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FERTILIZER BULK BLENDING GUIDE

HARMONIZED GUIDELINES OF GOOD PRACTICE FOR QUALITY CONTROL ACROSS WEST AFRICA

November 2022 edition

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IFDC Developing Agriculture from the Ground Up

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November 2022

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ACRONYMS

AP . . . . Ammonium phosphate
ATM . . . . Atmosphere/atmospheric
B. . . . . Boron
Ca . . . . Calcium
CBN . . . . Central Bank of Nigeria
CIF. . . . . Cost in Freight
Cu . . . . Copper
DAP. . . . . Diammonium phosphate
DPC. . . . . Damp-proof course
EDTA . . . . . . Ethylene diamine tetra acetic acid
EBITDA . . . . Earnings before interest, tax, depreciation, and amortization
ECOWAS . . Economic Community of West African States
EFBA. . . . . . . European Fertilizer Blenders Association
EIA. . . . . Environmental impact assessment
EMP. . . . . Environment management plan
EPCM . . . . . . Engineering, procurement, construction, and management
ETC. . . . . et cetera
Fe. . . . . Iron
FF. . . . . Fertilizer factor
GSI. . . . . Granulometric spread index
HQA . . . . Holistic quality approach
IFDC . . . . International Fertilizer Development Center
K. . . . . Potassium
Mg . . . . Magnesium
Mn . . . . Manganese
Mo . . . . Molybdenum
MOP . . . . Muriate of potash
MSDS . . . . . . Material safety data sheet
N . . . . Nitrogen
NPV. . . . . Net present value
P. . . . . Phosphorus
PMBOK . . . . Project management body of knowledge
PPE . . . . Personal protective equipment
PPM. . . . . Parts per million
RM. . . . . Raw materials
RP . . . . Rock phosphate
RR . . . . Recommended rate
RSSF . . . . Real sector support facility
S . . . . Sulfur
SHERQ. . . . . Safety, health, environment, risk, and quality
SOP. . . . . Sulfate of potash
SSP . . . . Single superphosphate
TSP . . . . Triple superphosphate
UEMOA . . . . West African Economic and Monetary Union *(Union Économique et Monétaire Ouest Africaine)*
YR . . . . Year
Zn . . . . Zinc

DEFINITIONS

Binder – Material sometimes added to a blend to aid in preventing segregation.

Conditioners – ***For soils:*** products added to soil to improve the soil's physical qualities, usually its fertility (ability to provide nutrition for plants) and sometimes its mechanics. In general, can be categorized as soil amentments (or soil improvement, soil condition), which includes a wide range of fertilizers and non-organic materials (SSSA, 2012). ***For fertilizers:*** substances added to enhance physical conditions of fertilizer mixtures and also reduce the hygroscopic nature, e.g. peat, groundnut shell, paddy husk.

Countries in ECOWAS – Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

Holistic Quality Approach (HQA) – A fertilizer bulk blending approach that encompasses the various sets of procedures adopted by each of the 15 countries of ECOWAS and synchronizes them into one.

Farm area computation – 10,000 sq. m = 1 hectare (ha)

Fertilizer – Any substance which is intended to be used as a nutrient(s) source to the crops for increasing agricultural production (ECOWAS Regulation C/REG. 13/12/12). Organic and mineral substances utilized to ensure proper plant nutrition and supplement the nutrients already available in the soil, which are essential for plants to grow, thrive, and be healthy (IFA, 2020).

Fertilizer grade – Percentage content of total Nitrogen, available Phosphorus (phosphoric acid), and soluble Potassium (Potash), e.g., 20:10:10 | 15:15:15 | 27:13:13.

Fertilizer raw material (RM) – These are inorganic sources of one or more of the essential nutrients required by plants for growth. They are required for preparing blended fertilizers.

Fertilizer requirement (FR) – (Recommended Rate RR ./. % Nutrient Content NC in Fertilizer Raw Material RM) * 100 * Area (ha), where "100" represents the reduced weight of the fertilizer raw material to 100 kg.

Filler – Materials added to fertilizers to help in the uniform distribution of nutrients within a given volume of the fertilizer product.

Guarantee – The minimum amount of nutrient content contained in fertilizer raw materials or fertilizer blends, expressed in percentage. Excluding Phosphorus (P2O5) and Potassium (K2O), they are expressed in simple element form, e.g., Sulfur (S). But for Chlorine (Cl) content, the guarantee should not be more than the amount shown, e.g., 46-0-0 | 18-46-0 | 0-0-60.

Neutralizers – Substances added to counteract the acidity or basicity of soils or fertilizers, e.g., Dolomitic limestone (basic) is added to Ammonium sulfate (acidic) mixed fertilizers (Kostiner

Edwards, 1992 and Shakhashiri Bassam Z, 1989).

Nitrogen (N) – This can be considered to be the most important nutrient. It makes plants grow big and strong and is also known as the "Green Up" nutrient.

Percentage nutrient content (NC) – Percentage quantity of each fertilizer nutrient in a fertilizer raw material.

Phosphorus (P) – This is the nutrient that is crucial in all reproductive phases of a plant, e.g., seedling, fruiting, flowering, and blooming phases. Thus it is known as the "Blooming" nutrient.

Potassium (K) – This nutrient is key to plants in that it regulates their activation of enzymes, uptake of carbon dioxide and water. It aids the plants to build strong and healthy seeds and stems. Hence it is also known as the plant "Photosynthesis" nutrient.

Recommended rate (RR) – Quantity in weight of fertilizer nutrients to be applied in the soil as recommended by an agronomist, soil expert, or from a soil test analysis. In other words, it is the total NPK expressed in kg/ha basis. This recommendation is based on crop requirement, soil fertility, soil texture, and planting season.

Unit of recommended rate – Amount of fertilizer nutrient required per area, usually expressed per hectare.

FOREWORD

Accessing and using quality inputs, particularly fertilizer, make significant contributions to growing the West Africa agriculture value chain. Hence the various high-level recommendations made to guide and promote the regional fertilizer industry, including the Abuja declaration of 2006 which announced the need to increase fertilizer consumption from 8Kg/ha to 50kg/ha to help sub-Saharan Africa achieve food sufficiency and eradicate poverty, while improving soil fertility.

Even though fertilizer quality is key in delivering agricultural productivity, West Africa farmers are faced with challenges of poor quality fertilizer that limit their yield potential. The West Africa regional fertilizer market is inundated with low quality and adulterated fertilizers that affect general agricultural output in the region.

As far back as 2010, the International Fertilizer Development Center (IFDC) conducted a regional fertilizer quality assessment study to provide evidence of the need for harmonized fertilizer quality control regulation. The study identified the lack of technical capacity of blenders as a critical cause of the region's poor quality of blended fertilizers. That study report became the basis for developing the ECOWAS Regulation C/REG.13/12/12 for fertilizer quality control.

In this regard, IFDC, with funding from the United States Agency for International Development (USAID), is implementing the Feed the Future Enhancing Growth through Regional Input Systems (EnGRAIS) project for West Africa to collaborate with strategic regional institutions, including the Economic Community of West Africa States (ECOWAS), the West Africa Economic and Monetary Union (UEMOA), and the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), as well as critical value chain partners such as the West Africa Fertilizer Association (WAFA), to develop and deploy tools across the region to address fertilizer quality issues.

IFDC and USAID believe that compromised fertilizer quality is compromising food systems and promoting food insecurity and poverty across the region. Thus, ensuring quality fertilizers requires monitoring and guiding blending practices across the region to conform to best practices.

The Fertilizer Bulk Blending Guide is a repertoire of uniform best practices and critical principles on quality fertilizer blending. This technical document provides blenders of the region with the information they need to produce blended fertilizer grades that meet ECOWAS' and internationally accepted standards, while remaining environmentally friendly and profitable.

– **Patrice Annequin, Chief of Party**
Feed the Future EnGRAIS Project

INTRODUCTION

Quality bulk blending occurs when more than one fertilizer raw materials of similar particle size, whose nutrient contents are known, are mechanically mixed using the appropriate equipment. Attention needs to be paid to how high-quality blends should be produced generally. In West Africa, the fertility of soils is degrading due to improper land use, low penetration of mechanized and high-tech farming methods, soil and nutrient depletion and climate change. These, among others, have resulted in continuous low yields and revenue loss for farmers. If the region will be food secure and self-sustainable, there is a need for an Integrated Soil Fertility Management (ISFM) approach that involves the use of quality fertilizers (organic and inorganic), improved crop varieties and good agricultural practices. Though organic fertilizers play a role in subsistence and small-scale farming, large-scale farming needs a volume of fertilizer supply which only chemical fertilizers can provide. The combination of the two kinds of fertilizers is encouraged regionally, since subsistence and small-scale farming is practiced more than large scale farming. Annex A1, A2 and A3, list where nitrogen and phosphorus, organic fertilizers and soil supplements or micronutrients are formally produced within the region respectively.

Producing quality blends depends on two factors, the quality of raw materials and the quality of the blending process:

- Manufacturers of fertilizer raw materials have a duty of care to ensure that the quality of what they produce is up to specification. The raw materials must be suitably sized, and the nutrient content guaranteed.
- It is the duty of the operators to have very good equipment, flexible enough to deal with multiple blend scenarios. It is their responsibility to maintain the equipment properly, ensure they operate using standard operating procedures, test raw materials received, and blends produced using standard testing methods.

The aims of this manual are to:

1. Be a standardized reference tool for best practices for quality bulk blending in a sustainable and environmentally friendly manner.
2. Increase awareness and encourage participation of all relevant stakeholders to ensure its implementation and regional uniformity.

The objectives of this manual are to:

1. Detail how quality blends are to be produced at the best location, using the right business plan, compatible materials, and most efficient process.
2. Illustrate methods for calculating fertilizer blend formulas.
3. Provide foundational guidelines for storage of raw materials, finished blends, dispatch of produced blends, accounting and record keeping.

4. Emphasize the essence of a proper quality control system in a bulk blending operation.
5. Provide indicative templates, forms and technical documents that are required for fertilizer blending.

1. FERTILIZER SOURCES AND QUALITY

1.2 NPK SOURCES IN WEST AFRICA

1.2.1 Nitrogen Sources in West Africa

Urea and Ammonium Sulfate are the most common sources of Nitrogen in fertilizer blends produced in West Africa. For Urea, Nigeria is the only country in West Africa that manufactures it. Notore, in Port Harcourt, Nigeria has an installed nameplate capacity to produce 500,000 metric tons of Granular Urea and 300,000 metric tons of Ammonia per annum. Indorama Eleme Fertilizer and Chemicals, in Port Harcourt, Nigeria has a total installed Granular Urea production capacity of 2.8 million metric tons per annum. With an installed production capacity of 3 million metric tons per annum, Dangote Fertilizer is the largest Granular Urea manufacturer in Nigeria and the largest in Sub Saharan Africa. In total, Nigeria has a 6.3 million metric tons of Granular Urea production capacity.

1.2.2 Phosphate Sources in West Africa

MAP and DAP are the most common sources of Phosphorus in fertilizer blends produced in West Africa. Majority of the Phosphates utilized for bulk blending in West Africa are imported from countries outside the region, especially Morocco. Geologic conditions suggesting deposits of Phosphates have been found in Benin, Côte d'Ivoire, Gambia, Ghana, Guinea Bissau, Liberia, Mali, Nigeria, Senegal (Schreiber and Matlock, 1978). Till date, none of these countries are mining and processing Phosphates in commercial quantities that will make for non-reliance on Phosphate imports from outside West Africa.

1.2.3 Potash Sources in West Africa

MOP is the most common source of Potassium in fertilizer blends produced in West Africa. Potash deposits have rarely been sighted in West Africa. Though some deposits occur in some parts of Northern Nigeria, little is known of its accessibility and the quantities have not been reported to be in commercial quantities. Alternatively, the Potash utilized for bulk blending in West Africa is imported from countries outside the region such as China, Russia, Ukraine, Israel, Jordan, Canada and the United States just to name a few.

1.3 QUALITY ISSUES OF BLENDED FERTILIZER IN WEST AFRICA

A joint ECOWAS, UEMOA and IFDC report assessing the quality of fertilizer traded in West Africa including factors influencing fertilizer quality in the region were carried out between 2010 and 2013. The findings from the assessments in Côte d'Ivoire, Ghana, Nigeria, Senegal, and Togo, which impact fertilizer quality in the region are:

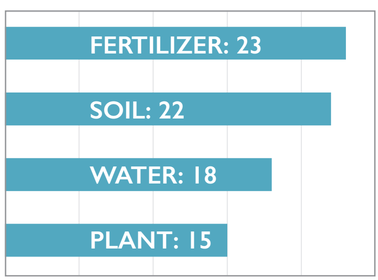
1. Underweight bags are predominant.
2. The quality of the same bulk blend formula varies from country to country.
3. Insufficient nutrients addition during blending operations is the major cause of nutrient deficiency in blended products.
4. The physical characteristics of fertilizer raw materials have direct correlation to the quality of blended products.
5. NPK blends present more cases of poor product quality than NPK compounds.
6. Segregation is a major issue for blend quality but has minimal effect on the deficiencies of nutrients content in blended products.
7. Adulterated blended products are minimal.

1.4 FERTILIZER QUALITY CONTROL AND TESTING LABS

To ensure that the blended products have the required "balanced" nutritional content, blenders must comply with ECOWAS regulation C/REG.13/12/12 relating to fertilizer quality control and the tolerance limits therein. As good practice for blend quality and traceability, blenders are mandated to take samples of their products per batch, store them for a minimum of six months, test them internally and send them to an external accredited and independent testing laboratory. According to the 2021 West Africa Information Business Guide, there are 23 adequately equipped fertilizer testing labs, 22 soil testing labs, 18 water quality testing labs and 15 plant testing labs in the region (IFDC WAFBIG, 2021).

Figure 1. *Testing and Quality Control Laboratories in West Africa*

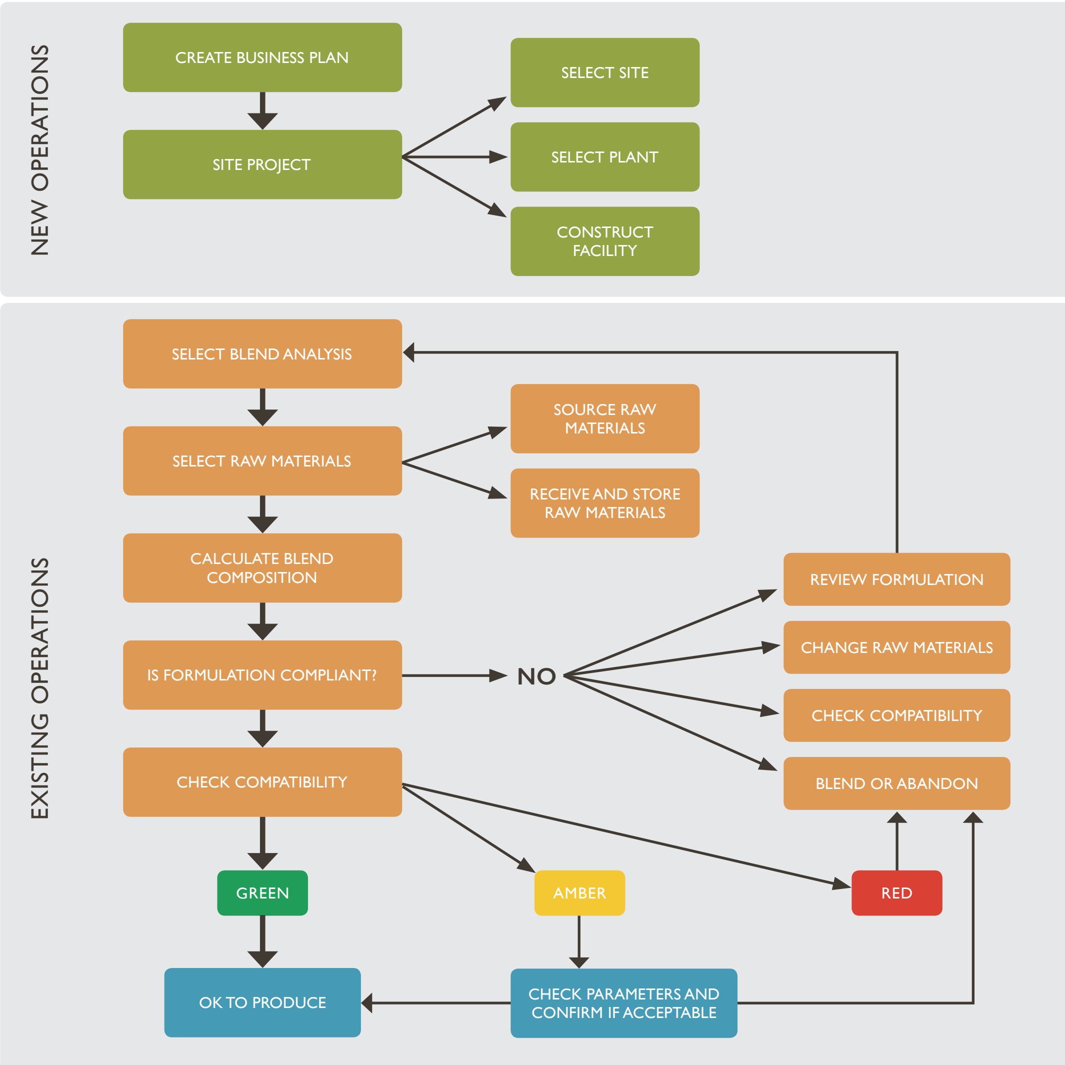
Source: IFDC, WAFBIG (2021)



2. FERTILIZER BULK BLENDING OPERATIONS

To produce quality fertilizer blends, attention must be paid to every aspect of the bulk blending operations. The flow diagram below highlights every aspect of the operational activities that should be carried out to enable the production of quality blends.

