applicable value specified in the Schedule of the Fertilizer (Control) Order (2013), which is currently used for regulating fertilizer quality in the country.

To evaluate the quality of fertilizer analysis by institutional laboratories, the fertilizer samples were sent to both the LUD laboratory in Yangon, Myanmar, and the University of Melbourne (UoM) soils laboratory in Melbourne, Australia, for total N analysis. Total contents of N were determined by using the Kjeldahl method in the LUD laboratory (Horwitz et al., 1970) and the C/N combustion method in UoM (LECO combustion at 1350°C in a stream of oxygen).

In this study, descriptive analysis was used to analyze the data. Simple linear regression analysis was used to investigate relationships between the two laboratories' results for N and between the laboratory results and bag label specifications of N content. These were conducted using the discrete sample data and the Regression (REG) procedure in SAS (SAS Institution, 2002).

3. Results and Discussion

3.1 Types of N Fertilizer Found in the Local Market

From the survey analysis of fertilizer sales in 2016, 12 wholesalers, 15 retailers, and 11 local distributors sold about 1,614 metric tons, 4,009 metric tons, and 173 metric tons, respectively, in the surveyed area. Nitrogen fertilizers were the highest proportion of total nutrients sold (from 55% to 70% of total) in the surveyed area. The N content of fertilizers found in the local market is shown in Figure 1.

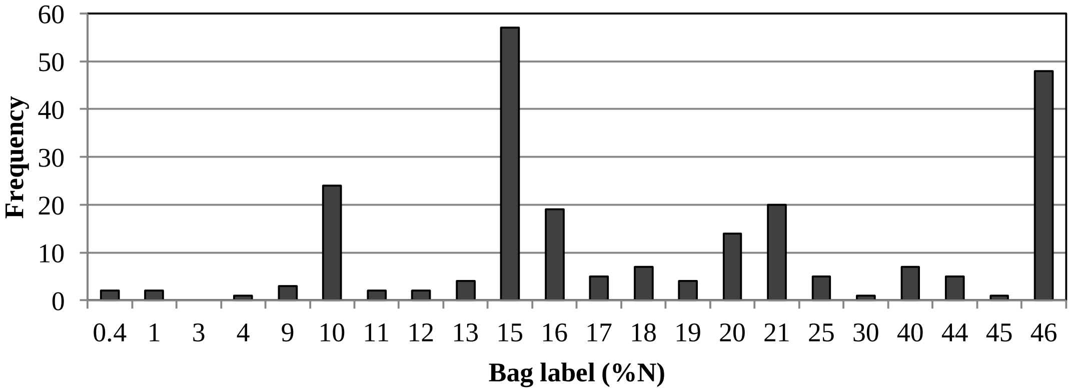

Figure 1. The stated N content (%) of fertilizers obtained in 2017 from the survey region (233 samples).

The results of this study show that compound fertilizers containing 15% N were the most common type sold in the surveyed area, followed by urea (46% N) and compound fertilizers with 10% N. This is in accord with the perception of interviewed dealers, who added that most farmers buy 15:15:15 NPK compound fertilizers, urea, and 10:10:5 NPK compound fertilizers for their crops. Dealers further stated that product sales were dictated by farmer preference. Based on the dealer interviews, fertilizer sales for individual townships in 2016 were dominated by N-containing products followed by P, K, and other nutrients, such as calcium and sulfur (Table 1).

Table 1. Average fertilizer sales in the surveyed region in 2016.

Townships	**Sold N%**	**Sold P_2O_5%**	**Sold K_2O%**	**Others %**
Pyinmana	58	18	19	5
Tatkone	61	20	18	1
Taungoo	70	11	6	13

3.2 Quality of Inspected N Fertilizers

3.2.1 Physical Characteristics of Fertilizers

Caking

About 17%, 13%, and 9% of urea samples from Pyinmana, Tatkone, and Taungoo townships, respectively, showed evidence of caking and this would reduce its free-flowing property. Improper storage conditions are the likely cause, as a much lower frequency of caking was found when urea had been repacked into polyethylene bags for home use.

Impurity/Adulteration

Visual inspections suggested there was no obvious impurity/adulteration of the N fertilizers and this was in accord with the interviews of 75 dealers and 10 fertilizer inspectors in the surveyed area.

Granular Degradation

Granular degradation was found in one brand of urea fertilizer produced locally in Myanmar. This degradation may reflect weak mechanical granular strength after manufacture and subsequent breakdown of product during handling.

3.2.2 Chemical Characteristics of Fertilizer

There was a strong correlation between the N content labeled on the bag and % N content of fertilizer determined by UoM (R^2=0.97, P<0.001) and LUD (R^2=0.99, P<0.001) laboratories (Figure 2).

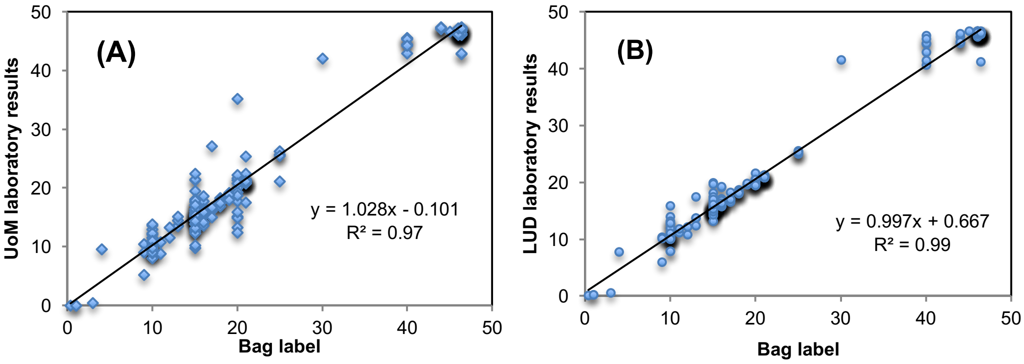

Figure 2. Relationship between % N figures for the UoM (A) and LUD (B) laboratories and bag label for commercial fertilizers obtained in the survey region.

The slope of the regression line was close to one in both cases and suggests adequate labeling of the N content of the local fertilizer products. A few samples (14 out of total 233 samples) were N deficient based on LUD results, as shown in Table 2.

Table 2. Frequency of fertilizer samples deficient in N.

Bag Label (%N)	Sample Size (n)	Deficient Products (n)	Average Lab Results* + Tolerance Limit	SED
0.4	1	1	0.18	
1	2	2	0.76	0.05
3	1	1	1.13	
9	3	1	6.49	
10	24	2	8.42	0.02
12	2	1	11.36	
13	4	1	12.89	
15	57	4	14.85	0.29
46	61	1	41.43	

*Results based on those determined by LUD.

Half of N-deficient samples were found in each of Pyinmana and Tatkone townships while all samples collected in Taungoo township met acceptable N quality standard. Among them, 11 out of 14 samples are imported from China. A disproportionate number of samples were unregistered products (five in all), suggesting that restrictions on the sale of unregistered fertilizers in the local market would improve fertilizer quality.

All urea (60 samples), AS (19 samples), and DAP (4 samples) contained at least the designated levels of N, with the exception of one urea sample, which was 41.4% N. Almost one in 10 NPK compound samples were N deficient. Further work will involve the analysis of the P and K content of these products by both laboratories.

3.3 General Requirement on Fertilizer Bag Labeling and Storage Facilities

In theory, the nutrient specification of fertilizer granules should be listed on the label in Myanmar or English language. In practice, at least three different brands of products were improperly labeled. In these cases, the list of nutrients was either stated only in Chinese script or those in Myanmar language did not include the nutrient specification. Most dealer shops had inadequate storage conditions with high relative humidity (34%), poor ventilation (73%), and lack of pallets (77%).

3.4 Assessment of Local Fertilizer Testing Laboratory's Capability

The regression analysis results provided the relationship of total N content of commercial fertilizers between the LUD and UoM laboratories, as shown in Figure 3.