Figure 2. *Guidelines on how to produce quality blends*



Adapted from Fertilizers Europe, 2014

2.1 CREATE A BUSINESS PLAN

To produce quality blends, the first step is to develop a good business plan. An experienced consultant, preferably one who has previous experience in this kind of project, should be contracted to prepare your business plan.

2.1.1 Guidelines on How to Create a Business Plan

The following points should be considered before creating a business plan.

1. Create a business plan with an investment period of at least 10 years.
2. Determine who your off takers are.
3. Find out what the market prices for the various blends are.
4. Register your company with the fertilizer/agricultural/manufacturing associations.
5. Register your blends with the fertilizer/agricultural/manufacturing associations.
6. Participate in the foreign exchange incentive procurement schemes for agriculture and manufacturing businesses if applicable.
7. Know what the local and international prices (per ton/50kg bag) of the NPK fertilizer inputs are.
8. Be regularly updated with the local Tax, Vat and Interest rates.
9. Establish an estimated monthly salary for management and non-management staff.

While creating a business plan, a financial model is required. To develop a financial model, the following guidelines can be utilized.

1. Cover page - project title, name of company and date.
2. Investment summary page - financial summary and capital expenditure.
3. Summary page - profit and cash flow, profit after tax, balance sheet, ratios.
4. General assumptions page.
5. Income statement page.
6. Balance sheet page.
7. Cash flow page.
8. Investment appraisal page - returns to equity investors, NPV, IRR and payback period.
9. Depreciation page.

Refer to ***Annex B*** for indicative cost estimates required to set up a complete bulk blending operation.

2.2 PROJECT SITING

To produce quality blends, the second step is to ensure the production facility is situated at the best location for such operation. Project siting consists of three components, site selection, facility construction and plant selection.

2.2.1 Guidelines on How to Select a Site for Bulk Blending

The merits of a good project site cannot be overemphasized because it contributes immensely to the success of a fertilizer blending operation. To select a site with ease and get optimal returns from it, ensure your site selection activities is in line with the following guidelines.

2.2.1.1 Site Location

The following are guidelines for an optimal site location:

1. **Accessible location:** The site should be easy to locate and accessible by road.
2. **Accessible market:** There should be a clear route to market from the site.
3. **Constant power supply:** Both from the grid and from alternative sources.
4. **Zero possibility of erosion:** The site should not be in an erosion prone area. If this cannot be helped, proper erosion control measures must be adopted during construction.
5. **Controlled humidity:** The coastal areas of West Africa are humid. If a site in such an area must be selected, proper humidity control measures must be adopted during construction and bulk blending operations. More on these will be discussed later.

2.2.1.2 Laws, Policies and Regulations

The following are guidelines to optimize laws, policies, and regulations:

1. Abide by the land zoning, building and construction regulations of the area.
2. Abide by the rule of law for operating in the community.

2.2.1.3 Environmental Impact Assessment (EIA)

An experienced consultant, preferably one who has previous experience in this kind of project, should be contracted to prepare your EIA. The following are guidelines that can be utilized to prepare an EIA.

1. Introduction.
2. Project justification.
3. Project description.
4. Description of the proposed project environment.

5. Associated and potential impacts.
6. Mitigation measures.
7. Environmental management plan (EMP).
8. Conclusion and recommendation.

2.2.1.4 Access to Raw Materials and Utilities

The following are guidelines to optimize access to raw materials and utilities:

1. The site should be located where materials for construction can be sourced.
2. The site should be located where raw materials for the production process can easily be delivered to or sourced from – if applicable.
3. The site should be in a location with accessible roads.
4. The site should be in an area with hard and soft infrastructure. Examples of hard infrastructure are roads, bridges, manufacturing/power plants etc. Examples of soft infrastructure are the internet, healthcare system, education system, etc.

2.2.1.5 Availability of Local Labor

The following are guidelines to optimize labor. They will further aid in the security of the facility because the locals will have a sense of involvement and ownership:

1. Direct and indirect labor should be sourced and engaged from within the community where the site is located.
2. Senior positions may be made up of qualified and talented local content.
3. Suppliers of goods and services required by the operations should be sourced from the immediate community where applicable.

2.2.1.6 Transportation Accessibility

In West Africa, road transportation is commonly used because of the absence or lack of adequate rail infrastructure. Therefore, the following are guidelines to optimize logistics:

1. The site should be located along major roads in good condition or not too far from the major road.
2. There should be other access roads leading to the facility which should be in a motorable condition.
3. The main or access roads should not be on flood or erosion plains. They should have good storm and surface water drainage.

2.2.1.7 Security

Bulk blending is an expensive business, so security of lives, property and investment is very important. The following are guidelines to optimize security:

1. Research the historic crime rate and political insecurity of the area.
2. Inform the neighbors of the proposed development and receive their buy-in.
3. Budget for provision for security personnel and electronic security systems.

2.2.1.8 Competition

Every viable business will be an attractive proposition to investors so competition should be expected. However, a successful business is one that finds ways to thrive amidst competition.

The following are guidelines to optimize competition when establishing a blending operation:

1. Establish the business in an area with little or no competition. This can accelerate industrial inertia and assure market edge.
2. Examine and understand the competition, if any, to create innovative mechanisms and best practices that will set you apart.

2.2.2 Guidelines on How to Construct a Bulk Blending Facility

Fertilizers can be corrosive in nature. For safety and durability of the facility, the following should be taken into consideration when planning such constructions:

1. Experienced engineering design and construction teams, preferably those who have previous experience in this kind of project, should be contracted to design and construct the facility.
2. Reinforced concrete elements should be to the engineer's specification. They should be of high-grade quality. Paint steel rods with anti-corrosion agents. Concrete mix and water ratio should be in accordance with the engineer's specification. The mixture should have minimum water content to reduce issues of pore formation within the concrete element. Ensure a minimum spacing of 50 mm between steel rods and concrete surface. cross ventilated space.
3. Structural steel elements should be to the engineer's specification. They should be of high-grade quality and coated or painted with anti-corrosion agents.
4. Roof coverings should be to the engineer's specification, to prevent water leakage.
5. Mechanical and Electrical installations e.g., plumbing and wiring, should be to the engineer's specification, to prevent pipe leakage and fire outbreak.
6. Lighting within and outside the facility should be to the engineer's specification.
7. Incorporate a dust expeller in the facility and on the plant, if possible.

8. Install a temperature and humidity reader within the facility.
9. For further reading on construction of industrial structures, refer to:
   i. *Reynold's Reinforced Concrete Designer's Handbook*, Charles E. Reynolds, James C. Steedman, Anthony J. Threlfall, 2008 edition.
   ii. *Handbook of Structural Steelwork*, BCSA Publication No. 55/13, BS EN 1993-1-1:2005 Eurocode 3: Design of Steel Structures.
10. For ease of construction, the process should consist of at least the following phases: Project Initiation, Project Planning, Project Execution, Project Monitoring and Control and Project Closeout.
    i. **Project Initiation Phase:** This is the phase in which the vision for the project is established and approvals for project continuity are secured.
    ii. **Project Planning Phase:** This is the phase where the project is methodically planned and a roadmap, which leads to the development of the project management plan, is established.
    iii. **Project Execution Phase:** This is the phase in which the project initiation and planning stages come to life. In this phase, all the plans are put to action.
    iv. **Project Monitoring and Controlling Phase:** This is the phase in which every phase of the project execution is monitored and controlled. This is a very important phase in the construction of the facility because it is the phase that guarantees that the project meets the necessary quality and safety standards.
    v. **Project Closing Phase:** This is the phase in which the goals of each phase of the project have been reached, therefore, the project is closed.
    vi. **Role of Each Resource:** Knowing the functions and selecting the ideal project resource are two factors for success in projects like this. The following are the standard resources for a project of this kind: land surveyor, architect, engineers (civil, structural, mechanical, electrical and instrumentation), quantity surveyor and foreman. Annex C details each role.
11. Refer to ***Annex D*** for an indication of an architectural layout of a bulk blending facility.
12. Refer to ***Annex E*** for an indication of the cost of constructing bulk blending facilities of various throughput capacities and procuring raw materials for their operations.
13. **Table 1** can serve as a guide for floor space and additional requirements for the establishment of new facilities and operations. The values shown on the table are NOT fixed but may vary depending on various factors unique to each location and operation.

Table 1. *Guidelines of sizes required for various plant and annual tonnage capacities*

	ANNUAL TONNAGE CAPACITY			
Component	**Up to 30 mtph (30,000 mt/yr)**	**Up to 60 mtph (60,000 mt/yr)**	**Up to 100 mtph (100,000 mt/yr)**	**Over 100 mtph (>100,000 mt/yr)**
Land	0.5 ha or 5,000 sq. m	≥0.5 ha ≤ 1 ha	1 ha	≥ 1 ha
Services buildings	20% of land or 1,000 sq. m	20% of land	20% of land	20% of land
Main factory building	75% of land or 3,750 sq. m	75% of land	75% of land	75% of land
Raw material storage	30% of main bldg. or 1,500 sq. m	30% of main bldg.	30% of main bldg.	30% of main bldg.
Bulk blending and bagging	10% of main bldg. or 375 sq. m	10% of main bldg.	10% of main bldg.	10% of main bldg.
Office and ablutions	10% of main bldg. or 375 sq. m	10% of main bldg.	10% of main bldg.	10% of main bldg.
Finished goods storage	10% of main bldg. or 375 sq. m	10% of main bldg.	10% of main bldg.	10% of main bldg.
Equipment	**Additional facility requirements for various plant and tonnage capacities**			
Frontend loaders	Not necessary	Maybe	Yes	Yes
Modified frontend loaders	Yes	Yes	No	No
Forklifts	Yes	Yes	Yes	Yes
Loading bays	Yes	Yes	Yes	Yes
Receiving conveyors	Not necessary	Not necessary	Yes	Yes
Weighbridge	Yes	Yes	Yes	Yes

Source: Chinedu Ohanyere, 2022

2.2.3 Guidelines on How to Select Bulk Blending Plants

To produce quality blends, a good blending and bagging plant is required. Refer to ***Annex F*** for indicative cost of blending plants of various capacities. To select and purchase the best equipment it is important to know the following:

1. The total quantity and types of blends to be produced per annum.
2. Required performance in terms of speed, accuracy, capability, and flexibility.
3. Simplicity of usage and operation, noting that all systems need good software.
4. Space requirements.
5. The budget.

2.2.4 Types of Bulk Blending Plants

Bulk blending plants can be categorized into two, batch and continuous types.

1. Batch Type Plants:
   i. Floor style batch – expandable (one loading hopper)

   ii. Floor style batch – (multi-hopper)

   iii. Tower style batch

2. Continuous Type Plants:

   i. Floor style continuous – (multi-hopper)

Annex G illustrates more examples of each type. While ***Annex H*** lists some major bulk blending plant manufacturers. For safety issues concerning both types of plants and guidelines on how to handle them, refer to the plant maintenance and safety, section 2.5.2.

Table 2. *Pros and cons of the types of bulk blending plants*

BATCH BLENDING SYSTEM	CONTINUOUS BLENDING SYSTEM
Advisable for tonnages ≤ 70 mtph	*Advisable for tonnages > 70 mtph*
PROS	
Layering/Proportioning of raw materials is not required. Therefore, ingredients do not require layering software	Automatically and dynamically (re)adjusts its dosing proportions without stopping
Transfers ingredients to mixer at high speed	Doses ingredients at once. Transfers ingredients to mixer continuously
Allows variability on blend cycle times i.e. blending can be slowed or paused	Negligible lag time in reloading time between discharges.
Flexibility to customize blend times for various blend specifications and quantities	Preset blend cycle times
Handles very complex blends	Can come in various sizes. Can be adapted to warehouse headroom
Tower systems can handle mid to very high tonnages	Can handle mid to high tonnages
Easier set up for smaller capacity. Therefore good for near/on farm set up	Cost effective compared to output (especially for high output tonnages)
Can be suited to powder and granular fertilizer	Full automation in blending line (computer and remote controlled monitoring) Encourages purchase of free flowing raw materials
CONS	
Blend time takes longer than a Continuous System	Not suited for small tonnages or small custom blends
Weighing and Blending can be separated	Requires proportioning and automatic adjustment to reach balanced layering
More upfront cost, especially in the case of a Tower Batch System	Possibility of inconsistent blend quality at the commencement and completion of batches
	No variability of blend cycle times ie blending cannot be slowed or paused once started
	Does not allow for adjustable blending/curing time
	Powder fertilizer can increase plant inefficiency
	Not suited for all new liquid products on the market

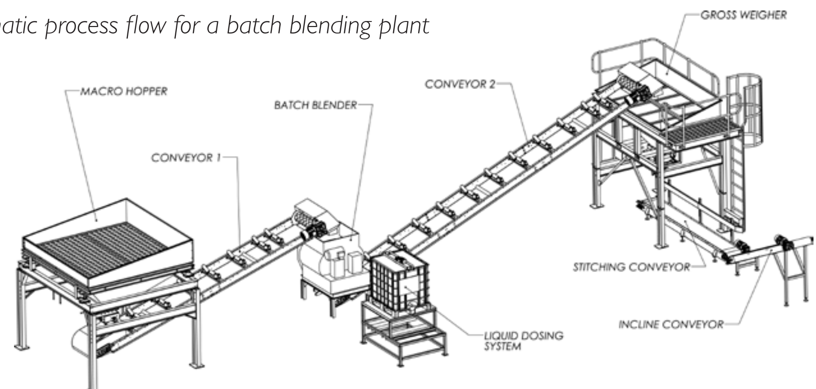
Source: Chinedu Ohanyere, 2022

2.2.4.1 Batch Bulk Blending Plant

This type of plant mixes free flowing fertilizer raw materials, in batches, to create blends. It uses a hopper or a set of hoppers and a loss in weight system to do this. The operations of this type of blending plant are listed below.

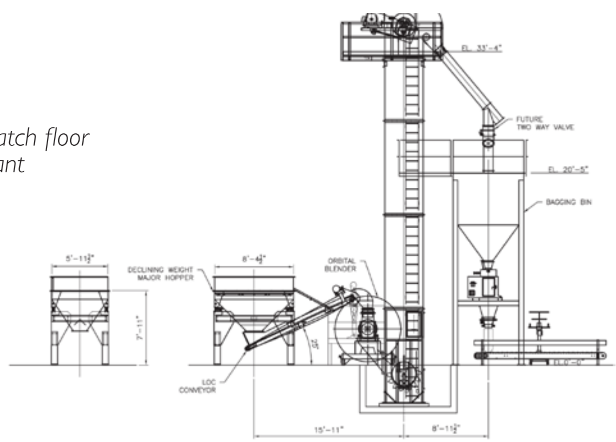
1. Establish the total quantity of blended product to be produced.
2. Break the total quantity into batches.
3. For each batch, calculate the exact quantity of each raw material (macro, secondary and micro and any other additives) required.
4. Measure each raw material based on its calculated weight and feed into the hopper(s).
5. When all the materials required are fed into the hopper(s), start the blending process by dispensing the product onto the under-bin conveyor, using the applicable discharge system, which transports the materials into the blender.
6. Repeat these steps until the final quantity of blended product required is reached.

Figure 3. *Schematic process flow for a batch blending plant*



Source: Bagtech International (2020)

Figure 4. *Schematic process flow for a batch floor style, single hopper blending plant*



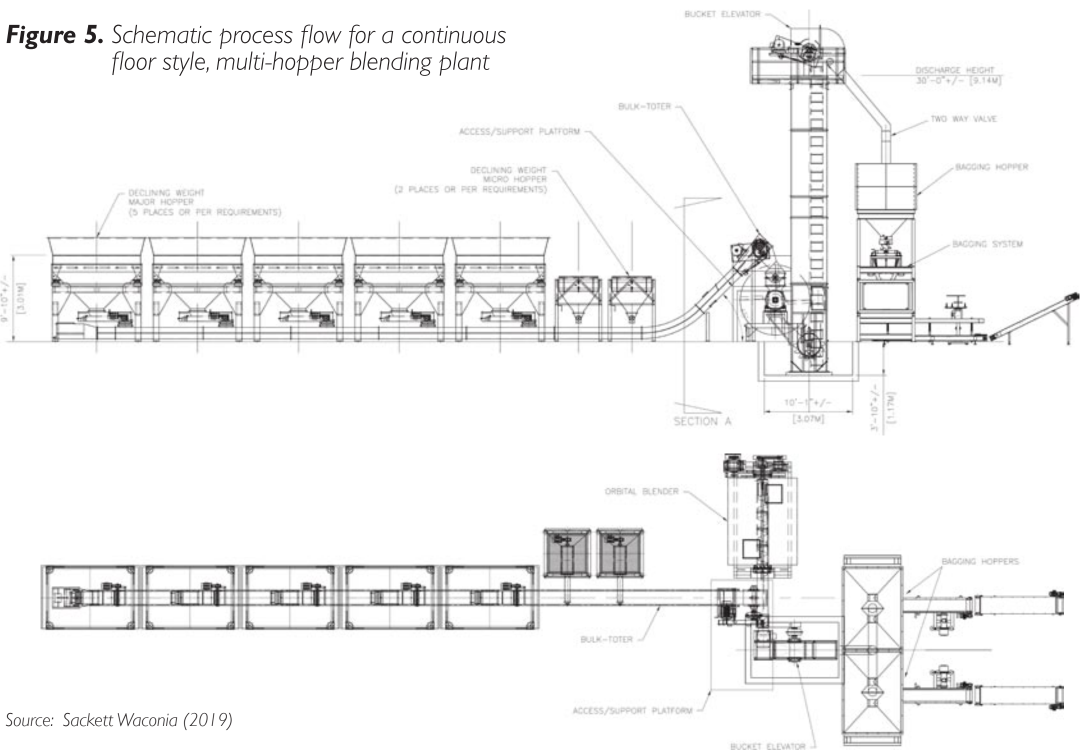
Source: Sackett Waconia, (2019)

2.2.4.2 Continuous Bulk Blending Plant

This type of plant mixes free flowing fertilizer raw materials, continuously, to create blends. It uses a set of hoppers and a dynamic weighing system to do this. The operations of this type of blending plant are listed below.

1. Establish the total quantity of blended product to be produced.
2. Break the total quantity into quantities of each raw material required for the blend.
3. For each quantity of raw material, calculate the exact quantity of each macro, secondary and micronutrient raw material required.
4. Measure each raw material required based on its calculated weight and feed into its designated hopper.
5. Feed all the raw materials required into their designated hoppers until they are full. Start the blending process. The plant should automatically start dispensing the products onto the under-bin conveyor, using the applicable discharge system, which feeds the blender.
6. Continue feeding raw materials into their designated hoppers.
7. Repeat these steps until the anticipated quantity of blended product required is reached.

Figure 5. *Schematic process flow for a continuous floor style, multi-hopper blending plant*



Source: Sackett Waconia (2019)

2.3 SELECT AND SOURCE RAW MATERIALS

To produce quality blends, the third step is to select and source the required raw materials. Poor quality blends are achieved when poor quality raw materials are used. ***Annex I*** list the characteristics of some fertilizer raw materials. However, the total quantity of raw material required must be known before they are selected and sourced. The approaches stated below can be used to obtain the blend analysis (dosage recommendation) of fertilizer blends, which when aggregated, help in determining the total quantity of raw material required by the plant.

1. **Blanket Recommendation Approach:** This is the most popular approach in West Africa. It occurs when uniform fertilizer doses and application are recommended across board e.g., for staple crops or main cash crops.
2. **Recommendation by Research Approach:** It happens when blend specifications which are derived by research, are issued by an expert or a group.
3. **Soil Fertility Category Recommendation Approach:** It is practiced after soil tests are carried out according to standards. The soil test results will indicate the exact type and quantity of nutrients it is deficient in to optimally provide for a specific crop.
4. **Soil Test and Yield Recommendation Approach:** It is adopted after soil tests are carried out and a specific crop yield is targeted.
5. **Critical Limit Fertilizer Recommendation Approach:** It is the determination of the nutrients required in soils for crops, taking micronutrients into consideration. It is an approach based on Leibig's law of minimum.
6. **Soil Test Crop Response Recommendation Approach (STCR):** It determines the exact nutrients (macro and micro) required and in what quantities they are required, to prevent fertilizer overdose.

2.3.1 Guidelines on How to Select and Source Raw Materials

It is important to source the right raw materials, with the right quality, at the right time and for the right price. To achieve these, the following can serve as guidelines:

1. Analyze the blend formula received to determine the raw material required and the quantities in which they are required.
2. Know the characteristics of each raw materials required e.g., the nutrient content, chemical compatibility, critical relative humidity, physical compatibility, and properties.
3. Ensure availability of the raw material.
4. Purchase the raw materials "just in time" or before the farming season.
5. Insist that the supplier provides an internationally recognized material safety data sheet for the materials you are purchasing. However, it is necessary to carry out your own tests (at source, after

arrival at your port and after offloading in your warehouse) to confirm information provided by the supplier. For example, material characteristics such as the nutrient content (%), particle size, product humidity and product compatibility should be verified.

2.3.1.1 Nutrient Content

Nutrient content or chemical analysis is the quantity of nutrient contained in every granule of a fertilizer raw material. To produce quality blends, the nutrient contents of the raw materials used must be known. Poor quality blends can be produced when raw materials having less quantities of nutrient contents are used. Raw material suppliers are to provide analysis reports showing nutrient contents and other characteristics of each material they sell. However, the onus is on the buyer or the blender to carry out their own analysis to confirm the results before using in a blend production. Annex J shows a summary of required plant nutrients, but the lab analysis of the raw material will be used to know the actual nutrient content of the raw material for eventual adjustment to the formula.

2.3.1.2 Compatibility of Fertilizer Raw Materials

To produce quality fertilizer blends, compatible raw materials should be used. If incompatible materials are used this will result in poor quality blends. The use of incompatible material can result in the creation of insoluble salts, unwanted precipitates, caking, or clogging issues. Chemical compatibility, critical relative humidity, physical compatibility, and physical properties are the most important characteristics to take note of.

Chemical Compatibility

Chemical compatibility of a fertilizer raw material is the measure of how stable it is when blended with another raw material. If more than one raw material can be blended and their characteristics remain stable individually and collectively, they are compatible. When selecting raw materials for blending, the chemical compatibility of the materials should be the first characteristic to be considered. Annex K shows a fertilizer raw material compatibility chart with explanations. From the figure, examples of incompatible materials commonly used in West Africa are urea and ssp/tsp. Examples of partially compatible materials commonly used in the region are urea and mop. Therefore, low quality blends can be produced when incompatible materials are blended. For example, sulfates and phosphates should not be blended with calcium-based fertilizers.

Critical Relative Humidity (CRH)

The CRH of a fertilizer raw material is a temperature point at which, if the relative humidity of the surrounding atmosphere is higher, the raw material starts to soak up atmospheric moisture. Or is the temperature point at which, if the relative humidity of the atmosphere is lower, the raw material will not soak up atmospheric moisture. When air temperature increases, CRH decreases. To avoid raw material being affected by surrounding humidity when stored for long periods or not in use, it is advisable to cover the raw materials or ensure the surrounding air is controlled in a manner that sustains their moisture content levels. Annex L shows the CRH of common fertilizer raw materials and those commonly used in West Africa. From the chart, ammonium sulfate or phosphate-based fertilizer raw materials have high CRH meaning they absorb less moisture from the air. But blended fertilizers mostly have CRH values lower than that of each of the individual raw materials used to formulate the blend. For example, blending urea (CRH 73) and MAP (CRH 92) gives a blend with CRH 65. So, the blend is likely to cake or form a slurry, in a 30°C environment like West Africa, due to its lower CRH. Therefore, low quality blends can be produced when CRH values of blended materials are lower than the CRH values of the individual materials used in the blend.

Physical Compatibility and Properties

The physical compatibility of fertilizer raw materials is essential in the production of quality blends. Physical characteristics of raw materials such as bulk density, shape, hardness, solubility, dust content, flow rate and level of contamination, can determine how compatible the raw materials can be. For example, if the sizes of raw materials to be used in a blend differ by more than 10%, segregation will most likely occur during transportation. This is also true for micronutrients because they usually have high densities and are required in small quantities.

Particle Size and Particle Size Distribution

When sourcing raw materials, it is important that the manufacturers provide the particle size (using the screen guide number, SGN) and particle size distribution (using the uniformity index, UI). Poorly matched particle size leads to product segregation and contributes to low quality blends. Depending on the sources of fertilizer raw materials, particles that are fine or lumpy in nature are bound to be present in the bulk. It is good practice to sieve or screen raw materials before blending and bagging operations commence. It is bad practice to sieve or screen raw materials after blending because unmixing of the raw materials and the loss of some of its particles may occur thus changing molecular chemistry of the mixture. It is advisable that plants should have lump and fines screeners at the blending and bagging lines.

There are two main methods of determining particle size of fertilizer raw materials, the jar test, and the size guide number (SGN)/uniformity index (UI).

The Jar Test Method

The Jar Test is a method used to obtain results of a particle size distribution of raw materials. These results are important to determine if segregation will occur. The equipment required are jars having straight sides of equal sizes and screens which are arranged together. Refer to Annex M for examples of jar test diagrams and particle size distributions. The test compares raw materials by using their volume. An equal volume of each raw material to be used for blending is passed through screens. The materials retained on each screen and those that passed through the fine screen are placed into different jars and visually compared. Materials of similar size distributions will not segregate when used for blends. Screens between Tyler sizes 5 and 20 will work, but for more uniform results, only two screen sizes i.e., mesh sizes 7 and 9 or 8 and 10 are to be used.

The Size Guide Number (SGN) and Uniformity Index (UI) Methods

The SGN is a system used to identify raw materials. It is based on the idea that only the SGN and the UI are required to describe the particle size distribution of a fertilizer raw material. It is the particle size that divides the mass of all the particles of the raw materials in two equal halves i.e., one with the larger particle size and the other with the smaller particle size. In other words, it is the median dimension in mm to a second decimal multiplied by 100. The SGN can be determined using any of the following methods.

1. A graph (see ***Annex N***).
2. Calculation from size analysis data (see ***Annex O***).
3. Estimation using the SGN Scale (see ***Annex P***).

The UI is best determined by mathematical methods. It is the ratio of small particle sizes to large particle sizes expressed as a percentage. In other words, it is the ratio multiplied by 100 of particle sizes matching the 95% level and those matching the 10% level in the cumulative distribution curve.

The Practical Method of using the SGN and UI

1. Calculate the average SGNs and UIs of the materials to be used for blending.
2. Establish acceptable ranges for both the SGN and UI.
3. If the materials fall within the limits of the acceptable ranges, the formulation will be calculated using the averages. If not, the averages will be raised to prevent the risk of segregation.
4. Determine what works best for your operation e.g., "average plus or minus 10%".
5. Given the example below, the SGN and UI of raw material B do not lie within the acceptable range so an average wide enough to prevent segregation should be used or another material with SGN and UI that lie within the acceptable range is used:

RAW MATERIAL	SGN	UI
A	250	50
B	210	45
C	260	55
Average	240	50
Acceptable range	215–265	45–55

Table 3. *Important physical properties of fertilizer raw materials*

EFBA TARGETS AND TOLERANCES FOR THE GRANULATION OF RAW MATERIALS FOR FERTILIZER BLENDING			
VERBAL NOTATION	**PHYSICAL DIMENSION**		
Mean particle size	d50 in mm	3.25 mm	+/- 0.25 mm
Fine particles	< 1 mm, % of mass	0%	0.25%
Coarse particles	> 5 mm, % of mass	0%	1%
Main range	2.5–4.0 mm, % of mass	90%	+/- 5%
Granulometric Spread Index (GSI)	$GSI = \frac{d_{84} - d_{16}}{2\ d_{50}}\ 100$	< 18	–

It is assumed that the sieve analysis is carried out according to European Standard EN 1235/A1.
EFBA recommends the use of these seven sieves : 1,00 mm – 2,50 mm – 2,80 mm – 3,15 mm – 3,55 mm – 4,00 mm – 5,00 mm (the justification for these sieves is linked to the recommendations).

Source: Handbook of solid fertilizer blending, code of good practice for quality, 2016.

2.3.2 Guidelines on How to Receive and Store Raw Materials

Raw materials are expensive and constitute the largest expenditure in a fertilizer bulk blending operation. Handling them properly during transportation and storage is very important to preserve their nutrient content and properties. To receive and store raw materials adequately, the following should serve as guidelines for an operation:

1. Refer to in-house standard operating procedures (SOPs) for receiving and warehouse storage procedures. However, note the four critical points below.
   i. Preplan raw material holding bays/bins taking note of the chemical compatibility of raw materials. Use the compatibility chart in Annex L to ensure their safe storage.
   ii. A transport medium in good condition should be used to convey the cargo.
   iii. Cover and tie down trucks carrying the products with tarpaulin, so that the product does not get wet (due to rain), contaminated or spill onto road surfaces, into public drains or watercourse ways.
   iv. The bay/bin should be adequately sized to take up the incoming product. Do not overload the space so products do not spill into other bays/bins to avoid contamination.

2. Well-taken samples must be labeled appropriately and sent to a laboratory for analysis and/or kept on site for reference purposes. Refer to sampling techniques in ***Annex T***.
   i. Contact the supplier immediately raw material being received does not meet up with the nutrient content and particle size requirements.
   ii. Use the Jar Test and SGN/UI methods for quick sampling and physical test methods.
   iii. For more in-depth tests, a riffled portion should be adopted for chemical analysis.

3. For raw materials received in bags, flip each bag over on all four sides before carefully arranging them in a pile. This will prevent product segregation.

   i. Stockpile the raw materials from a height but from different points to prevent product segregation and maximize storage capacity. For safety reasons.

      - Stockpile height for raw materials in bags should not exceed 5 m.
      - Stockpile height for raw materials in bulk should be at least 6 m.

   ii. Use an infeed overhead conveyor system or a trapezoidal shaped flow diverter with a hole in the middle, where applicable.

   iii. In the absence of an overhead conveyor system, carefully decant bags of raw materials into product bays and ensure bags are emptied from a height and dropped at different product streaming points.

   iv. While feeding hoppers for production, the front-end loader should not pick product from only one end of a stockpile but should work the pile from one end of the bay/bin to the other.

   v. If a vertical face is created in a stockpile, knock it down gently for safety and to ensure product uniformity.