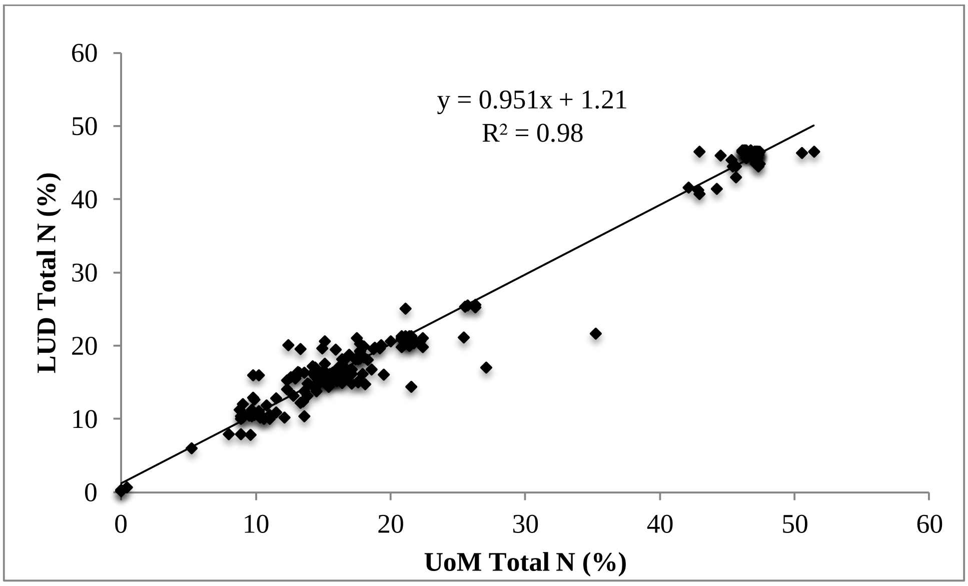

Figure 3. Comparison of total N content (%) of the commercial fertilizers as determined by the LUD and UoM laboratories.

There was a strong linear relationship between % N content of fertilizer samples for the UoM and LUD laboratories (Root Mean Square Error of Estimate [RMSE]=1.003). The results indicate that the LUD laboratory in Yangon, a local laboratory, is at least as reliable as the UoM for analysis of total N content of fertilizer samples. Clearly, the LUD laboratory is competent for monitoring and regulation of fertilizer quality in terms of total N content.

3.5 Factors Influencing Fertilizer Quality in the Local Market – Survey Results

3.5.1 Frequency of Inspection

Dealers were asked how many times government fertilizer inspectors visited their shops annually and how many fertilizer samples were taken. On average, there was one inspector visit a year, with around one-third of the dealer shops in Pyinmana and Tatkone townships visited and around two-thirds of dealer shops visited in Taungoo township. On average, two fertilizer samples per shop per year were taken in Pyinmana and Taungoo townships. In Tatkone township, inspectors took one sample per shop per year. The inspectors mainly check sales licenses, packing, and labeling. They also verify the product registration. There are three inspectors per township. None of the dealers surveyed had attended training, either from the government institutes or INGOs/NGOs, for fertilizer quality control. All fertilizer inspectors indicated that they were unable to properly train dealers about how to control fertilizer quality in their shops, mostly owing to time constraints.

3.5.2 Resourcing of Inspectors

There is an inadequate number of extension staff at township and village levels, which means most dealers are infrequently inspected. On average, one agricultural extension officer covers between 1,500 and 1,600 farmers in Central Myanmar. Dealer visits and product sampling are secondary to the extension service activities. There are no additional budget allocations for inspection of dealer shops supported at regional and/or national levels. In addition, the LUD has field staff to inspect fertilizer shops at the district level; however, most fertilizer shops are located at township and village levels.

3.5.3 Import Controls

There are weak border controls for imported fertilizer owing to lack of facility for checking fertilizer quality, especially entering through the border crossing at Muse in Shan State. According to the data from the Ministry of Commerce, Department of Trade, commercial fertilizers are mainly imported from the border area, which was about 77% of total fertilizer imported in 2015-2016. Gregory et al. (2014) reported that improperly labeled bags without Myanmar language were found with Chinese imported products. About 80% of the respondent inspectors stated that imported products should be sampled and analyzed at the border as a first line of defense. Controlling of fertilizer quality at township and village levels will be more efficient if there are effective fertilizer quality control standards at the border.

3.5.4 Product Information

About 70% of the inspectors interviewed claimed that one of the constraints to control fertilizer quality includes delay in providing up-to-date information on fertilizer products to dealers and farmers. This information should be provided in a timely way after the meetings of fertilizer committees (which are responsible for product registration approval, registration of fertilizer business licenses and product import licenses, brand and bag/label specification approval, and sampling and analysis of fertilizer imports and in retail stores), because retailers and local distributors mostly stock commercial fertilizers one month before the growing season and one month during the growing season. Supporting booklets of fertilizer information, such as the registered and canceled product list, is limited due to budget constraints. Many dealers (38 out of 75) also complained that verification was time-consuming with over 3,000 registered products on the list. Consequently, they sometimes stock unregistered products in their shops.

3.5.5 Training

According to the surveyed results, most of the dealers in the surveyed area have limited knowledge of fertilizer quality control owing to the lack of training. For instance, the actual nutrient content of the products is never questioned by wholesalers as this is beyond their capacity. Verification of quality was limited to the inspection of the physical characteristics of fertilizer, such as caking, obvious impurity, and condition of the bag. Further, most retailers and all local distributors do not check the quality of the products as they only sell them based on farmers' orders. It was noted that there was no balance to verify the weight of fertilizer bags at most of the dealer shops in the surveyed area. Farmers have to pay based on the weight of fertilizer mentioned on the bag in local market. About 87% of dealers answered that they were interested to attend the training on fertilizer quality control in their own township.

3.5.6 Analytical Response Times

There are no regional laboratories at the Pyinmana and Tatkone townships and inspectors have to send the collected samples to the main laboratory at LUD headquarters in Yangon. Turnaround times are at least one month, since the analysis of regular inspected samples is low priority for the main laboratory service. Consequently, 40% of inspectors mentioned that little could be done to control substandard fertilizers for the current growing season.

4. Conclusion and Recommendations

N fertilizer is a major nutrient addition to crops such as rice, maize, and legumes in the Central Zone of Myanmar. The main institutional laboratory (LUD) for analysis of N content in commercial fertilizer in Myanmar is reliable when compared to UoM laboratory. The study concluded that commercial N fertilizers in the local market are generally of good quality, with only 6% of total inspected fertilizers deficient in N content. These were NPK compound fertilizers. Physical degradation of product was relatively minor (caking, 13%; granular degradation, 0.43%; and mislabeling, 1.29%). The analysis of fertilizer shop samples from this study appears to show that fertility quality for Myanmar farmers is generally satisfactory. The problems of the sale of urea fertilizers deficient in N, as described by Bold et al. (2015) in Uganda, do not appear to apply in Myanmar.

Institutional factors influencing fertilizer quality control are weak border controls, inadequate number of and poorly resourced fertilizer inspectors, delays in providing up-to-date information of fertilizer products, limited knowledge of dealers, and slow feedback from the laboratory.

The following recommendations are made as a way forward to maintain fertilizer quality at the township level:

1. In terms of N fertilizer quality control, fertilizer inspectors should concentrate their monitoring effort on NPK compound fertilizers and blended fertilizers.
2. Stringent import agreements should be entered into with neighbouring countries. Fertilizers without appropriate certification should be denied entry.
3. Since the number of fertilizer inspectors and budget are limited, policymakers should assign more inspectors at the township level and provide additional budget for increasing dealer visits and product sampling.
4. Regional laboratories should be established to provide quick feedback to the dealers.
5. The concerned institutes should provide dealer training on topics including product characteristics, physical and fertilizer quality control, storage conditions, and efficient use of fertilizer for sustainable crop production in conjunction with farmers. A joint training program of fertilizer quality control with private and public sectors should also be held.
6. To update the commercial fertilizer information immediately after the meetings of fertilizer committee, the concerned institute should establish an official website of the product information. This will be very efficient and convenient to access the information of the products not only for the fertilizer inspectors but also for the dealers.