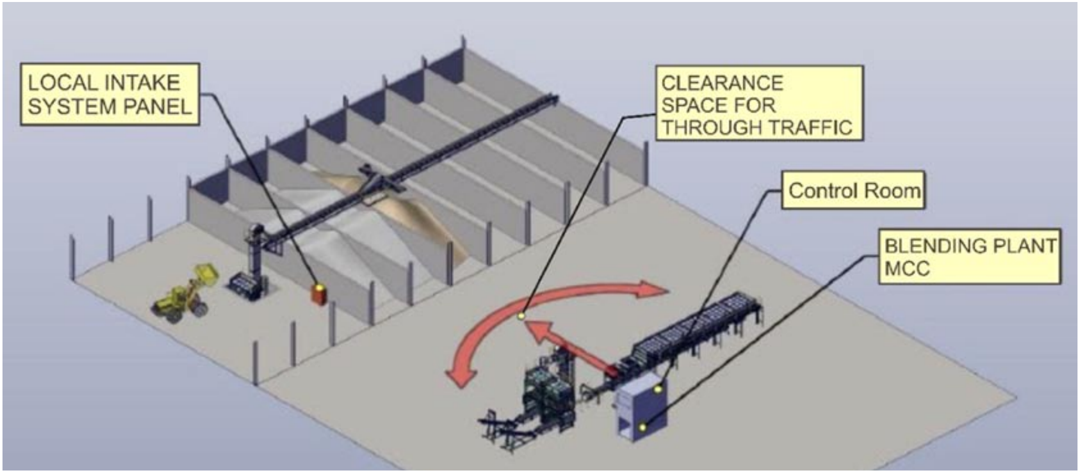
   vi. Use Table 4 as a guide for storage sizes required for various plant sizes and annual tonnage projections.

Table 4. *Indicative guidelines for storage.*

GUIDELINES FOR STORAGE SIZES REQUIRED FOR VARIOUS PLANT AND ANNUAL TONNAGE CAPACITIES

Component	Up to 30 mtph (30,000 mt/yr)	Up to 60 mtph (60,000 mt/yr)	Up to 100 mtph (100,000 mt/yr)	>100 mtph (>100,000 mt/yr)
Land	0.5 ha or 5,000 sq. m	≥ 0.5 ha but ≤ 1 ha	1 ha or 10,000 sq. m	≥ 1 ha Example 1.5 ha or 15,000 sq. m
Main factory building	75% of land or 3,750 sq. m, or 45 m wide * 84 m long	75% of land or 5,625 sq. m, or 55 m wide * 100 m long	75% of land or 7,500 sq. m, or 65 m wide * 115 m long	75% of land or 11,250 sq. m, or 75 m wide * 150 m long
Raw material storage	30% of main bldg. or 1,500 sq. m, or 15 m wide * 20 m long * 5 no off	30% of main bldg. or 1,650 sq. m, or 15 m wide * 22 m long * 5 no off	30% of main bldg. or 2,250 sq. m, or 15 m wide * 30 m long * 5 no off	30% of main bldg. or 3,375 sq. m, or 20 m wide * 34 m long * 5 no off
Finished goods storage	10% of main bldg. or 375 sq. m, or 12 m wide * 15 m long * 2 no off	10% of main bldg. or 560 sq. m, or 13 m wide * 22 m long * 2 no off	10% of main bldg. or 750 sq. m, or 15 m wide * 25 m long * 2 no off	10% of main bldg. or 1,125 sq. m, or 20 m wide * 28 m long * 2 no off
Height of stockpile	for bulk, ≤ 6 m for bags, ≤ 5 m	for bulk, ≤ 6 m for bags, ≤ 5 m	for bulk, ≤ 6 m for bags, ≤ 5 m	for bulk, ≤ 6 m for bags, ≤ 5 m

Figure 6. *Indicative Raw Material Receipt and Storage Layout*



Source: Grant Ruwers, Lagos, 2019

2.4 CALCULATE BLEND COMPOSITION

To produce quality blends, the fourth step is to accurately calculate the quantities required to satisfy the given blend formula. After receiving the recommendation, the bulk blending operator should be able to analyze and interpret it. The operator will determine how much raw materials are required, in their correct proportions, to satisfy the nutrient recommendation. If the correct materials, which should be of good quality, are not used, the blended product will most likely fail quality tests and should not be applied on the farm.

2.4.1 Guidelines on How to Calculate a Blend Formula

Before commencing any calculation, it is important to select the correct fertilizer raw materials (the list of raw materials and their characteristics are in Annex I), determine the physical and chemical compatibility of the raw materials and ensure the raw materials are analyzed so that the value of the material guarantees used in the formula are exactly the guarantees of the materials in stock.

The following steps can serve as a guide to perform accurate calculations:

1. State the given nutrient guarantees in their given percentages and then in decimals.
    a. The first three numbers in a fertilizer grade represent the required nutrients N:P:K in that order, i.e., the required total Nitrogen, available Phosphorus and soluble Potassium. Therefore, a fertilizer bag labeled 20:10:10 contains 20% total Nitrogen, 10% available Phosphorus and 10% soluble Potassium.

2. Reduce the total weight of the formula so their total amount is 1, 000 kg or 1 ton.

3. Determine the quantity of each raw material required to supply the nutrient amounts.
    a. Starting from the last nutrient and working your way to the first nutrient, determine the weight of 1% of each nutrient in the formula.
        - Since the total weight of the given blend formula is reduced to 1%, i.e., 1, 000 kg is reduced to 10 kg, a formula containing 1% of a nutrient will contain 10 kg per ton of that nutrient.
        - Round up all weights to the nearest whole number.
4. The P/N ratio is defined as the ratio of Phosphate to Nitrogen in a fertilizer raw material containing both nutrients. This method is used for raw materials containing both Nitrogen and Phosphate. Therefore,
    a. If the P/N ratio in the grade formula is more than 2.56, Nitrogen is the limiting factor and should be calculated first.
    b. If the P/N ratio is less than or equal to 2.56, Phosphate is the limiting factor and should be calculated first.
5. Calculate the quantity of each nutrient content supplied to satisfy the grade formula.
    a. Multiply total formula weight by nutrient guarantee in decimal to get nutrient content i.e., Amount of Nutrient Content (NC) = Quantity of raw material required (RM) * Nutrient Guarantee expressed in decimal (NG) thus,
       $NC = RM * NG$
    b. Firstly, calculate the quantity of any material that supplies only one nutrient so the extra "room" left in the formula can be known before the final calculations.
    c. If the total weight of raw materials required is more than the total formula weight, either the formula is incorrect, or the intended blend cannot be made with those raw materials. The solution will be to use other raw materials or reduce the nutrient guarantees.
    d. A binder can be added to prevent segregation if using material in powder form.
    e. To exclude Filler in a grade formula calculation.
        - Add varying quantities of two materials possessing the same nutrient but of different analysis, e.g., two materials each with Nitrogen, Phosphate and Potash nutrient contents.
        - Create "room" in a formula so other materials can be included.

2.4.2 Calculating Fertilizer Blends

Example 1

To produce a 1T blend using the fertilizer grade formula 27:13:13, how much of each raw material will be required, if the available materials are Urea (46-0-0), Diammonium Phosphate, DAP (18-46-0), Muriate of Potash, MOP (0-0-60) and Filler if necessary?

SOLUTION

Step 1. Nutrient guarantees = 27% : 13% : 13% = 0.27 : 0.13 : 0.13

Step 2. Take total weight = 1,000 kg

Step 3. Quantity of MOP containing 13% K_2O = 1,000 kg * 0.13 = 130 kg
Quantity of DAP containing 13% P_2O_5 = 1,000 kg * 0.13 = 130 kg
Quantity of urea containing 27% N = 1,000 kg * 0.27 = 270 kg

Step 4. Check the P/N ratio since DAP is among the raw materials.
Using the P/N ratio method, 46 / 18 = 2.56 therefore, calculate for P first before N.

Step 5. From the formula NC = RM * NG, RM = NC / NG
To satisfy the given grade formula,
Quantity of MOP required to provide 13% K_2O = 130 kg / 0.60 = 217 kg
Quantity of DAP required to provide 13% P_2O_5 = 130 kg / 0.46 = 283 kg
But 283 kg of DAP also supplies 18% N. So, applying the formula NC = RM * NG,

- quantity of N supplied from DAP = 283 kg * 0.18 = 51 kg
- quantity of N required from Urea = 270 kg - 51 kg = 219 kg

Therefore,
Quantity of urea required to provide 27% N = 219 kg / 0.46 = 477 kg.
Determine if filler is required.
217 kg of MOP + 283 kg of DAP and 477 kg of urea = 977 kg
But total formula weight should be 1,000 kg.

Therefore "room" = 1,000 kg - 977 kg = 23 kg to be filled by a filler material 0-0-0

Completed calculation sheet:

RAW MATERIAL	N (kg)	P_2O_5 (kg)	K_2O (kg)	Weight (kg)
MOP (0-0-60)	0	0	130	217
DAP (18-46-0)	51	130	0	283
Urea (46-0-0)	219	0	0	477
Filler (0-0-0)	0	0	0	23
Total	270	130	130	1,000
Percent (%)	27	13	13	100

Completed calculation sheet where filler is NOT used:

If no filler must be used, then the quantities of raw materials with nutrients should be varied to make up the deficit.

For example:

RAW MATERIAL	N (kg)	P_2O_5 (kg)	K_2O (kg)	Weight (kg)
MOP (0-0-60)	0	0	130	220
DAP (18-46-0)	51	130	0	290
Urea (46-0-0)	219	0	0	490
Filler (0-0-0)	0	0	0	0
Total	270	130	130	1,000
Percent (%)	27	13	13	100

Example 2

To produce a 1T blend using the fertilizer grade formula 20:10:10, how much of each raw materials will be required if the available materials are Ammonium Sulfate (21-0-0), Diammonium Phosphate, DAP (18-46-0), Muriate of Potash, MOP (0-0-60) and Filler if necessary?

SOLUTION

Step 1. Nutrient guarantees = 20% : 10% : 10% = 0.20 : 0.10 : 0.10

Step 2. Take total weight = 1, 000 kg

Step 3. Quantity of MOP containing 10% K_2O = 1, 000 kg * 0.10 = 100 kg
Quantity of DAP containing 10% P_2O_5 = 1, 000 kg * 0.10 = 100 kg
Quantity of AS containing 20% N = 1, 000 kg * 0.20 = 200 kg

Step 4. Check the P/N ratio since DAP is among the raw materials.
Using the P/N ratio method, 46 / 18 = 2.56 therefore, calculate for P first before N.

Step 5. From the formula NC = RM * NG, RM = NC / NG
To satisfy the given grade formula,
Quantity of MOP required to provide 10% K_2O = 100 kg / 0.60 = 166 kg
Quantity of DAP required to provide 10% P_2O_5 = 100 kg / 0.46 = 217 kg
But 218 kg of DAP also supplies 18% N. So, applying the formula NC = RM * NG,

- quantity of N supplied from DAP = 217 kg * 0.18 = 40 kg
- quantity of N required from AS = 200 kg - 40 kg = 160 kg

Therefore,

Quantity of AS required to provide 20% N = 160 kg / 0.21 = 762 kg
Determine if filler is required.
166 kg of MOP + 217 kg of DAP and 762 kg of AS = 1,145 kg

But the total formula weight exceeds 1, 000 kg.

Therefore "no room" for filler and the formula should be reworked according to step 5(c)

Completed calculation sheet:

RAW MATERIAL	N (kg)	P_2O_5 (kg)	K_2O (kg)	Weight (kg)
MOP (0-0-60)	0	0	100	166
DAP (18-46-0)	39	100	0	217
Ammonium sulfate (21-0-0)	161	0	0	762
Filler (0-0-0)	0	0	0	0
Total	200	100	100	1,145
Percent (%)	20	10	10	100

To maintain the formula grade and include urea (46-0-0) as a raw material:

217 kg of DAP also supplies 18% N. So, applying the formula NC = RM * NG,

- quantity of N supplied from DAP = 217 kg * 0.18 = 40 kg
- quantity of N required from AS and urea = 200 kg - 40 kg = 160 kg

Split the nitrogen sources. For example, AS 65% and urea 35%
Quantity of AS required to provide 20% N = (65%*160 kg) / 0.21 = 495 kg
Quantity of urea required to complete 20%N = (35%*160 kg) / 0.46 = 122 kg.
Determine if filler is required.
166 kg of MOP + 217 kg of DAP + 495 kg of AS + 122 kg of urea = 1,000 kg
Since total formula weight = total weight of raw materials = 1, 000 kg, therefore "no room" for filler material 0-0-0.

Completed calculation sheet:

RAW MATERIAL	N (kg)	P_2O_5 (kg)	K_2O (kg)	Weight (kg)
MOP (0-0-60)	0	0	100	166
DAP (18-46-0)	40	100	0	217
Ammonium sulfate (21-0-0)	104	0	0	495
Urea (46-0-0)	56	0	0	122
Filler (0-0-0)	0	0	0	0
Total	200	100	100	1,000
Percent (%)	20	10	10	100

Example 3

To produce a 1T blend using the fertilizer grade formula 15:15:15, how much of each raw materials will be required if the available materials are urea (46-0-0), Diammonium phosphate, DAP (18-46-0), Muriate of potash, MOP (0-0-60), and filler if necessary?

SOLUTION

Step 1. Nutrient guarantees = 15% : 15% : 15% = 0.15 : 0.15 : 0.15

Step 2. Take total weight = 1, 000 kg

Step 3. Quantity of MOP containing 15% K_2O = 1, 000 kg * 0.15 = 150 kg
Quantity of DAP containing 15% P_2O_5 = 1, 000 kg * 0.15 = 150 kg
Quantity of urea containing 15% N = 1, 000 kg * 0.15 = 150 kg

Step 4. Check the P/N ratio since DAP is among the raw materials.
Using the P/N ratio method, 46 / 18 = 2.56 therefore, calculate for P first before N.

Step 5. From the formula NC = RM * NG, RM = NC / NG
To satisfy the given grade formula,
Quantity of MOP required to provide 15% K_2O = 150 kg / 0.60 = 250 kg
Quantity of DAP required to provide 15% P_2O_5 = 150 kg / 0.46 = 326 kg
But 326 kg of DAP also supplies 18% N. So, applying the formula NC = RM * NG,

- quantity of N supplied from DAP = 326 kg * 0.18 = 59 kg
- quantity of N required from urea = 150 kg - 59 Kg = 91 kg

Therefore,

Quantity of urea required to provide 15% N = 91 kg / 0.46 = 198 kg
Determine if filler is required.
250 kg of MOP + 326 kg of DAP and 198 kg of urea = 774 kg
But the total formula weight is less than 1, 000 kg
Therefore "room" = 1, 000 kg - 774 kg = 226 kg to be filled by filler material 0-0-0.

Completed calculation sheet:

RAW MATERIAL	N (kg)	P_2O_5 (kg)	K_2O (kg)	Weight (kg)
MOP (0-0-60)	0	0	150	250
DAP (18-46-0)	59	150	0	326
Urea (46-0-0)	91	0	0	198
Filler (0-0-0)	0	0	0	226
Total	150	150	150	1,000
Percent (%)	15	15	15	100

For further reading on blend calculations and more examples, refer to section C of The Fertilizer Institute (TFI) manual, 2019 edition.

2.5 FERTILIZER BLENDING AND BAGGING OPERATIONS

To produce quality blends, the fifth step is to carry out the blending and bagging operations. Fertilizer blending and bagging is the process of mixing free flowing fertilizer raw materials and liquid coatings and packaging them into bags with open mouths. Every blender should have an internally developed set of standard operating procedures (SOPs) in addition to those listed in the plant's manual. These SOPs work to guide the entire process by ensuring operational uniformity. For further reference, ***Annex Q*** show an indicative checklist for bulk blending and bagging operations, while the following can serve as general guidance:

1. Use a batch or continuous blending system to produce accurate blends.
2. For either system, the general functions include, but are not limited to:
    a. Set the plant and scales to your predetermined zero setting.
    b. Load raw materials in receiving hopper(s).
    c. Start the blending process.
    d. Start the bagging process simultaneously with the blending process.
    e. Start the bag stitching process simultaneously with the bagging process.
    f. Palletize and store as required.

2.5.1 Labeling

All fertilizer bags should be labeled accordingly in line with the ECOWAS Implementing Regulation (Ref. Implementing Regulation ECW/PEC/IR/02/03/16) because it covers nutrient content, health, safety and environmental protection (Fig. 7). Labeling should be of a permanent kind, clear, prominent, and as stipulated by the regulation, can be in the official language(s) of the Member State(s) where the fertilizer product is marketed.

2.5.2 Plant Maintenance and Safety

Plant maintenance refers to the actions taken to maintain an existing plant or return it to its optimal operating levels. For any production operation, it is important to note the five types of maintenance. They are reactive, preventive, predictive, routine, and planned maintenance. Except for reactive maintenance, the other types are proactive in nature.

Figure 7. *ECOWAS fertilizer labeling regulation*

ECOWAS FERTILIZER LABELING

Economic Community
of West African States

(Ref. Implementing Regulation ECW/PEC/IR/02/03/16)

The label illustrated here is not a standard. It's a model that simply shows the minimum information required on fertilizer labels, as prescribed by an ECOWAS Implementing Regulation on labeling.

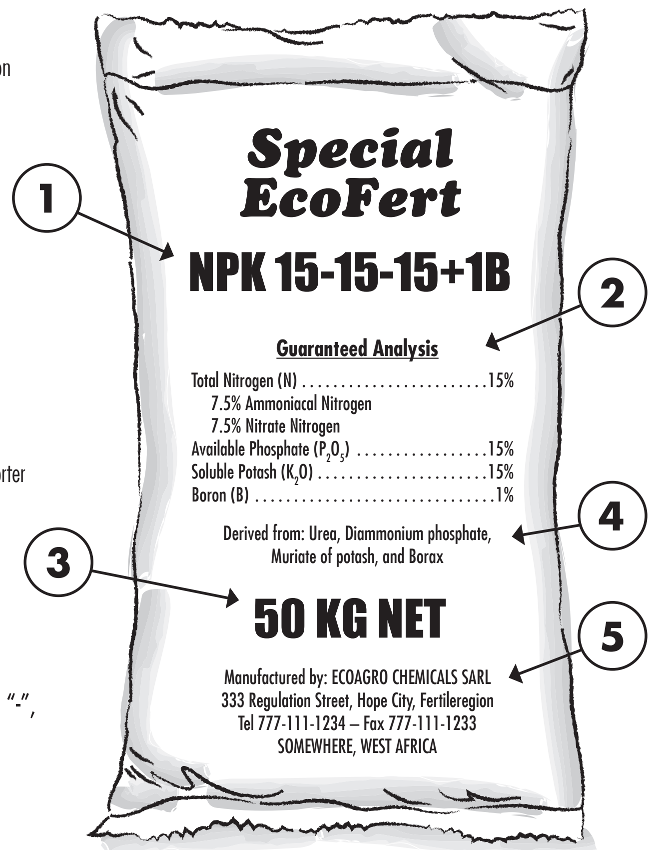
THE BIG FIVE

Five required components must appear on a fertilizer label:

1. Grade
2. Guaranteed analysis
3. Net weight
4. Sources of nutrients
5. Name and address of the manufacturer, importer or re-packing agent

GRADE

Grade is a shorthand representation of the guarantees for Total Nitrogen (N), Available Phosphate (P_2O_5) and Soluble Potash (K_2O) with each guarantee separated by a hyphen, "-", e.g., 15-15-15. The grade shall be in whole numbers and in the same terms, order, and percentages as in the guaranteed analysis.



Source: WAFBIG, 2021

2.5.2.1 Guidelines for Plant Maintenance

Every blending plant should have a maintenance schedule. It is a strategically laid out plan developed to execute maintenance activities with a purpose of achieving plant optimization. To optimize a plant's functionality, the following best practices should be applied:

1. Keep the plant clean and devoid of obstacles that can hinder its operation. Note that these are simple preventive maintenance procedures and are not related to plant malfunction and failure.
2. Remove all products stuck within crevices and along the blending or bagging line pathway in a manner that will not affect the structure of the plant.
3. Use an air compressor for dry products and a rag for wet or caked products.
4. Re-circulate a good cleaning agent through the pumping system of liquid impregnators to clean it out.
5. Check the fastenings and mountings of all moving parts and parts prone to vibration. Any looseness, restricted motion or deviations should be noted and reported.

Every plant supplier should supply a maintenance manual along with the plant. An adequate maintenance schedule should have a detailed tool and consumables list. The supplier must advise as to which tools and consumables are essential with reference to the type and size of plant being supplied. To effectively maintain a plant, refer to Annex R for an indicative maintenance checklist that can be used on every part of the plant.

2.5.2.2 Guidelines for Plant Safety

For safety in and around the area where the plant is, refer to Annex S for an indicative plant safety checklist. Steps detailing how movement of staff and mobile equipment should be conducted around the plant are highlighted.

2.5.3 Housekeeping

Good housekeeping at the facility is important because it can affect product quality, minimize product loss, and ensure safety of operators.

2.5.3.1 Guidelines for Good Housekeeping Practice

Every blender should have an internally developed set of SOPs for housekeeping (Toolbox Talks). However, the following can serve as guidance to achieve standard housekeeping levels in a fertilizer bulk blending operation.

1. Floor supervisors are to hold "Toolbox Talks" on a shiftly basis.
2. It is a fundamental duty for supervisors to provide concise information, training, personal protective equipment (PPE) and clear instructions as may be required to ensure the health and safety of all employees at work.
3. Sweep up spills after every operation.
4. Mix the clean and uncontaminated sweepings back with the main bulk product in its bay/bin.
5. Bag dirty contaminated sweepings and store separately from the good products.
6. Clean up the plant after every shift.
7. For facilities with overhead conveyor belts, ensure that product spillage while the belt is running is checked to prevent contamination of bulk products stored in the bays/bins below the belt.
8. Keep on high alert for contamination during receiving, storage, blending and bagging operations because this is the main cause of bad or low-quality blends.
9. Ensure that all product bays/bins are sealed properly at the bottom to avoid leakage and unplanned product mixture. The heights of product bays/bins should be adequate to avoid leakage and unplanned product mixture from the top when they are filled.
10. Product hoppers should be arranged and aligned such that leakage through shut off gates and from the top, when filled, are avoided.
11. Loading operators must take care when transferring product from bays/bins to the hoppers to avoid drip spillage all the way.
12. All driveways, accessways and walkways within the warehouse confines should be kept free of fertilizer, debris, foreign materials/objects, and moisture.
13. Label all product bays/bins as well as product hoppers correctly.
14. Some fertilizer raw materials are dusty in nature. Since dust is known to absorb moisture from its environment quicker than granular materials, it is important to keep the plant and warehouse dust free, as much as possible and for as long as possible. This will help in decelerating corrosion, reduce, or totally eliminate slippery conditions and make the general aesthetic appearance of the plant and warehouse more appealing.
15. Do not always rely on others to clear things up. Put tools away tidily rather than leaving them laying around benches, on the floor, on scaffolding, resting on pipes or in other positions. They can create trip hazards, fall onto a person, or get damaged in a fall. There is a place for everything, and

everything should be in its place.

16. If dismantling anything, stack the parts away neatly and tidily. Do not leave materials in gangways because they could block escape routes or cause hazards. When dismantling wood, make sure all nails are removed. If this is not possible, hammer nails flat and make sure that no parts are left protruding that could cause injury to anyone. Damaged lengths or parts of wood should be cleared as those also create hazards.
17. All waste should be placed in dust bins or skips to be removed. So, if a fire occurs, it can be confined to a small area and dealt with quickly and efficiently, thus preventing the fire from spreading, especially in high winds.
18. When finishing each shift, return tools and equipment to the store. If tools get damaged, get them repaired or replaced. Do not leave them lying around as they can cause hazards.
19. If you notice waste piling up which you cannot remove, bring this to the attention of your supervisor.
20. Should you be working at height and notice loose objects on boards or walkways, put them somewhere where they cannot be dislodged to avoid these items falling and injuring someone.

3. STORAGE AND DISPATCH OF BLENDED PRODUCTS

3.1 STORAGE OF BLENDED FERTILIZER

After bagging and stitching, the blended products are taken to bagged storage locations or loaded directly onto trucks for dispatch. Every blender should have an internally developed set of SOPs for storing blended products, but the following can serve as guidance for storage of blended products.

3.1.1 Guidelines for Storage of Blended Fertilizer

1. Sample blended products. It is good practice to label samples with date and batch number and keep them for at least 3 months. Refer to section 5.3.1 and ***Annex T***, for more on sampling.
2. Secure the storage bay or bin and provide controlled access for the finished products.
3. Provide signs or labels indicating what is in the fertilizer storage area.
4. Provide pallets to keep bags off the floor.
5. Store products separate from liquids to prevent wetting from liquid spills.
6. Do not store products that react in any form side by side or close to each other.
7. Cover stored fertilizer with plastic polyethylene sheets to prevent contamination from dust, humidity, rainwater, and other raw materials.
8. The inner part of the bags should be lined with a waterproof material e.g., plastic, to prevent moisture exchange which will damage the bagged product.
9. Store the bags according to internal SOPs i.e., in a manner that will allow for easy and safe access when manually or mechanically loading onto dispatch trucks.
    a. As indicated in ***Annex U***, it is suggested that bags should not be stacked at more than 5 m height.
10. Turn bags on all four sides and shake properly before loading onto dispatch trucks to maintain the homogenous nature of the mixture to avoid product segregation.
11. Used bags should be bundled and disposed of in an approved landfill. In some cases, fertilizer blenders sell used bags to local furniture makers who thoroughly clean the bags and reuse them as filling or padding for hand-made furniture e.g., sitting room couches.
12. Blend only what is required when it is required. This helps avoid unnecessary long-term storage.
13. If fertilizer of whatever quantity spills, clean it up immediately.
14. Have an emergency response plan for the site.

3.2 DISPATCH OF PRODUCED BLEND

In West Africa, fertilizer blends are usually handled in bags. It is rare to see an operation in this region where blended cargo will be dispatched in bulk. The most common bag sizes are 50 kg and 25 kg. However, a lot of operations and end users are adopting the one-ton cargo type whereby 20 x 50 kg bags are systematically arranged together in a sling bag, stacked on a pallet, or shrink wrapped together while on a pallet. The success of a fertilizer operation does not only lie in completing the blending and bagging activities but is linked with the post bagging activities. This includes how the blended products are handled from the stitching lines till dispatch. This manual will discuss how produced blends should be handled.

3.2.1 Guidelines for Dispatch of Produced Blends

Every blender should have an internally developed set of SOPs for dispatching blended products. But the following can serve as guidance.

1. Inspect blended products in bays/bins before dispatch to ensure the correct request is exactly what is being dispatched.
2. Load trucks as requested by the client. Loading should be done in a manner that is easy, smooth, and efficient.
   a. Use inclined conveyors, long enough to reach the truck beds from the stitching lines, when loading loose bags directly onto trucks.
   b. Use forklifts when loading loose bags in stacked slings, bulk bags or shrink wrapped.
3. Turn bags on all four sides when loading out of blended storage bays/bins, so the product does not un-mix or cake.
4. Samples from every batch or at least one truck load should be taken, analyzed, and kept until the farmer is satisfied.

4. ACCOUNTING AND RECORD KEEPING

To promote high quality blends and reduce or eliminate cases of underweight bags finding their way into the market, accurate record keeping is becoming more important for good agricultural practices (GAP) and good handling practices (GHP), which are embedded in the ECOWAS Regulation as well as the International Organization for Standardization (ISO) certification. All these require you to not only keep good records but also provide accurate documentation. Every blender should consider becoming certified because many larger fertilizer customers are now requiring that bulk blenders become certified. To be certified requires another level of record keeping and documentation. A coordinator will have to be designated in the operations primarily to handle all the record keeping needed and work with the certifying agencies. You will need to train your entire team about safe handling practices and document that training.

4.1 GUIDELINES FOR ACCOUNTING AND RECORD KEEPING

Every blender should have an internally developed set of SOPs for accounting and record keeping. But the following can serve as guidance.

1. When receiving raw materials:
    a. Weigh all inbound raw materials across a certified weighbridge.
    b. Capture and tally the corresponding weights accurately.
    c. Audit all inbound cargo. This should be done by a certified external surveyor/auditor to ascertain the quantity of product received at every given time.
    d. Compare weighbridge and survey figures and act immediately if anomalies are more than the prescribed tolerance limits.

2. Before blend production:
    a. Compute blend calculations correctly per batch so that too much raw material is not used and hence lost within the system.
    b. Record these figures accurately per batch and work back to floor stock balance on a shiftly basis.

3. During blend production:
    a. Accurately tally raw materials taken from product bays or bins into blending plants to ensure quantities deducted from storage bays or bins during production are in accordance with pre calculated weights.
    b. Ensure the automated scales are capturing each bag weight then manually weigh random bags per batch. This will ensure that bag weights are accurately matched to how much was taken out of the storage and accounted for at the postproduction stage.

4. After blend production:

   a. Calculate the total weight of every batch and work the weights back to how much was taken out of the storage. Compare this with what is left on the floor to maintain total product stewardship in terms of quantities.

5. Automated systems are encouraged because of ease of access, data safety and security. However manual copies can be kept as back up in case of system failures.

4.2 OTHER FORMS OF RECORD KEEPING

4.2.1 Production Records

Keeping records of your hourly, daily, weekly, monthly, and annual production is critical to analyze what worked and what did not. Combining these records with the cash flow records will enable you to see that you will be more profitable if you use known quantities of raw materials, bought at a certain price, for bulk blending and you achieve the same quantities of production output using minimal expenses and selling for higher prices.

The key to profitability is buying raw materials in bulk when the international or market prices are lower than usual, keeping blending operations' overheads and expenses as low as possible without compromising the quality of output and selling produced blends when market prices are higher than usual. Production records should be kept for each type of fertilizer raw material and blend recipe. Find a method that works for you but keep track of raw material receipts, blend production and dispatch to customers.

4.2.2 Financial Records

A ***detailed check register*** will enable you or your accountant to produce several financial records. With additional information you or your accountant can produce an income statement, balance sheet, and performance ratios that will enable expert analysis of your business.

A ***cash flow*** is a record of all income and expenses listed by category. For example, you may have a category for each type of fertilizer sold i.e., blend or straight. It is like a moving picture because you will record all income and expenses in the applicable categories monthly. A record of your cash flow for a year will enable you to decide when additional cash is needed and when certain bills will be due enabling you to better plan.

An ***income statement*** combines some of the items from your cash flow into more broad categories. The income statement is where you make your accrual adjustments, considering the changes in inventories.

A ***balance sheet*** is a snapshot of your business on a given day. These are usually completed at the end of your fiscal year to make consistent comparisons of your business. The information from a balance sheet and income statement can be then used to calculate specific ratios for financial analysis.

5. QUALITY CONTROL

Maintaining a high level of quality control in every aspect of the blending and bagging process, will lead to the production of quality blends. For existing blenders, "the process", which includes selecting and sourcing chemically compatible raw materials with correct quantities of nutrient contents, calculating blend composition, blending, bagging, storage, dispatch, accounting, and record keeping, was discussed in detail. But for new blenders, "the process" of producing quality blends will from the onset include creating a good business plan and siting the project correctly.

5.1 QUALITY CONTROL FOR FINISHED PRODUCTS

For finished products, blenders should comply with their National Fertilizer Regulations or the ECOWAS/UEMOA Regulations. Every blender should have an internally developed set of SOPs for quality control of finished products.

5.3 GUIDELINES FOR QUALITY CONTROL OF FINISHED PRODUCTS

5.3.1 Sampling

Sampling of materials is a serious undertaking and should not be taken lightly. It involves special procedures and requires dedicated equipment. Blenders must go through recognized sampling methods such as those described in this manual. It is pointless collecting and analyzing samples that do not represent the batch, hence all samples must be correctly taken to ensure accurate representation. For accurate sampling, blenders must know the following:

1. The acceptable sampling and testing methods (see ***Annex T*** and ***Annex V***).
2. The most appropriate sampling and testing equipment and methods (***Annexes T*** and ***V***).
3. The sample quantity to be collected
4. The increments in which samples should be taken.
5. The samples collected should be reduced to 250 g for sieve analysis and 500 g for chemical analysis.