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Quality of Fertilizer and Its Rapid Assessment using MicroNIR

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Abstract

Fertilizer quality affects farmer decision-making processes in many developing countries. In this study, we tested 78 fertilizers collected across the Central Dry Zone of Myanmar and compared their nutrient content for N, P, and S with values stated on the fertilizer bags. We also evaluated fertilizer quality using a MicroNIR technique that can be deployed quickly, easily, and inexpensively in village markets. Less than 4% of fertilizers did not contain any N or P as indicated on the bag. The range in N values was +/- 20% for fertilizers containing 15% N. The range in P values was from -30% to +60% for fertilizer containing 6.3% P. Heavy metal analysis of the tested fertilizers revealed no contamination. MicroNIR spectrometry is able to determine N% within +/- 1.4% of the actual N concentration with rapid scanning, and accuracy can be improved if time is taken to either scan samples directly (without placing in a vial) or by grinding samples (+/- 0.8% N). The small size of the MicroNIR spectrometer, cost-effectiveness, and performance can allow real-time testing of N fertilizer quality in the field for supplier verification or at the point of trading.

Introduction

Soils in Myanmar's Central Dry Zone (CDZ) are generally considered to be of low fertility. A recent survey of soils in the CDZ confirms the low-nutrient status, with 61% of sites identified as being low in phosphorus (P), 48% sites low in potassium (K), 35% sites low in sulfur (S), and 18% sites characterized as low in all three nutrients (Guppy et al., 2017). The expectation is that yields for pulses in the CDZ of Myanmar would be considerably improved through the application of fertilizer, the current amount applied being typically low and predominantly consisting of manure and/or compound fertilizer applied before the onset of the monsoon (hence, susceptible to leaching) (Birchall et al., 2017). Two years of multi-location experiments across the CDZ has revealed little response to P, K, and S fertilizer additions (Guppy et al., 2017). In these experiments, biomass cuts at 45 days revealed that there was zero, or apparently negative, fertilizer recovery observed in the majority of trials. The lack of fertilizer response may have been associated with either fertilizer mislabeling or low efficacy. In Myanmar, the Land Use Department of the Ministry of Agriculture, Livestock and Irrigation (MOALI) is responsible for administering fertilizer regulations, under direction of the Fertiliser Committee and MOALI. Typical concerns over fertilizer include mixing of fertilizers, adulteration of fertilizers with inert materials, the use of inferior product, misleading labels on bags, and underweight bags (Gregory, 2015). As an alternative to standard laboratory analysis, we sought to develop a rapid test with the potential to distinguish counterfeit from legitimate fertilizers. The aims of our study, therefore, were to (1) develop a rapid near infrared (NIR)-based test for the evaluation of fertilizers and (2) compare the accuracy of the rapid test with standard laboratory testing of fertilizer integrity.

Materials and Methods

Fertiliser Sources

Initially, triple superphosphate (TSP) fertilizer used in 2015/16 chickpea field experiments was retained, analyzed for P and S content, and compared with a reference Australian TSP fertilizer. Following the initial fertilizer analyses, 78 fertilizer samples were collected from the Mandalay, Magway, and Sagaing regions of the CDZ. Fertilizers included variations of compound fertilizers (often labeled as 15:15:15 $N:P_2O_5:K_2O$), triple superphosphate, urea, sulfate of potash, and gypsum.

Elemental Analyses

Nutrients in fertilizers were analyzed using standard analytical methods (Rayment and Lyons, 2011) in the Environmental and Analytical Research Laboratory, Agronomy and Soil Science, University of New England, Australia, using appropriate standards for calibration and verification.

Near Infrared Analysis

Near infrared analysis was conducted using the MicroNIR™ spectrometer, a relatively new instrument developed and commercialized by JDSU Corporation (Santa Rosa, California, USA) (Alcala et al., 2013). Fertilizer samples were scanned by placing the MicroNIR in direct contact with the unground sample and through the plastic vial in which the sample was stored. The MicroNIR is an ultra-compact spectrometer designed to be used in diffuse reflection, transflection, or transmission modes. The MicroNIR uses a linear variable filter (LVF) component mounted over a diode array detector that separates incoming light into individual wavelengths. The spectrometer integrates the light source and readout electronics in a small construction. Key attributes of the MicroNIR 1700 spectrometer are summarized in Table 1. The samples were scanned in diffuse reflectance mode. Each sample was scanned three times, and both the average and individual spectrum values were used for further analysis. The NIR spectra were recorded on the MicroNIR Pro Software version 2.2 provided by JDSU. The spectrum for each sample was obtained by taking the average of 100 scans (12.1 ms integration time). The dark and white spectrum reference was obtained after every 10 samples.

Chemometrics

Multivariate data analysis was conducted using The Unscrambler X software (version 10.1, CAMO ASA, Norway). The NIR spectral data were processed using the second derivative to provide a measure of the change in the slope of the curve ignoring the offset. The use of this pre-processing technique is also very effective in removing both baseline offset and slope from a spectrum. Principal component analysis (PCA) was performed before discriminant analysis and classification. PCA was used to derive the first principal components from the spectral data to examine the possible grouping of samples and to detect possible spectral outliers.

Results and Discussion

The initial analysis of retained TSP from experiments in the Zaloke and Sagaing regions indicated that the % P in the fertilizer sample was eight times lower than expected. As confirmation, the proportion of S in this sample was three times greater than that observed in the standard fertilizer sample. A comparative TSP sample sourced from Myith Thar region had P and S concentrations that were not dissimilar to a reference Australian TSP.

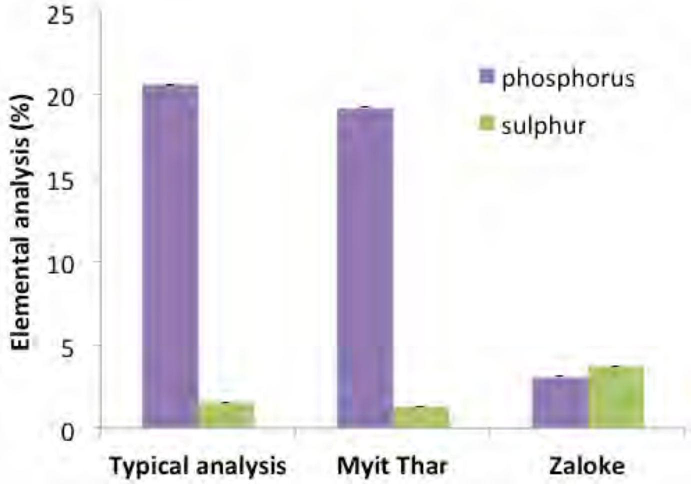

Figure 1. ***Variation among samples of TSP used in field experiments in Myit Thar and Zaloke, compared with a reference Australian TSP fertilizer.***

For the follow-up sampling and analysis of 78 fertilizers from the CDZ, there was generally good agreement between the labeled P contents and that determined by standard analytical methods (Figure 2). However, there were deviations among fertilizers, both higher and lower than the expected amounts, particularly for samples listed as compound fertilizers and for TSP fertilizers. For compound fertilizers, two-thirds of farmers would be receiving more P than stated, while for TSP, two-thirds would be receiving slightly less than stated on the label (Figure 2). In some cases, nearly twice as much P was present in the compound fertilizers than indicated on the label.

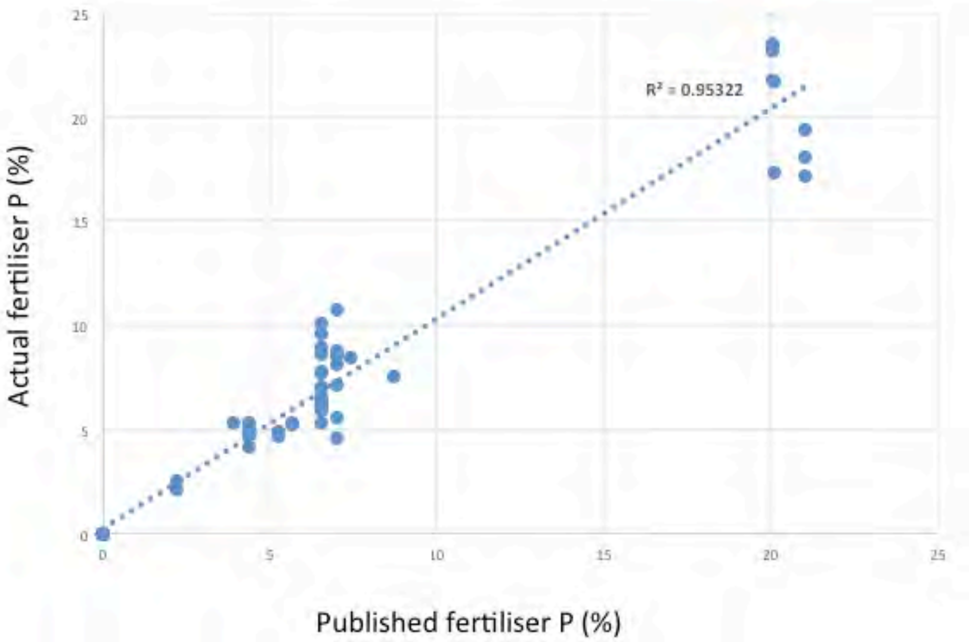

Figure 2. Labeled and measured P concentrations of fertilizers sampled from resellers in Magway, Mandalay, and Sagaing regions of the CDZ, Myanmar.