5.3.2 Tolerance

Tolerance is defined by the ECOWAS Tolerance Limits for plant nutrients, heavy metals and bag weights document and the Regulation C/REG.13/12/12 as the permitted deviation of measured values of a nutrient content or bag weight below values claimed on the label, or the maximum allowable heavy metal limits in a fertilizer (Ref. Implementing Regulation ECW/PEC/IR/02/03/16).

5.3.3 Safety Classification

Fertilizer blending and bagging operators need to be knowledgeable about the possible risks linked with raw materials, for example Ammonium Nitrate. If classification systems are understood and adhered to, identifying risks will be easier. Therefore, the ECOWAS/UEMOA regulatory framework must be adopted by all blenders for synergy and good practice.

6. CONCLUSION

In conclusion, low quality blends are sold in West Africa because:

1. There is no uniform set of rules guiding bulk blending in West Africa.
2. High and continuously rising costs of quality fertilizer raw materials.
3. The type, quality, age and flexibility of bulk blending plants and production facilities.
4. Scarcity of expertise that understands the science and business of bulk blending.
5. Absence of or very expensive financial instruments for bulk blenders and farmers.

This document was prepared through an exhaustive consultation process. A strict adherence to the guidelines in this document will ensure quality blends. By providing foundational guidelines that can be built upon, each section of this manual detailed steps that can positively affect the quality of bulk blends.

To develop this manual, quantitative and qualitative methodologies, consisting of web-based, in-person surveys, field, and applied research, were employed.

7. RECOMMENDATION

To produce quality fertilizer blends, this manual recommends the following:

1. Select a suitable location for the operation, source the right raw materials from credible suppliers so that the quality/quantity of the nutrient contents are guaranteed, blend and bag to the prescribed standard, carry out plant maintenance as prescribed and adhere to good general housekeeping.
2. Receive and store raw materials such that their compatibility is taken into consideration.
   a. Incompatible raw materials should not be stored close to each other or used in blends because the quality of the final blend will be compromised.
   b. Raw materials with limited compatibility should be assessed for their chemical, physical and safety-based compatibility before being stored in their designated bays/bins or before being used in blends.
3. Select a good bulk blending plant. The key points to note are performance in terms of speed, accuracy, capabilities, simplicity of operation (both types of plants need capable software to run the system and interact with the accounting software), budget and space requirements.
4. Store produced blends in a manner that ensures their quality will not be compromised and dispatch is seamless.
5. Employ good accounting and record keeping practices that tie into the entire operations.
6. Adhere to the following quality control measures:
   a. Select raw materials with known nutrient content and closely matched particle sizes.
   b. Know the chemical, physical and compatibility properties of the raw materials.
   c. Carry out sampling and physical tests of both the raw materials and finished blends.

7.1. GENERAL RECOMMENDATION

1. Bulk blenders should be encouraged to utilize bags with inner lining and transparent sides. The transparent sides enable visual inspection of the quality of blends contained therein.

   a. Indicative bag characteristics are given as:

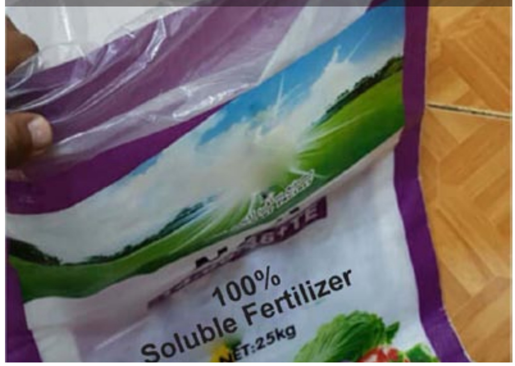
FERTILIZER BAG CHARACTERISTICS	
Product	■ Fertilizer packaging bag ■ Laminated polypropylene woven sack ■ Polyethylene liner ■ Transparent sides – recommended
Material	■ 100% virgin polypropylene
Size	■ 10 kg: L 610 mm * W 350 mm ■ 20 kg: L 760 mm * W 450 mm ■ 25 kg: L 800 mm * W 450 mm ■ 50 kg: L 980 mm * W 580 mm
GSM	■ 40 gsm – 80 gsm ■ 75 gsm recommended
Description	■ High tensile strength ■ Falls and friction ■ Dimensional stability ■ Good printing surface ■ Compliance contact

2. Carry out capacity building exercises (at least annually), to boost and sustain the technical and business know-how of all bulk blending players in the region.

3. Bulk blenders should be equipped to carry out in-house test and analysis of raw materials and blends analysis.

4. Fertilizer blends not meeting the stipulated tolerances should result in penalties and prosecution.

Fertilizer bags with PE liners and transparent sides enable inspection of the contents.



Source: 1st photo adapted; 2 and 3 taken by Chinedu Ohanyere, 2021

5. All blenders should be properly registered and should register their fertilizer blends according to the stipulations in the country within which they operate.
6. The roles and responsibilities of each sector should be clearly defined e.g., government is to create an enabling environment and encourage private sector-led fertilizer operations.
7. ECOWAS should set, measure, manage and track blend quality targets.
8. ECOWAS should create an active and effective regulatory body to control issues relating to low nutrient content and sampling methods for fertilizer raw materials. For example, the Canada Food Inspection Agency is empowered to carry out such functions.
9. ECOWAS should coordinate and collaborate as a unit to reduce raw material distribution and receiving challenges e.g., high freight, high discharge, and demurrage costs within and across member countries.
10. ECOWAS should adopt the 8R Fertilizer Blend Quality Stewardship™ as a precursor to the 4R nutrient stewardship. These are:
    a. Right grade formula
    b. Right raw material selection
    c. Right calculation of blend composition
    d. Right blend compatibility
    e. Right blending
    f. Right bagging
    g. Right storage
    h. Right application of the 4Rs:
        - Right source.
        - Right rate.
        - Right time.
        - Right place.

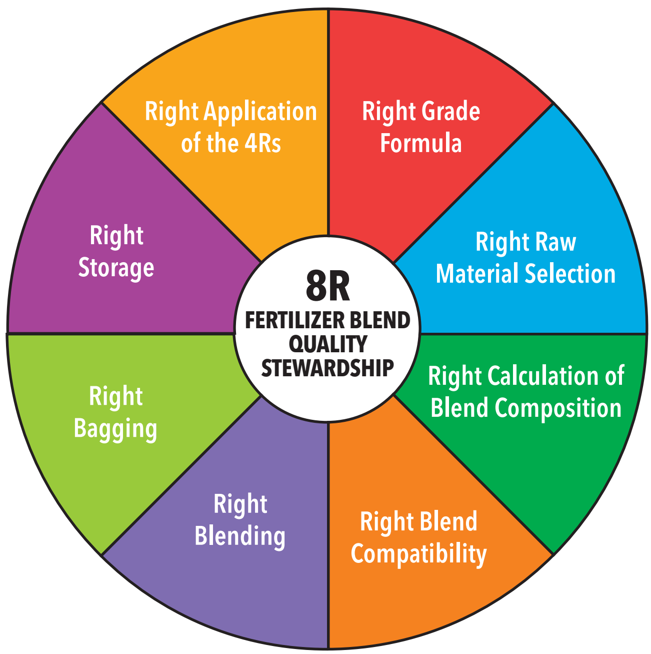


Figure 8. *Variables that impact blend quality*

Source: 8R Fertilizer Blend Quality Stewardship™

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ANNEXES

A. FERTILIZER MANUFACTURING FACILITIES IN ECOWAS

Table A1. *Nitrogen and Phosphorus manufacturing facilities in ECOWAS, 2022*

#	Country	Plant Site	Company	Product	Year Est.
1	Burkina Faso	Bobo Dioulasso	Faso Fert	Crushed Dolomite	2022-2023
2	Burkina Faso	Diapaga	Société d'Exploitation des Phosphates du Burkina (SEPB)	Natural Phosphate Rock	2012
3	Mali	Bourem	Sangoye	Granular Phosphate	2023–2024
4	Mali	Bamako	Toguna Agro Industries – Tilemsi	Natural Phosphate Rock	2009
5	Nigeria	Bayelsa	Brass Fertilizer	Granular Urea	Unknown
6	Nigeria	Ibeju Lekki, Lagos State	Dangote Fertilizer Limited	Granular Urea	2021
7	Nigeria	Eleme, Rivers State	Indorama Eleme Fertilizers & Chemicals Ltd – Phase 1	Granular Urea	2016
8	Nigeria	Eleme, Rivers State	Indorama Eleme Fertilizers & Chemicals Ltd – Phase 2	Granular Urea	2021
9	Nigeria	Onne, Rivers State	Notore Chemical Industries Plc	Granular Urea	2005
10	Senegal	Dakar	Amafrique SUARL	Granular Phosphate	2023–2024
11	Senegal	Dakar	Industries Chimiques du Sénégal (ICS)	Phosphate Rock, Phosphoric Acid, DAP, NPK, Gypsum	1976
12	Senegal	Matam	Société d'Études et de Réalisation des Phosphates (SERPM)	Natural Phosphate Rock	2007
13	Senegal	Matam	Société Minière de la Vallée du Fleuve (SOMIVA)	Phosphate Rock	2008
14	Togo	Kpémé	Société Nouvelle des Phosphates du Togo (SNPT)	Phosphate Rock	1961

Source: AfricaFertilizer.org and IFDC, 2022

Table A2. *Organic fertilizer manufacturing facilities in ECOWAS, 2022*

#	Country	Plant Site	Company	Year Est.
1	Benin	Allada	Bio Phyto	2013
2	Burkina Faso	Ouagadougou	Arom-H/Sol Fertile	2014
3	Burkina Faso	Ouagadougou	Faso Biogaz	2015
5	Côte d'Ivoire	Adzopé	Éléphant Vert Côte d'Ivoire	2014
6	Ghana	Adjen Kotoku	Accra Compost & Recycling Plant (ACARP)	2012
7	Ghana	Akorley, Somanya	JVL-YKMA Recycling Plant	2020
8	Ghana	Ashaiman	Safisana	2016
9	Ghana	Borteyman, Tema	JVL Fortifier Compost Plant	2017
10	Ghana	Jamestown, Accra	Ga Mashie Aerobic Compost Plant	2013
11	Ghana	Mpasatia/Nkawie	New Okaff Industries Limited	2014
12	Mali	Bamako	Orgafert	2018
13	Mali	Bamako	PROFEBA	2017
14	Mali	Ségou	Éléphant Vert Mali	2018
15	Nigeria	Kaduna	Dharul Hijrah Fertilizer Company Ltd	2016
16	Nigeria	Kano	Excel Standards Ltd	2013
17	Senegal	Dakar	Biotoss	2017
18	Senegal	Dakar	Éléphant Vert Sénégal	2018

Source: AfricaFertilizer.org and IFDC, 2022

Table A3. *Soil supplements and micronutrient manufacturing facilities in ECOWAS, 2022*

#	Country	Plant Site	Company	Product	Year Est.
2	Ghana	Takoradi	Carmeuse Lime Products GH Ltd	Lime Supplements	2020
3	Nigeria	Kaduna South	Cybernetics Nigeria Ltd	Micronutrients	1985

Source: AfricaFertilizer.org and IFDC, 2022

B. INDICATIVE COST ESTIMATES REQUIRED TO SET UP A TURNKEY BULK BLENDING OPERATION

Table B1. *Plant Type: BATCH Complete Blending and Bagging System*

Capacity	Total Cost Estimate	OPEX Estimate	Total
1 - 10 Mtph	$125,000	$6,862,400	$6,987,400
11 - 20 Mtph	$250,000	$13,724,800	$13,974,800
21 - 30 Mtph	$375,000	$20,587,200	$20,962,200
31 - 60 Mtph	$625,000	$41,174,400	$41,799,400
61 - 70 Mtph	$875,000	$48,036,800	$48,911,800
70 - 150 Mtph	$1,850,000	$102,936,000	$104,786,000
150 - 200 Mtph	$2,400,000	$137,248,000	$139,648,000
over 200 Mtph	over $1,500,000	over $150,000,000	over $150,000,000

Table B2. *Plant Type: CONTINUOUS Complete Blending and Bagging System*

Capacity	Total Cost Estimate	OPEX Estimate	Total
1 - 10 Mtph	N/A	$6,862,400	N/A
11 - 20 Mtph	N/A	$13,724,800	N/A
21 - 30 Mtph	$525,000	$20,587,200	$21,112,200
31 - 60 Mtph	$800,000	$41,174,400	$41,974,400
61 - 70 Mtph	$1,250,000	$48,036,800	$48,286,800
70 - 150 Mtph	$1,650,000	$102,936,000	$104,586,000
150 - 200 Mtph	$2,200,000	$137,248,000	$139,448,000
over 200 Mtph	over $1,500,000	over $150,000,000	over $150,000,000

** The price ranges are NOT cast in stone so may vary significantly based on various global and local factors.*

** Considering a batch system for a production of over 70 tph, it is advisable to utilize a Tower System.*

** Considering a continuous system for a production of under 30 tph is not advisable, hence the N/A comment.*

** The price range includes prices from manufacturers in America, Canada, China, Europe, India and South Africa.*

** OPEX was based on global average cost, as at Jan 2022, for UREA, MAP, DAP and MOP. But Filler price in Nigeria was adopted.*

** OPEX costs can be split into three tranches within a financial year.*

** OPEX estimates calculated with these parameters; highest tph for each capacity, 10h/day, 20days/mth, 6mths/yr, av RM price, 80% production rate.*

** Average plant and building costs are half of the sum of the lowest plus highest costs.*

** Primary costs include a weighbridge system.*

** Total Costs: Bldg. and Plant CapexOpex+Primary, Secondary and Sundry Costs where applicable.*

** Total Costs: ONLY 1 equipment each of Secondary Costs was taken into consideration.*

** Primary Cost for FEL was added after 60tph for continuous system.*

** $200,000 for Conveyor Cost was added after 100tph for continuous system.*

Additional facility requirements for various plant and tonnage capacities

Equipment	Up to 30 mtph	Up to 60 mtph	Up to 100 mtph	Over 100 mtph
Frontend loaders	Not necessary	Not necessary	Yes	Yes
Modified frontend loaders	Yes	Yes	No	No
Forklifts	Yes	Yes	Yes	Yes
Loading bays	Yes	Yes	Yes	Yes
Receiving conveyors*	Not necessary	Not necessary	Yes	Yes
Weighbridge	Yes	Yes	Yes	Yes

** Receiving Conveyor System estimated at $200,000.*

C. ROLE OF EACH RESOURCE

Land Surveyor

When a piece of land has been identified for the project, the first thing to do is to get an architect who will spearhead the project and bring it to fruition. A good architect should contract the services of a land surveyor whose responsibility is to survey the piece of land in its entirety, produce a working sketch and a final diagram that will be used throughout the project. Important details such as the true North, sun and wind directions, land contours, survey levels taken off an established datum point, beacon numbers, physical and environmental characteristics of the land, etc. must be collected and detailed on the survey drawings. The land surveyor should stamp the drawings and work with the local city officials to register the survey and ensure final approvals are received.

Architect

This is usually the project lead. The architect is responsible for conceptualizing the project and bringing it to life, on paper, in a manner that its functionality requirements are met. Using the approved survey plan, they produce a full set of well detailed architectural drawings which should show plan, section and elevation views, door details and schedules, window details and schedules, roof details and other finer details. In most cases they select the other resources and ensure the client's expectations are met to the budget. They should be qualified and experienced. All architectural drawings should be stamped, signed, and sealed in accordance with the local and international laws of the respective architectural societies. S/he should be involved in the project from start to finish.