The use of NIR, in combination with post-analytical chemometrics, proved to be a powerful technique for discriminating among different fertilizer types and could clearly distinguish real and counterfeit compound fertilizers from each other and from urea (Figure 3). Analysis indicated that variation among different compound fertilizers was largely driven differences in N-based spectral properties.

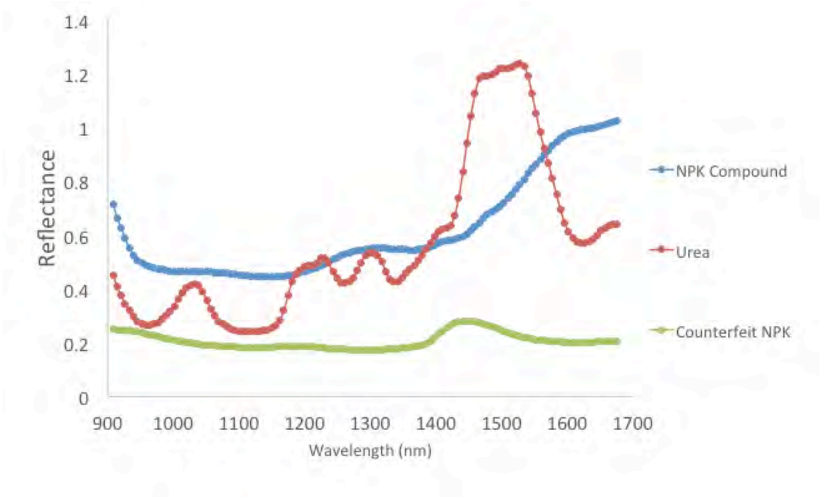

Figure 3. ***Fast, non-destructive characterization of fertilizers using MicroNIR-based technology to discriminate between two compound fertilizers (legitimate and counterfeit) and urea.***

Principal component analysis (PCA) based on spectral properties from the MicroNIR provided a means to separate different fertilizers (Figure 4). The PCA analysis separated different fertilizers into general clusters, but with the exception of urea, there was some overlap of clusters and multiple clusters for NPK compound fertilizers, triple superphosphate, potash, and gypsum.

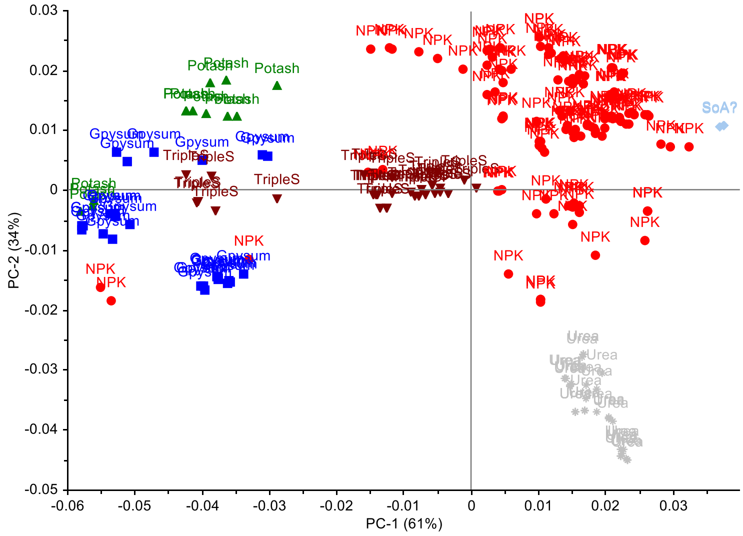

Figure 4. ***Multivariate analysis idenfitying clusters of fertilizer types for model prediction.***

An analysis of nitrogen in fertilizer samples indicated that there was a close relationship between N in fertilizer predicted by standard chemistry methods and that using the MicroNIR (r^2 >0.98) (Figure 5). While the prediction of % N as accurate to within 0.8% when scanning the fertilizers directly, scanning through vials did not manifestly reduce accuracy (+/- 1.4%).

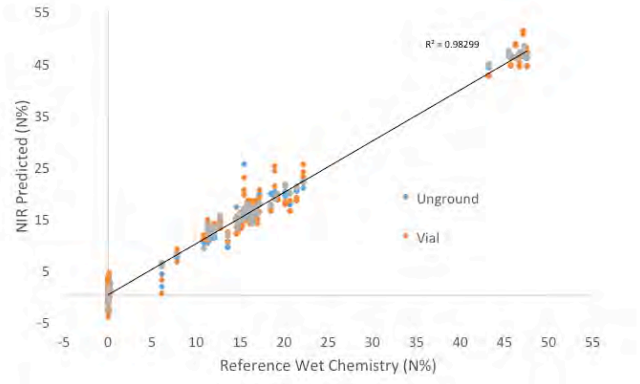

Figure 5. ***Prediction of % N using NIR compared with standard laboratory-based chemical laboratory analysis.***

The development of a MicroNIR to assess fertilizer quality provided was an effective technique for rapid testing. NIR spectroscopy had already shown promise in the analysis of blended fertilizers in South Africa (van Vuuren and Groenwald, 2013). This technology shows significant promise for use in Myanmar and has the potential to be adapted by importers and resellers to initially screen and assess fertilizer quality. Although counterfeit compound fertilizer was identified, 96% of fertilizer samples were true to label, so there do not appear to be widespread quality issues with general fertilizer supplies. Caution is warranted, however, as this screening trial did not set out to identify the extent of counterfeit fertilizers in all regions of Myanmar. The presence of counterfeit fertilizers is not unique to Myanmar, as counterfeit fertilizers were reported recently in Uganda (Bold et al., 2015). Additional analysis of fertilizers from Myanmar also indicated that no heavy metal contamination was detected in any sample (data not shown).

Conclusion

Seventy-eight fertilizer samples from the marketplace were analyzed for nutrients using standard chemistry techniques. Results indicated 96% were true to label, with no heavy metal contamination detected in any sample. A MicroNIR system was developed that provided rapid assessment of fertilizer quality by direct scanning, once post-scanning analysis had been established. The NIR shows strong correlations with wet chemistry, particularly for N. Further work will focus on NIR for P and K analysis. The portability of the MicroNIR spectrometer, cost-effectiveness, and performance can allow real-time testing of N fertilizer quality in the field for supplier verification, or at the point of trade, which provides an effective system to use in countries such as Myanmar.

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Challenges in Establishing a Private Fertilizer Quality Assurance Laboratory in Myanmar

Z.W. Min

Myanma Awba Group

Abstract

Myanma Awba group is the leading group of companies in Myanmar focused on agriculture. Established in 1995, Myanma Awba Group has steadily grown to become the market leader of the Myanmar agriculture sector. With a team of over 1,500 people, Myanma Awba Group is the country's largest manufacturer and distributor of agricultural technology and plays a leading extension role in training farmers how to optimize their growing practices. Its research and development (R&D) team develops crop solutions and tests new products and varieties to bring to market. Myanma Awba Group employs the largest number of agronomists outside the government and commands a footprint that extends across the country. The company is a broad-scale agribusiness player active across the agriculture value chain, with upstream and downstream assets and capabilities. It has a particular focus on crop protection, crop nutrition, high-quality seeds, microfinance, digital tools, manufacturing, and logistics. The company also works in partnership with a number of globally respected organizations and welcomes further collaboration opportunities across the private, government, and non-governmental organization sectors.

The ambition of Myanma Awba Group is to set a global standard for agriculture value chain companies as a farmer-focused, sustainable, and responsible partner of choice. Its missions are to:

- ✓ Produce more and better quality food.
- ✓ Upskill and develop smallholder farming.
- ✓ Enrich and strengthen rural communities.

Myanma Awba Group's strategic business units and subsidiaries extend across the value chain. The company provides holistic solutions from R&D, formulation, granulation, manufacturing, packaging, and logistics up to marketing, extension, and finance.

This manuscript aims to:

1. Share knowledge and experience with the private sector, which may want to set up a fertilizer testing laboratory while establishing a fertilizer quality assurance protocol.
2. Help the newly establishing fertilizer testing laboratory avoid problems and limitations encountered by Myanma Awba.
3. Encourage private sector companies in the establishment of a fertilizer quality assurance laboratory, so that quality of fertilizers in the market meets public demand.

1. Introduction

Background of Myanmar Agriculture

Myanmar contains within its borders a wide range of agro-ecological zones. Rainfall varies from 5,000 mm in the Southern Coastal areas to about 800 mm in the Central Dry Zone. Altitude ranges from sea level to over 5,000 meters and latitude from 10 to 29 degrees. The maximum daily temperature ranges from an average of 32°C in the Delta to 21°C in the hill region. This diversity gives rise to an enormous variety of microclimates. There is, consequently, a wide variety of crops, including rice, maize, and wheat, many kinds of beans and peas, oilseeds, potato, onion and garlic, many types of temperate and tropical fruits and vegetables, spices, and industrial crops like sugarcane, cotton, rubber, cashew, and oil palm (Jansonius, 1999).

Despite the country's richness in resources and strategic location, development of the agriculture sector has been constrained by macroeconomic instability, infrastructure constraints, marketing and financial issues, and farmers' lack of access to quality research and extension support. Relatively weak agricultural performance also has negatively impacted the overall development of the rural sector (Kyi, 2016).

Major issues raised by rural people are mostly related to lack of market access, which also relates to quality and quantity of the products. While implementation of good agricultural practices (GAP) is slow, Myanma agricultural products are not in line with market requirements in terms of quality. On the other hand, production of value-added products is very rare along the crop value chain. There are no subsidies for farmers to mitigate migration and abandonment of their farmland. Increasing use of farmland for other purposes (e.g., increased crude oil drilling area), urbanization, and acquisition of land jeopardize agricultural land and leverage farmers to abandon their farms (Min, 2016).

Farmer Practices on Use of Fertilizers

Soil is a precious production asset that needs maintenance. In Myanmar and in many other parts of the world, soil maintenance and its involved costs are not considered. As a result, soils are becoming increasingly exhausted, resulting in higher (chemical) fertilizer needs and increasing costs to achieve the same yields as before.

Chemical fertilizer plays an important role in increasing Myanmar's agricultural production and improving food security for millions of people. Fertilizer can also have a negative effect, as overuse of chemical fertilizer spoils groundwater sources and increases eutrophication of lakes, streams, and rivers. Inefficient use will increase production cost without leading to improved production. Where fertilizer is purchased on credit (particularly unfavorable credit with high interest rates), farmer face increased indebtedness.

Farmers' knowledge on fertilizer and fertilizer use is limited. The choices farmer make on what type of fertilizer to use and how much are usually based on observations of farmers in their villages with neighbors, friends, and family. Soil testing is typically done by fertilizer traders in order to advise farmers and is only done sporadically.

There are rumors circulating among farmers and shopkeepers with regard to mixing fertilizer. Many shopkeepers mentioned that rebagging at the border of China is the point of mixing high- and low-quality fertilizer. Although we cannot verify these rumors, it is important not to deny them either. *There is a need for quality testing of fertilizer at the point when farmers purchase fertilizer*. Farmers need to be protected against companies that deliver bad quality fertilizer (FSWG, 2015).

In accordance with the need for controlling quality of fertilizers as well as registration and marketing of fertilizers, the Myanmar government enacted the fertilizer law in 2002. In 2015, a revised fertilizer law was approved by the parliament. The main purpose of the fertilizer law is to regulate quality and reduce environmental risks. The law is doing this through a registration licensing system. The law itself works in favor of farmers in the sense that the quality of fertilizer is crucial to smallholder farmers.

There are 3,093 fertilizer resellers in Myanmar registered with the Land Use Division (LUD) of the Myanmar Ministry of Agriculture and Irrigation (IFDC, 2014).

2. Objectives

The followings are reasons why Myanma Awba has established its own fertilizer testing laboratory:

1. Since Myanma Awba Group of companies is one of the country’s leading agro-chemical companies, all the products of the company are supposed to be in line with existing laws, such as the fertilizer law.
2. The government is to conduct regular checks on the quality of fertilizers and to punish the companies that do not adhere to the law.
3. The company itself is also obligated to fulfill public demand for quality fertilizers in the market. The quality of fertilizer is crucial, especially to smallholder farmers.
4. On the other hand, the company has long been importing both fertilizers and raw materials. The quality of those imported items is not only crucial for the benefit of the company but also for the end user farmers. However, the number of accredited laboratories is too small to analyze a reasonable number of samples to be able to accept or reject poor quality fertilizer.

3. Site Selection

Myanma Awba’s fertilizer quality assurance laboratory is located in Shwe Lin Pan industrial zone on the west bank of Hlaing River. The laboratory was built on an area of about 100 m^2 between a factory and a warehouse. This location was selected because Myanma Awba’s bulk fertilizer blending factories and warehouse are located there.

Sampling of both bulk blended fertilizers and imported fertilizers as well as raw materials is much easier by locating the laboratory near the factories and warehouses. Information flow among respective teams, such as the quality assurance team, factory team, and logistic team, is quite fast; thus, the analysis can be done in a timely fashion.

However, the location is quite far from Yangon city. It is about an hour-and-a-half drive from the eastern townships of Yangon like South Okkalapa, Thingangyune, and Tarmwe in normal situation and a two-hour drive in heavy traffic condition. By taking the ferry, the laboratory staff spend about three to four hours in the car for a roundtrip every day. This is about half of their daily official working time of eight hours. On Saturday, it is longer than the three working hours. One might suggest that we can select staff from nearby townships, e.g., Insein and Danyingone. But it is difficult to do so, because of the need for qualified persons. Although Shwe Lin Pan is an industrial zone, the electricity outages occur frequently, making analysis difficult to complete. As the laboratory is between a warehouse and a factory, noises from the factory and from trucks entering the warehouse are disturbing to laboratory staff members. Moreover, the ground and lab building vibrate due to movement of heavily loaded vehicles.

4. Laboratory Building

The laboratory building is made by Japan Modular house, which is a sophisticated container-type construction. Exterior walls and roof are made of steel plate or sheet, insulated with phenolic foam to resist fire as well as weather changes. The floor is made of hardwood chip cement board, insulated with styrene foam. The ceiling is made of coated plywood. The available space of the whole building is 83.32 m^2, with 34.06 m^2 for the sample preparation room, 17.73 m^2 for the staff room, 25.74 m^2 for the storage and equipment room, and 5.79 m^2 for the entrance space.

Table 1. Available spaces in the laboratory building.

Partition	**Space (m^2)**
Sample preparation room	34.06
Staff room	17.73
Storage and equipment room	25.74
Entrance space	5.79
Total available space	83.32

The laboratory building is mobile, which is an advantage in relocating to a more suitable area. The quality and durability of the building are comparable to brick and concrete buildings. However, it is more expensive than a concrete building. Although it was built on a reinforced concrete foundation, it vibrates when heavily loaded tucks and fork lifts move around, making the use of some analytical equipment, such as the digital balance, difficult.

5. Selection of Laboratory Equipment

The quality assurance laboratory was primarily aimed to ensure not only the quality of fertilizers produced by Myanma Awba, but also those imported from abroad. Therefore, the laboratory was furnished with equipment necessary for the analysis of fertilizers. The nitrogen, phosphorus, and potassium content in the fertilizers are the major nutrients to be analyzed initially in the quality assurance laboratory. For nitrogen determination, the Kjeldahl digestion assembly and auto distillation assembly were equipped. The spectrophotometer was later equipped for the determination of phosphorus and sulfur that were initially analyzed gravimetrically. Myanma Awba called for tenders from supplier companies to provide that equipment as well as other laboratory equipment, such as the fume hood, oven, shaker, balance, pH meter, distilled water assembly, and glassware. Among the supplier companies, AMTT and NANOVA were selected after evaluating product price and brand. Cost and brand of each equipment are shown in Table 2.