Civil and Structural Engineer

The civil and structural engineer is responsible for ensuring the architect's vision for the facility is made to be structurally safe and sound for its intended use. S/he breaks down the architect's plans into structural members, allocates loads to each member, analyzes the member's reactions to the loads, prescribes reinforcements according to the local and international building codes and standards of practice. Civil drawings are produced to show cuts and fills required to maintain a reasonable surface area. Structural detail drawings are produced to show reinforcement details to each structural component that make up the sub and super structures. They should be qualified and experienced. All civil and structural drawings should be stamped, signed, and sealed in accordance with the local and international laws of the respective civil engineering societies.

Mechanical Engineer

The mechanical engineer is responsible for planning and designing the wet works i.e., how clean and wastewater will safely flow in and out of the building respectively and not contaminate the raw materials and/or finished products. S/he determines the best position for the source of water i.e., bore hole, water treatment and storage systems, piping types, sizes, and network for both clean and wastewater, position and design of sewage/septic tank systems, air and ventilation quality and cooling systems and their positions. Mechanical detail drawings are produced showing the characteristics of selected accessories and their sizes. They should be qualified and experienced. All mechanical drawings should be stamped, signed, and sealed in accordance with the local and international laws of the respective mechanical engineering societies.

Electrical Engineer

The electrical engineer is responsible for planning and designing the electricity distribution and network systems of the entire facility. They are responsible for how the building gets electrical energy, transmits it from the source into the building, the plant and equipment in addition to how each part uses it. A set of detailed electrical layout drawings are produced for the entire project and component parts and their characteristics are selected, adopted, and arranged systematically to meet the aims and objectives of the project. S/he should be qualified and experienced. All electrical drawings should be stamped, signed, and sealed in accordance with the local and international laws of the respective electrical engineering societies.

Instrumentation Engineer

The instrumentation engineer is responsible for planning and designing the instrumentation and communication systems of the plant and equipment to be utilized in the operations. Modern equipment is becoming more sophisticated nowadays and hence require more attention in their set up and use. Fertilizer blending plants and generator sets are not an exception. The latest state of the art technology e.g., artificial intelligence which enhances machine learning, are employed in most of them and as such need specialized skills to maintain their functionality. In most projects, the electrical engineer doubles up as the instrumentation person and usually the same company handles the mechanical, electrical and instrumentation aspects of projects, hence the nomenclature ME&I. They work hand in hand with the plant/equipment manufacturers and are usually the people directly trained on site, during installation and commissioning, for business continuity. S/he should be qualified and experienced. All instrumentation drawings should be stamped, signed, and sealed in accordance with the local and international laws of the respective instrumentation engineering societies.

Quantity Surveyor (QS)

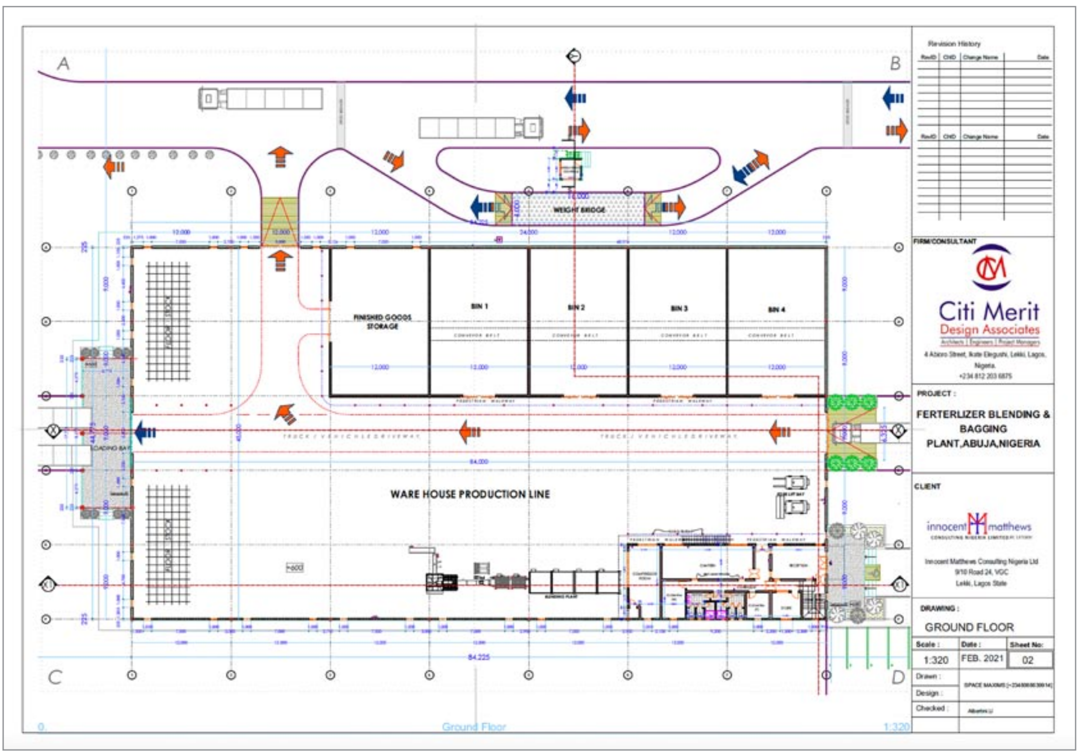
The QS is responsible for populating all the certified detailed drawings from the architect and engineers, described above, breaking them down into the finest details, quantifying each component, costing the entire project, and producing a detailed document usually known as the Bill of Quantities

(BoQ). This document acts as the project "bible" because it is used by the project lead to guide the project expenditure to ensure there are no budget overruns. They work with the project lead and the client from start to finish. S/he should be qualified and experienced. The BoQ should be stamped, signed, and sealed in accordance with the local and international laws of the respective quantity surveying societies.

General Foreman

The "foreman" is responsible for interpreting land surveyor, architect and engineers' detailed drawings and translating them onto the site. They select, supervise and manage the entire building construction team and processes. They work with each resource at every phase of the project, especially with the architect (project lead) and the QS. S/he should be dedicated to the project, qualified and vastly experienced.

D. INDICATIVE ARCHITECTURAL LAYOUT OF A BULK BLENDING FACILITY



Source: Innocent Matthews Consulting Ltd, 2020

E. INDICATIVE BUILDING AND OPEX COSTS

Table E1. *Plant Type: BATCH Complete Blending and Bagging System*

Capacity	Total Cost Estimate	OPEX Estimate	Total
1 - 10 Mtph	$50,000	$6,862,400	$6,912,400
11 - 20 Mtph	$125,000	$13,724,800	$13,849,800
21 - 30 Mtph	$200,000	$20,587,200	$20,787,200
31 - 60 Mtph	$400,000	$41,174,400	$41,574,400
61 - 70 Mtph	$600,000	$48,036,800	$48,636,800
70 - 150 Mtph	$850,000	$102,936,000	$103,786,000
150 - 200 Mtph	$1,250,000	$137,248,000	$138,498,000
over 200 Mtph	over $1,500,000	over $150,000,000	over $150,000,000

Table E2. *Plant Type: CONTINUOUS Complete Blending and Bagging System*

Capacity	Total Cost Estimate	OPEX Estimate	Total
1 - 10 Mtph	N/A	$6,862,400	N/A
11 - 20 Mtph	N/A	$13,724,800	N/A
21 - 30 Mtph	$200,000	$20,587,200	$20,787,200
31 - 60 Mtph	$400,000	$41,174,400	$41,574,400
61 - 70 Mtph	$750,000	$48,036,800	$48,786,800
70 - 150 Mtph	$850,000	$102,936,000	$103,786,000
150 - 200 Mtph	$1,250,000	$137,248,000	$138,498,000
over 200 Mtph	over $1,500,000	over $150,000,000	over $150,000,000

* *The price ranges are NOT cast in stone so may vary significantly based on various global and local factors.*

* *Considering a batch system for a production of over 70 tph, it is advisable to utilize a Tower System.*

* *Considering a continuous system for a production of under 30 tph is not advisable, hence the N/A comment.*

* *The price range includes prices from manufacturers in America, Canada, China, Europe, India and South Africa.*

* *OPEX was based on global average cost, as at Jan 2022, for UREA, MAP, DAP and MOP. But Filler price in Nigeria was adopted.*

* *OPEX costs can be split into three tranches within a financial year.*

* *OPEX estimates calculated with these parameters; highest tph for each capacity, 10h/day, 20days/mth, 6mths/yr, av RM price, 80% production rate.*

* *Average building costs are half of the sum of the lowest plus highest costs.*

F. INDICATIVE COSTS OF BULK BLENDING PLANTS

Table F1. *Cost Ranges of BATCH and CONTINUOUS Complete Blending and Bagging Systems*

	BATCH SYSTEM	CONTINUOUS SYSTEM
Capacity	Cost Range	Cost Range
1 - 10 Mtph	≤ $100,000	N/A
11 - 20 Mtph	$100,000 - $150,000	N/A
21 - 30 Mtph	$100,000 - $300,000	$100,000 - $300,000
31 - 60 Mtph	$300,000 - $500,000	$300,000 - $500,000
61 - 70 Mtph	$500,000 - $700,000	$500,000 - $1,000,000
70 - 150 Mtph	$700,000 - $1,000,000	$700,000 - $1,000,000
150 - 200 Mtph	$1,000,000 - $1,500,000	$1,000,000 - $1,500,000
over 200 Mtph	over $1,500,000	over $150,000,000

* *Plant costs as at 2021.*

* *Types of Batch Plants: 1. Floor Style Systems (Single or Multi Hopper) 2. Tower Style Systems.*

* *Types of Continuous Plants: 1. Floor Style Systems (Multi Hopper).*

* *The cost ranges are NOT fixed. They may vary significantly based on various global and local factors.*

* *Considering a batch system for a production of over 70 tph, it is advisable to utilize a Tower Style Batch Plant.*

* *Considering a continuous system for a production of under 30 tph is not advisable, hence the N/A comment.*

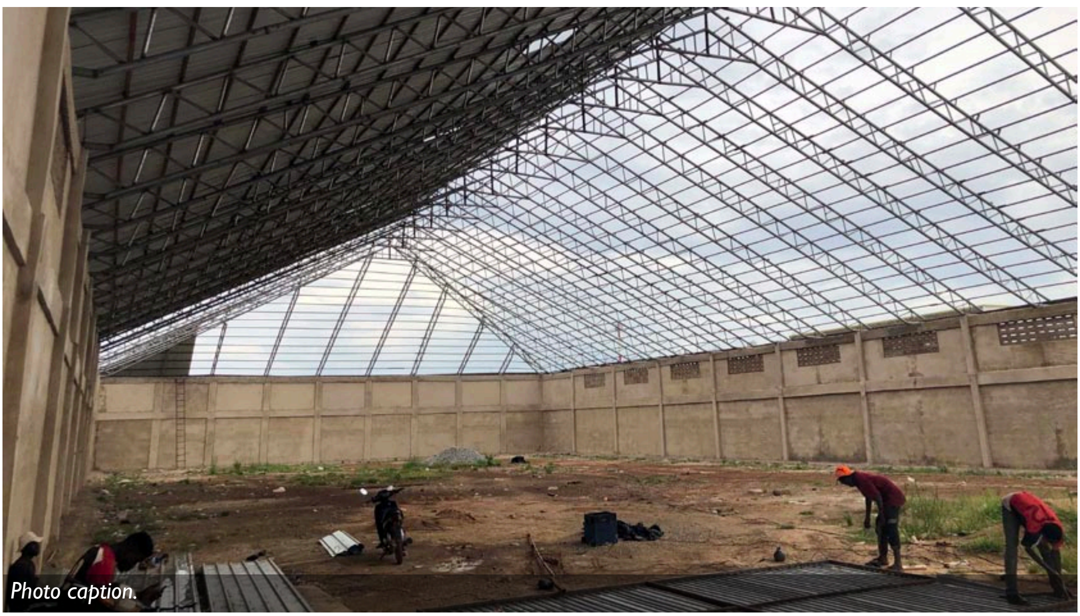


Photo caption.