Table 2. Final selected supplier companies and brand of equipment supplied.

No.	Instruments	Quantity	Price Offer (MMK)	Delivery	Brand	Supplier Company	Total Cost*
1	Kjeldahl digestion assembly	1	12,400,000	Sea freight	Gerhardt (Germany)	AMTT	22,250,000.00
2	Nitrogen distillation assembly	1	9,850,000	Sea freight			
3	Fume hood	1	7,497,000	Sea freight	Labtech (Korea/Indo)	AMTT	7,497,000.00
4	Mechanical shaker	1	2,800,000		Human-Lab (Korea)	NANOVA	2,800,000.00
5	Distilled and deionized water assembly	1	1,728,000	Sea freight	Boeco (Germany)	AMTT	1,728,000.00
6	pH meter	1	1,000,000		Horiba (Japan)	NANOVA	1,000,000.00
7	Conductivity meter	1	1,000,000		Horiba (Japan)	NANOVA	1,000,000.00
8	Oven	2	2,458,000		Labtech (Korea)	AMTT	2,458,000.00
9	Analytical balance	1	1,125,000		Shimadzu-Japan	AMTT	1,125,00.00
10	Digital balance (display 0.1 g)	1	291,000		Shimadzu (Japan)	AMTT	291,000.00
			Grand Total				**39,024,000.00**

Laboratory glassware was provided by First Prime Company Ltd. The company was selected for the quality of glassware and the prices they offered. The glassware provided by that company is one of the world's most reliable brands, Duran. The total cost for glassware was about 124 lks MMK.

Lab furniture was provided by Sinma Co. Ltd. Design and laboratory table sizes were adjusted for the available space in the sample preparation room. Staff office of the laboratory was also furnished by Sinma, and price and total cost can be seen in Table 4.

Table 3. List of laboratory furniture and total purchase price from Sinma Co. Ltd.

No.	Items	Price (MMK)	Discount (MMK)	Total Price (MMK)
1	Lab table (central and side)	9,400,000	940,000	8,460,000.00
2	Storage cabinet (5W*2D*7H ft^3)	1,930,000 x 2	-	3,860,000.00
4	Storage cabinet 2 (5W*1.5D*6H ft^3)	1,240,000	-	1,240,000.00
5	Table with granite top/metal frame	320,000 x 2	-	640,000.00
6	Glass tube holder	990,000 x 2	-	1,980,000.00
	Total Cost			**16,180,000.00**

Table 4. List of furniture for laboratory staff office and total cost.

No.	Items	Unit Price (MMK)	Quantity	Total price (MMK)
1	Manager table	930,000	1	9300,000.00
2	Staff table (2 units)	910,000	1	910,000.00
4	Staff table (3 units)	1,380,000	1	1,380,000.00
5	Lab table chairs	70,000	5	350,000.00
6	Staff chairs	125,000	5	625,000.00
7	Manager chair	270,000	1	270,000.00
		Total Cost		**12,835,000.00**

Additional costs included:

- Service tank = 1,200,000 MMK.
- Emergency bath and eye wash = 1,140,000 MMK.
- Spectrophotometer = 14,500,000 MMK.

6. Purchasing Selected Equipment

Purchasing of laboratory equipment was done three months before the estimated starting time of the laboratory. All selected suppliers were called for final quotes and contracted. Terms of payment of the suppliers were varied from company to company. Most companies required a 50-70% down payment, but some did not ask for it. One company offered payment credit two weeks after complete delivery. Validity of quotes varied from one to two months after submission. Most companies offered three to four months of delivery time after the date of the contract. However, due to a long transportation route, delivery was delayed, especially for glassware, which was purchased at the end of March but delivered in July. Some delayed delivery times are presented in Table 5.

Table 5. Some example of delay delivery of equipment from selected suppliers.

No.	Specification	Model	Brand	Country of Origin	Qty	Proposed Delivery Period	Estimated Delivery Date	Contract Signing Date	Due Delivery Date	Delay Period
1	Kjeldahl digestion assembly	KT-8S	Gerhardt	Germany	1	Within 2.5 months	15.3.17	15.12.16	28.2.17	2 weeks
2	Scrubber unit	Turbosog	Gerhardt	Germany	1	Within 2.5 months	15.3.17	15.12.16	28.2.17	2 weeks
3	Nitrogen distillation assembly	VAP-200	Gerhardt	Germany	1	Within 2.5 months	15.3.17	15.12.16	28.2.17	2 weeks
4	Fume hood	LPH-2120V	Labtech	Korea	1	Within 3-4 months	14.3.17	15.12.16	15-30.3.17	In time
5	Water distiller	WS 4000	Boeco	Germany	1	Within 2.5 months	7.3.17	15.12.16	28.2.17	1 week
6	Deionizer	DS 450	Boeco	Germany	1	Within 2.5 months	7.3.17	15.12.16	28.2.17	1 week
7	Oven	LDO 060E	Labtech	Korea	2	Stock on hand	31.3.17	15.12.16	28.2.17	3 week
8	Analytical balance	ATX 224	Shimadzu	Japan	1	Stock on hand	Stock on hand	15.12.16	OK	No
9	Digital balance	ELB 3000	Shimadzu	Japan	1	Within 3-4 months	Stock on hand	15.12.16	OK	No

7. Equipment Setup

Most laboratory equipment was placed in the sample preparation room, with a space of about 34.06 m^2. The laboratory building was built before the equipment was received. Electric sockets and power lines were assembled by Japanese engineers in accordance with the power requirements of each piece of equipment. The water supply to the basin and nitrogen digestion and distillation assemblies was made by Myanmar experts. The central laboratory table was placed at the center of the sample preparation room surrounded by a side laboratory, two ovens, one fume hood, and Kjeldahl digestion and distillation units. The cabinets to store samples, glassware, and the spectrophotometer (bought later) were placed in the storage and equipment room.

Since the laboratory building was built before the equipment was received, there were some modifications to the building for water inlet, outlet, and electricity supply. It was impossible to build the drainage channel from the basin on the laboratory table undern the floor; thus, it was built on the floor, interfering with movement of the staff. Holes for water inlet and drainage were made in the modular building. Some new electricity supply lines were added in accordance with the newly purchased additional equipment.

8. Staff Recruiment

Laboratory staff were recruited while the building was being furnished. A team leader, one laboratory supervisor, and three laboratory assistants were recruited. A team leader was recruited for assisting the head of the group laboratory in conducting fertilizer and soil analysis, developing suitable and advanced methods for those analyses, training lab assistants for chemical analysis, maintenance of the laboratory and analytical instruments, reporting analytical results, ensuring product quality, and other related assigned duties (including office work). Qualifications for team leader included a minimum of a bachelor’s degree (master’s degree preferred) in a related field of work (e.g., agriculture chemistry or industrial chemistry), with five years of experience in chemical analysis preferred, and knowledge of analytical instruments, such as GC, HPLC, and AAS, highly preferred.

The laboratory supervisor and assistants were recruited for conducting fertilizer and soil analyses, sampling of soil and fertilizers, sample preparation, maintenance of the laboratory and analytical instruments, and other related assigned duties (including office work). Qualifications for lab supervisor and assistants included a minimum of a bachelor’s degree in a related field of work (e.g., agriculture chemistry or industrial chemistry), with experience in chemical analysis preferred, and knowledge of analytical instruments, such as a nitrogen digestion unit, distillation unit, and AAS, highly preferred. Someone with experience in chemical analysis and analytical equipment was employed as lab supervisor.

A total of seven persons applied for the team leader post and nine persons applied for the lab assistant and supervisor posts.

9. Analytical Procedures

As a quality assurance laboratory, it is very important that the laboratory uses relevant official analytical method for determination of a nutrient. All the methods used in the Myanma Awba fertilizer quality assurance laboratory were validated using the appropriate reference reagent.

The Myanma Awba quality assurance laboratory uses the Kjeldahl method for nitrogen determination. Organic nitrogen was digested with H_2SO_4 using $CuSO_4$ and K_2SO_4 catalysts. Nitrate nitrogen was reduced to ammoniacal nitrogen catalyzed by Devarda's alloy. The ammoniacal nitrogen was distillated in base condition and the distillate was received in 4% boric acid solution with a mixed indicator of bromocresol green and methyl read indicator and then titrated against standard HCl.

For determination of phosphorus (P_2O_5), potassium (K_2O), and sulfur (S), gravimetric analysis was first adapted before the spectrophotometer was received. Phosphorus was precipitated as quinolinium phosphomolybdate using quimociac reagent and the amount of precipitate was gravimetrically determined and weight of P_2O_5 was calculated. The amount of phosphorus in the fertilizer was reported as % P_2O_5. Potassium was precipitated as potassium tetraphenylborate, which was gravimetrically determined after oven drying. The amount of K_2O was then calculated and reported as % K_2O in the fertilizer. For determination of sulfur, sulfur was precipitated as $BaSO_4$ and the amount of precipitate was determined gravimetrically. Then, the amount of sulfur was calculated and reported as % sulfur in the fertilizer.

For determination of calcium, volumetric analysis of Ca with standard EDTA, which was standardized using standard $CaCO_3$, was adapted.

In the conventional Kjeldahl method for determination of nitrogen, standard HCl was used to receive the distillate and excess HCl was back-titrated with standard NaOH. In the new modified Kjeldahl method, the distillate was received in 4% boric acid and the $(NH_4)_3BO_3$ was directly titrated with standard HCl and concentration of boric acid did not need to account for calculation of nitrogen; thus, the result is more accurate. However, determination of P_2O_5, K_2O, and S by the gravimetric method was a somewhat laborious and time-consuming process, although the results are accurate. Precipitation, filtration, washing, drying, and weighing are all time-consuming processes; thus, an analysis took from eight to 24 hours.

In addition, the quality of reagents used for the precipitation process was uncertain. For example, while trying to precipitate quinolinium phosphomolybdate, no precipitates were observed, even though several tests were performed. The analytical method was modified many times and tests were performed for precipitation of phosphorus, but nothing happened again and again. Finally, the assumption was made that no precipitation could be due to uncertified repacked reagents; thus, all the reagents used were substituted with new branded reagents and tested again for precipitation of quinolinium phosphomolybdate. Precipitation then occurred and the results were satisfactory. It was obvious that the analysis was disturbed by uncertified reagents and there are many more uncertified reagents in Myanmar local market.

Therefore, an alternative method that could be faster with accuracy as high as the gravimetric ones was sought and adapted. A UV visible spectrophotometer was used for analysis of P_2O_5 and sulfur. Phosphorus- and sulfur-containing samples were digested and colored with respective compounds (ammonium metavanadate for P_2O_5 and gum acacia and $BaCl_2$ for sulfur). KH_2PO_4 was used as a standard for P_2O_5 whereas K_2SO_4 was used for sulfur. Detection was achieved at wavelength in the visible region.

10. Staff Training

Recruited laboratory staff were trained for analysis of fertilizers. For laboratory assistants, the training started with how to wash laboratory glassware, since glassware is the most important source of contamination and error. Analysis of N, P, and K was taught to the staff step by step during the month of May. Solvent preparation, preparation of standard solution as well as standardization, operation of laboratory equipment, and calculation of nutrient content based on the analytical results were taught to the staff in a timely manner. Myanma Awba products, as well as imported raw materials, were tested for training purposes. Staff were also trained for recording the analytical works, keeping data, sample information, handling of samples, etc.

11. Sampling Methodology

Sample details, as described in Table 6, were recorded when obtaining samples to easily track sample information when complaints were made.

Table 6. Sample details.

No.	Description
1	Sample name
2	Arrival date
3	Container number
4	Batch number
5	BL number
6	Amount arrived
7	Sample type (liquid/powder/gravel)
8	Brand name and Name of dealer/manufacturer/exporter
9	Name of inspector who collected sample
10	Warehouse location

Sampling from Bagged Material

Scale of Sampling

a. Lot (for manufacturers/importers) – All bags in a single consignment of material of the same grade and type drawn from a single batch of the manufacturer/importer shall constitute a lot. If a consignment is declared to consist of different batches of manufacturer/importer, all bags of each batch shall constitute a separate lot. In the case of a consignment drawn from a continuous process, 2,000 bags (or 100 tons) of the material shall constitute a lot.

b. Selection of bags for sampling – The number of bags to be chosen from a lot shall depend upon the size of the lot, as shown in Table 7.

Table 7. Number of bags to be selected for sampling depending upon lot size.

Lot Size (No. of bags) (N)	No. of Bags to be Selected for Sampling (n)
< 10	1
10-100	2
100-200	3
200-400	4
400-600	5
600-800	6
800-1,000	7
1,000-1,300	8
1,300-1,600	9
1,600-2,000	10

All the bags of a lot should be arranged in a systematic manner. Counting can begin randomly with any bag and continue consecutively up to r and so on, with r being equal to the integral of N/n. Thus, every rth bag counted shall be withdrawn and all bags shall constitute the sample bags from where the sample is to be drawn for preparing a composite sample.

Sampling Probe

An appropriate sampling instrument to be used by the inspectors for collection of a representative sample is called sampling probe. The probe may be comprised of a slotted single tube with soil cone tip, made of stainless steel or brass, or double tubes with a partition (Figure 1). The length of the probe may be approximately 60 to 65 cm and the diameter of the probe may be approximately 1.5 to 2 cm, with a slot width of 1.2 to 1.5 cm. The probe may be used if the physical condition of the fertilizers and the packing material permits its use.

Figure 1. Prototype of sampling probe made of stainless steel.

Extraction of Samples from Bags

Extraction of samples and preparation of composite samples – Extract, with an appropriate sampling instrument (sampling probe), small portions of the material from the selected bags. The sampling probe shall be inserted into the bag from one corner to another diagonally (Figure 2) and the inner tube shall be pulled off and the probe will be filled with fertilizer. When the probe is withdrawn, the fertilizer is emptied into a container, on a polythene sheet, or on a clean hard surface and made into one composite sample.

Figure 2. Sampling of bagged fertilizers.

Sampling of Bulk Fertilizers

(1) Sampling from the bulk storage piles

The bulk storage piles (level or flat) up to 100 tons can be sampled as per Figure 3. Take 10 cores to the maximum possible depth of the probe from the positions indicated in Figure 3 and cores are composited.

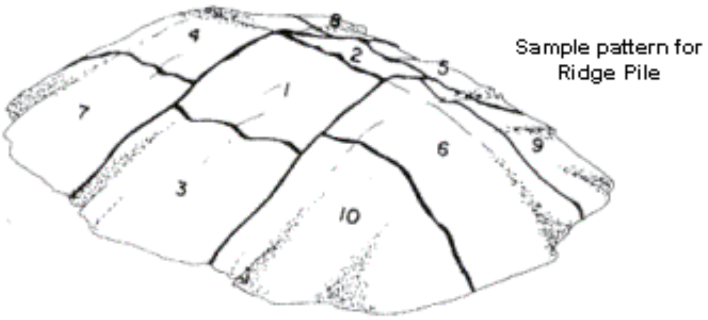

Figure 3. Sampling from the bulk storage pile.

(2) Sampling from a one-sided or sloped pile

A one-sided or sloped pile may be sampled at the points illustrated in Figure 4. Withdraw one vertical core of material from locations 1 and 6 and two cores from locations 2, 3, 4, and 5. Combine all the probe samples and prepare the composite sample for analysis.

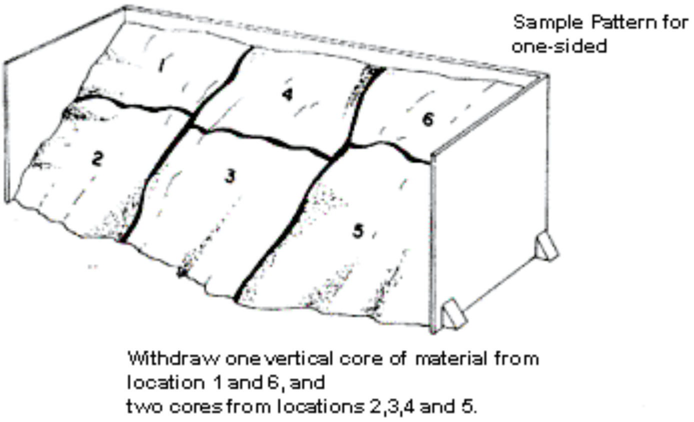

Figure 4. Sampling from one sided or sloped pile.

Preparation of Composite Sample

If the composite sample collected from the different selected bags is larger than required weight, its size shall be reduced by method of quartering as detailed below:

- Spread the composite sample on a level, clean, and hard surface.
- Flatten it out and divide it into four equal parts.
- Remove any diagonally opposite parts.
- Mix the two remaining parts together to form a cone.
- Flatten out the cone and repeat the operation of quartering until a composite sample of required weight is obtained.

Weight of One Sample

One sample of fertilizer shall have the approximate weight as specified below:

(i) For straight micronutrient fertilizers – 100 g
(ii) For chelated micronutrient fertilizers or mixtures of micronutrients – 50 g
(iii) For other fertilizer and mixtures of fertilizers – 400 g

Preparation of Test Sample and Reference Sample

i. The composite sample obtained above shall be spread out on a clean, hard surface and divided into two approximately equal portions (each of the weight specified). Each of these samples shall constitute the test sample.
ii. Each test sample shall be immediately transferred into a suitable container.
iii. Each test sample container shall then be sealed with the seals of the inspector.
iv. One sealed sample shall be sent to the person in charge of the laboratory, Fertilizer Quality Assurance Section, for analysis, and the second sample shall constitute the reference and shall be retained by the laboratory in charge.

12. Operating the Fertilizer Testing Laboratory

Test operation of the laboratory was started simultaneously with staff training. Myanma Awba products of known nutrient composition, as well as imported items, were analyzed for test operation as well as staff training. When analyzing, validation of method was performed using the appropriate reference reagent. Test operation was done during the month of May simultaneously with staff training.

Operation with real samples with specified nutrient compositions that need to be evaluated was started at the beginning of June. From June until the present, a total of 226 samples were analyzed for mitrogen (total, nitrate, and ammonium), phosphorus (total and water-soluble), potassium (water-soluble), sulfur, and calcium in accordance with the needs for production and distribution. As for physical properties, moisture content and granularity were also determined.

13. Reporting the Analytical Results

The reports are heading to the GCEO and GCOO, with a copy to MD of Myanma Awba Industry. The analytical results will be reported as soon as the analysis is completed. For fertilizers produced in Myanma Awba Industry's factory, the analytical results should be reported on the day of production, so that the next day's production can be adjusted if the first day's results show any problems. Imported cargoes are analyzed as soon as possible. The analytical results should be delivered within a week of arrival.

The report included nutrient compositions of the products/cargoes, moisture content, granularity, color, and shape. Sample information such as arrival date, supplier company, and BL number are also included in the report. The inspector's remark regarding whether the product/cargo is qualified or disqualified is the main content of the report.

14. Conclusion

Myanma Awba Group has successfully established a private fertilizer testing laboratory for quality assurance of both produced and imported fertilizers as well as raw materials. The whole process is summarized as follow:

- Purchasing of necessary lab equipment is a time-consuming process. It took three to five months to receive all the purchased equipment.
- Laboratory furniture can be made by a local company, giving them the design of the furniture.
- Water inlet, drainage, exhaust fan, and electricity source should be planned in accordance with installed laboratory equipment.
- It is somewhat difficult to recruit qualified laboratory staff outside of the government departments. Recruited staff should be well-trained for the required skills.
- Analytical methods used for fertilizer testing should be official methods that are well-validated.
- Some locally available reagents are unreliable in quality and interfere with the analysis.
- Sampling methodology should be well set up so that the analytical sample is a representative of the whole bulk/bag fertilizers. One reference sample should be retained for every test sample.
- Operation of the fertilizer testing laboratory can only begin after six months of preparation.

- A total of nearly 1,640 lks of Myanmar kyats (excluding reagent costs, minor expenses, and land value) were used for the establishment of a private fertilizer testing laboratory as summarized in Table 8.

Table 8. Major costs for establishment of a fertilizer testing laboratory.

Kinds	MMK
Building and lab equipment	121,224,000.00
Glassware	12,400,000.00
Lab furniture	17,320,000.00
Office furniture	12,835,000.00
Total Cost	**163,779,000.00**

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The Future of Research in Soil Fertility and Fertilizer Management in Myanmar – What to Do, How to Do, Who to Do It

Panel Discussion

The conference closed with a panel discussion. Panel members were:

- Dr. Tin Htut, Permanent Secretary, Ministry of Agriculture, Livestock and Irrigation.
- Dr. J. Scott Angle, President and CEO, International Fertilizer Development Center.
- U. Naing Kyi Win, Director General, Department of Agricultural Research.
- Dr. Raymond Weil, Professor, University of Maryland.
- Dr. Robert Edis, Research Program Manager, Australian Centre for International Agricultural Research.

Other participants spoke from the floor.

The Permanent Secretary repeated the call from the Minister to achieve sustainable agriculture through proper fertilizer management and a sound fertilizer management policy. He wants to see national and international experts working together to formulate a "Myanmar National Fertilizer Policy and Strategy." But that is not the end; it needs to be followed by an investment strategy, proper institutionalization, and then organizational restructuring.

It was noted that the United States, European Union, China, and some countries in Africa and Latin America have made and are making the same mistakes with improper fertilizer management. Myanmar's fertilizer sector is still immature, and moving forward, policy must be developed to prevent those same mistakes from being made. Myanmar must learn from the experiences of other countries, e.g., the toxicity problem in Mexico and the water pollution problem in China. This conference provides the impetus to establish the procedure for making the right decisions in the future.

Fertilizers are more than just for feeding plants. They feed the soil, and in doing so, they improve the environment. But fertilizer is only one component; we need to think about others that will sustain the soil and sustain crop growth. Better soil health can produce higher yields of high-quality food to feed the world. Human health depends on agriculture, agriculture depends on soil health, and soil health depends on fertilizers.

As we focus on food security, along with soil fertility and maintenance of the soil, we often overlook secondary and micronutrients, but they cannot be ignored. Balanced fertilizer requires consideration of all nutrients. How will we manage micronutrients? What is the source of micronutrients? What amount should be used? Improper application of micronutrients to fields could lead to a toxicity problem. The right amount, at the right time, and from the right source are very important factors. At the moment, we do not have enough good soil data. Laboratories for research are necessary. Mapping, such as soil mapping and soil carbon mapping, is needed and should be based on thousands of results. Modern technology for determining soil nutrients, such as scanning technology, is also desirable and important. It could prove to be a much cheaper and a much more efficient technology for providing fertilizer recommendations to farmers.

Farmers plow and harrow at shallow depths and create a hard pan, which means plants are only able to utilize the topsoil. Roots cannot penetrate to reach moisture and nutrients. We need to think not only about fertilizer management, but also cultivation, soil preparation, and fertilizer application.

Fertilizers must be managed within an integrated system that includes crop rotation and organic matter management. Of the various aspects of soil management, organic matter management is critical in the Central Dry Zone, although it is difficult to convince farmers to use it. Crop residue management to use as manure in the Dry Zone is desirable. The projects in the Dry Zone, including improved cropping system management, which is integrated with livestock, can change communities. Normally, livestock provide manure to the fields. Very sandy, acidic soils can be improved with the addition of organic matter. Organic matter management is important for farmers. Supporting ready-made compost from industrialization or government is also desirable. However, transportation costs are high, and there is a need for compact, ready-made compost that can be pressed or caked. Biochar is being used in the Dry Zone; however, charcoal should not be produced from firewood.

Research, development, and extension should be united. Myanmar needs quite advanced research on technology related to farming systems for improving soil fertility and farming communities. As climate change affects the Central Dry Zone and the Delta, there will be many challenges.

Unfortunately, the Department of Agriculture does not have the budget for a comprehensive extension service. Using non-governmental organizations and agro-input suppliers as farm advisers is an alternative.

Credit for farmers is an issue. Development of a banking system would allow farmers to access affordable credit that can be applied to many of the technologies being extended. Farmers cannot afford the current high interest rate of 25%.

For more than 20 years, Thai farmers used 16:20:0 NPK. Over time, P has increased in the soil, and a new formula recommendation is needed. This is a lesson for Myanmar.

Farmers can be confused by the choice of many types of fertilizer in the market. The experience of Thailand has been to use a fertilizer formula that is common and easy for farmers.

Closing Remarks by Dr. Tin Htut

We strongly require a “modern fertilizer strategy” through evidence-based results and results-based facts. Software and hardware balance is very important. A soil health development strategy is critical.

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