G. SOME TYPES OF BLENDING SYSTEMS


Dynamic weight control system


Mesh DCS multi blending system


Tower blending system


Mix plants


Auto batch


On-farm blender


Rotary blender

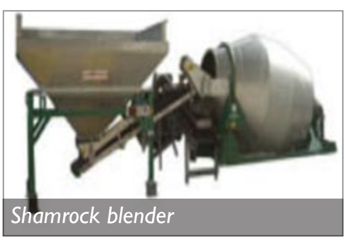

Rotary blender


Orbital blender


Direct drive


Precision blender


Vertical blender


Shamrock blender

Source: Various

H. LIST OF SOME BULK BLENDING PLANT MANUFACTURERS

AFRICA

- Bagtech Fertilizer Management and Handling Solutions
  https://bagtechint.com/

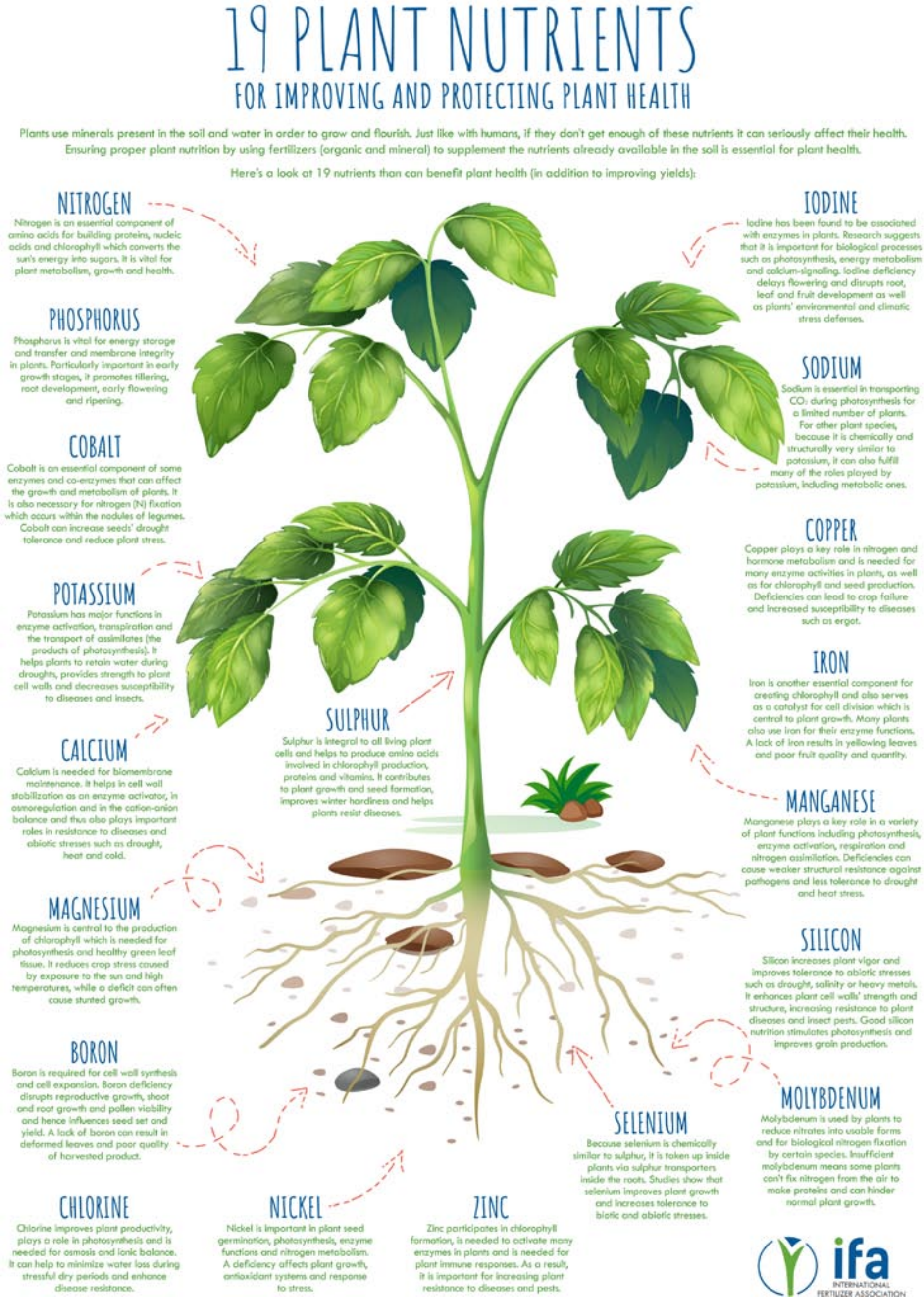
EUROPE

- EMT
  https://emt.tech/

NORTH AMERICA

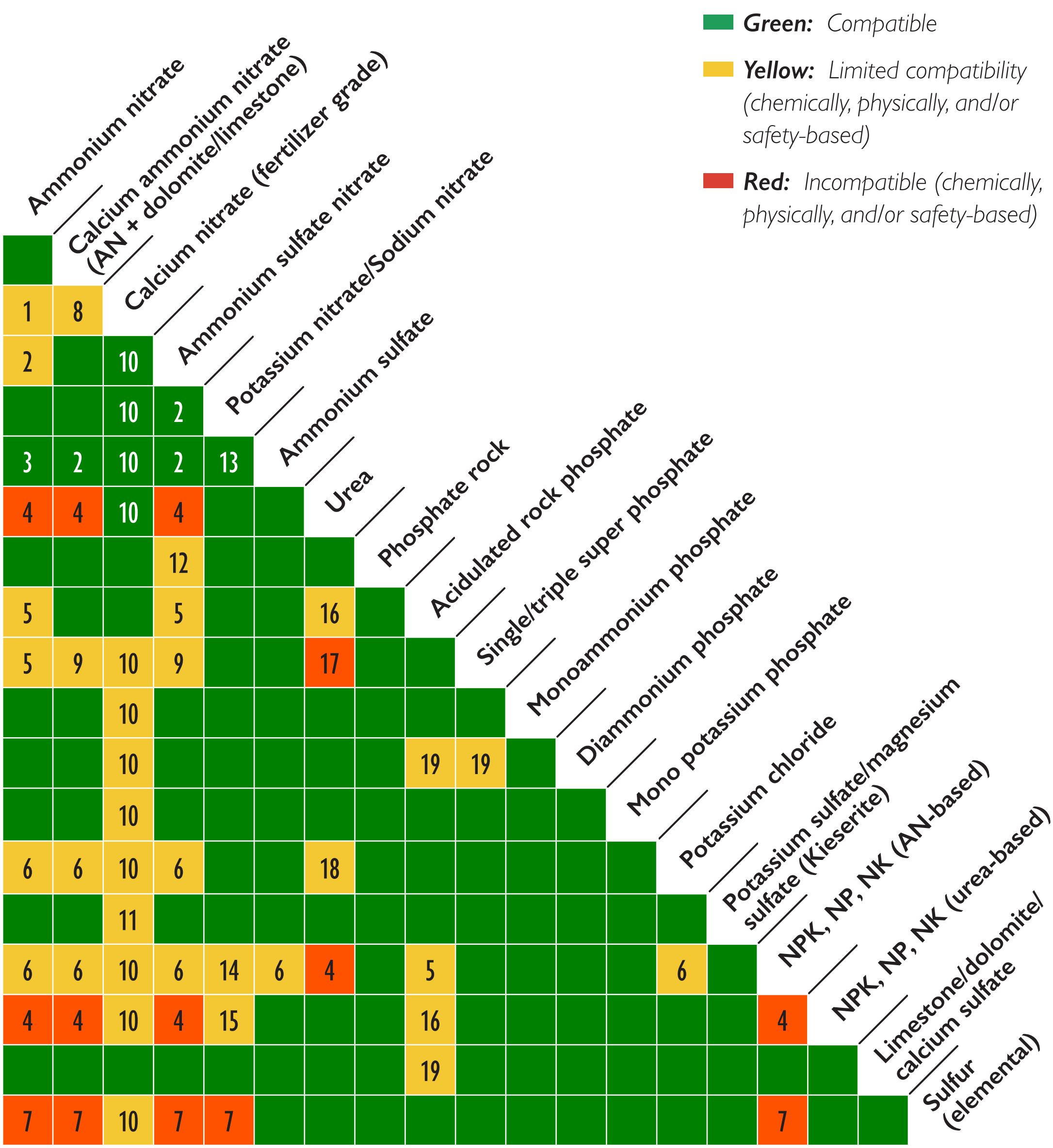
- Adams Fertiliter Equipment
  https://www.adamsfertequip.com/
- AGI Fertilizer Systems/Yargus
  https://aggrowth.com/en-us/fertilizer
- Doyle Equipment Manufacturing
  https://www.doylemfg.com/
- Murray Equipment Inc.
  https://www.murrayequipment.com/target-markets/dry-fertilizer.html
- Ranco Fertiservice Inc.
  https://www.rancofertiservice.com/
- Sackett-Waconia
  https://www.sackettwaconia.com/

I. ESSENTIAL PLANT NUTRIENTS



Source: IFA, fertilizer.org

J. FERTILIZER COMPATIBILITY CHART



Source: Handbook of solid fertilizer blending, code of good practice for quality, 2016.

COMPATIBLE MATERIALS

1. Due to the hygroscopic behaviour of both products, the type of stabilisation of the ammonium nitrate grade could influence storage properties.
2. Consider the safety implications regarding detonability of the blend (AN/AS mixtures) and legislative implications.
3. Consider the safety implications regarding detonability of the blend (AN/AS mixtures), impact of free acid and organic impurities, if present, and legislative implications.
4. If free acid is present it could cause very slow decomposition of AN, affecting, for example, packaging.
5. Consider the possibility of self-sustaining decomposition and the overall level of oil coating.
6. Due to the hygroscopic behaviour of both products, the type of stabilisation of the ammonium nitrate based fertilizer could influence the storage properties.
7. Consider the moisture content of the SSP/TSP.
8. Consider the relative humidity during blending.
9. Risk of formation of gypsum.
10. No experience but this can be expected to be compatible. Confirm by test and/or analysis.
11. Consider impurities in AS and the drop in the critical relative humidity of the blend.
12. Consider the likely impact of additional nitrate.
13. Consider the possibility of ammonium phosphate/potassium nitrate reaction with urea and relative humidity during blending to avoid caking.
14. If free acid present, there is a possibility of hydrolysis of urea giving ammonia and carbon dioxide.
15. Formation of very sticky urea phosphate.
16. Potential caking problem due to moisture.
17. If free acid is present, consider the risk of a reaction e.g. neutralisation with ammonia and acid attack with carbonates.

NOT COMPATIBLE

- **NC1.** Mixture will quickly become wet and absorb moisture resulting in formation of liquid or slurry. There could also be safety implications.
- **NC2.** Sulphur is combustible and can react with nitrates e.g. AN, KNO3 and NaNO3.

From the chart, it is clear that urea and ammonium nitrate should never be used together as the mixture will quickly become wet and absorb moisture. Blends containing urea and single or triple superphosphate may also become sticky and cake. Such blends should never be bagged. Mixtures of di-ammonium phosphate and superphosphates should be avoided as chemical reactions may take place which can lead to caking or changes in the solubility of the phosphate.

For reasons of safety, it is very important to avoid blending ammonium nitrate or raw materials containing ammonium nitrate with any organic materials.

Photo caption.

K. CHARACTERISTICS OF SOME FERTILIZER RAW MATERIALS BY NUTRIENT AND SOURCE

**NC = nutrient class: P primary; S secondary; M micronutrient*

FERTILIZER SOURCE	FORMULA	NC*	NUTRIENT CONTENT	REMARKS
NITROGEN (N)				
Anhydrous ammonium	NH_3	P	82% N	Highest N analysis of all inorganic fertilizers. Must be kept under pressure because it evaporates under normal atmospheric pressure. Harmful to human tissue when in direct contact.
Urea	$CH_4N_2O/CO(NH_2)_2$	P	45%-46% N	Least caking, corrosion capabilities, handling, transportation and storage costs of all nitrogen sources. Contains a transforming enzyme called urease. Temporarily increases soil pH. Volatilization losses are reduced by washing urea into soils. Can contain biurate which acceptable levels range between 0%-2% depending on the types of crops. Can be hygroscopic. Usually white in color. Granular or prilled in nature.
Ammonium nitrate (AN)	NH_4NO_3	P	33%-34.5% N	Usually white in color. Granular or prilled in nature.
Urea ammonium nitrate (UAN)	UAN	P	28%-33% N	
Ammonium sulphate (AS)	$(NH_4)_2SO_4$	P	21% N 24% S / 60% SO_3	Essential for sugarcane and pineapple production. Acid forming, lowers soil pH. Low hygroscopicity. Chemical stability. Usually white or off white in color. Crystalline in nature.
Calcium nitrate	$Ca(NO_3)_2$	P	15% N 34% CaO	Water soluble. Readily available N. Highly hygroscopic.
Calcium ammonium nitrate (CAN)	$CaCO_3/NH_4NO_3$	P	26%-28% N 11% CaO	
Ammonium sulphate nitrate (ASN)	$(NH_4)_2SO_4/NH_4NO_3$	P	26% N 35 SO_3	
PHOSPHORUS (P)				
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	P	18%-21% N 46%-53% P_2O_5 0% K_2O 0%-2% S	Water soluble. Temporarily lowers soil pH to 8.5. May produce free NH_3 in high pH soils, so do not place near seed rows. Has variety of gray colors. Granular in nature.
Monoammonium phosphate (MAP)	$(NH_4)H_2PO_4$	P	11%-18% N 48%-62% P_2O_5 0% K_2O 0%-2% S	Water soluble. Temporarily lowers soil pH to 3.5. Has variety of gray colors. Granular in nature.
Triple superphosphate (TSP)	$Ca(H_2PO_4)_2$	P	0% N 44%-52% P_2O_5 0% K_2O 1%-1.5% S / 3% SO3 13% Ca	Produced by treating rock phosphate with phosphoric acid. Insignificant effect on soil pH. Has variety of gray colors. Granular in nature.
Single superphosphate (SSP)	$CaH_4P_2O_8/Ca(H_2PO_4)$	P	0% N 16%-22% P_2O_5 0% K_2O 11%-12% S / 30% SO_3 20%-21% Ca	Manufactured by reacting RP with Sulfuric Acid: Insignificant effect on soil pH.
Ammonium polyphosphate (APP)	$[NH_4PO_3]n(OH)_2$	P	10%N 34% P_2O_5 0%K_2O	

Rock phosphate (RP)	$Ca_{10}(PO_4)_6(X)_2$	P	0% N 14%-41% P_2O_5 0% K_2O 25% Ca	Not water soluble. Available to plants only in acidic conditions. Most reactive when ground and applied in warm, moist, acidic soils with long growing seasons. Though availability is slow, it has long-term residual effect.
POTASSIUM (K)				
Potassium chloride/ Muriate of potash (MOP)	KCl	P	0% N 0% P_2O_5 60%-63% K_2O	Has red, tan or white color. Granular or crystalline in nature.
Potassium sulphate (SOP)	K_2SO_4	P	0% N 0% P_2O_5 50%-53% K_2O 17%-18% S / 45% SO_3	Completely water soluble: Lower salt index than KCl. Used on soils sensitive to Cl, e.g. avocado. Has gray or pink colors.
Potassium nitrate	KNO_3	P	13% N 0% P_2O_5 44%-46% K_2O	Water soluble. Increases soil pH. Source of N. Has pink or white colors. Granular in nature.
Potassium-magnesium sulphate (K-mag/Sul-Po-Mag)	$K_2SO_4(2MgSO_4)$	P	0% N 0% P_2O_5 22%-30% K_2O 11% Mg / 10% MgO 22% S / 42% SO_3	Minor effect on soil pH. Can supply both Mg and S. Useful when low Cl is required. Has tan or pink colors. Granular in nature.
Potassium thiosulphate	$K_2S_2O_3$	P	0% N 0% P_2O_5 17%-25% K_2O 17% S	
CALCIUM (CA)				
Pure lime	$CaCO_3$	S	100% $CaCO_3$	Important for phosphate fixation. Boosts biological activities in soils. Increases availability and up-take of N, P, K. Decreases losses due to leaching of K, Ca and Mg. Calcium hydroxide is also known as slaked, builders, and hydrated lime. Higher neutralizing value than agricultural lime, and more expensive. Rarely used for pastures. Calcium oxide is also known as burnt or quicklime. Faster-acting lime; highest neutralizing value. Mostly used in horticulture and less for pastures. Agricultural lime is the most used to increase soil pH and for pastures. Most cost effective.
Agricultural limestones	$CaCO_3$	S	48%-97% $CaCO_3$	
Calcium oxide	CaO	S	72% Ca 28% O / 52% CaO	
Calcium hydroxide	$Ca(OH)_2$	S	54% Ca 3% H 23% O	
Calcium carbonate	$CaCO_3$	S	38% $CaCO_3$	
Gypsum	$CaSO_4.2H_2O$	S	23% Ca 19% S	
Dolomitic lime	$CaMg(CO_3)_2$	S	22% Ca 13% Mg 13% C 52% O	
Compacted dolomite	$CaCO_3$ - MgCO3	S	20% MgO 30% CaO	
Calcium nitrate	$Ca(NO_3)2$	S	15% N 34% CaO	Water soluble. Readily available N. Highly hygroscopic.
Single superphosphate (SSP)	$CaH_4P_2O_8$	S	0% N 12%-22% P_2O_5 0% K_2O 10%-14% S 18%-21% Ca	Manufactured by reacting rock phosphate with sulfuric acid. Insignificant effect on soil pH.

Triple superphosphate (TSP)	$Ca(H_2PO_4)$	S	0% N 44%-52% P_2O_5 0% K_2O 1%-1.5% S 13% Ca	Produced by treating rock phosphate with phosphoric acid. Insignificant effect on soil pH.
Rock phosphate (RP)	$Ca_{10}(PO_4)_6(X)_2$	P	0% N 14%-41% P_2O_5 0% K_2O 25% Ca	Not water soluble. Available to plants only in acidic conditions. Most reactive when ground and applied in warm, moist, acidic soils with long growing seasons. Though availability is slow, it has long-term residual effect.
MAGNESIUM (Mg)				
Magnesium oxide	MgO	S	61% Mg 39% O	High K can reduce Mg plant uptake. Low pH (acidic soils) reduces availability. Not highly water soluble. Increases soil pH. Mixed in the soil for high reactivity.
Dolomite	$CaMg(CO_3)_2$	S	22% Ca 13% Mg 13% C 52% O	
Magnesium sulphate (epsom salt)	$MgSO_4.7H_2O$	S	9.8% Mg 12%-13% S	AKA Magnesium sulfate heptahydrate. Boosts plant chlorophyll production, hence catalyzes photosynthesis.
Kieserite	$MgSO_4$	S	50% SO_3 25%-28% MgO	
Magnesium carbonate	$MgCO_3$	S	10% MgO 40% CaO	
Potassium-magnesium sulphate (K-mag/Sul-Po-Mag)	$K_2SO_4(2MgSO_4)$	P	0% N 0% P_2O_5 22%-30% K_2O 11% Mg / 10% MgO 22% S / 42% SO_3	Minor effect on soil pH. Can supply both Mg and S. Useful when low Cl is required. Has tan or pink colors. Granular in nature.
SULFUR (S)				
Elemental sulfur	S_8	S	50% S.50% SO4-2	Most concentrated S carrier. Reduce soil pH. Reclaim acidic soils. Water insoluble. Taken up by soils/plants when oxidized.
Ammonium sulphate (AS)	$(NH_4)_2SO_4$	p	21% N 24% S / 60% SO_3	Essential for sugarcane and pineapple production. Acid forming. Lowers soil pH. Low hygroscopicity. Chemical stability.
Single superphosphate (SSP)	$CaH_4P_2O_8$	p	0% N 12%-22% P_2O_5 0% K_2O 10%-14% S 18%-21% Ca	Manufactured by reacting rock phosphate with sulfuric acid. Insignificant effect on soil pH.
Triple superphosphate (TSP)	$Ca(H_2PO_4)$	p	0% N 44%-52% P_2O_5 0% K_2O 1%-1.5% S 13% Ca	Produced by treating rock phosphate with phosphoric acid. Insignificant effect on soil pH.
Ammonium phosphate-sulphate	$H_{11}N_2O_8PS$		16% N 20% P_2O_5 0% K_2O 14% S 13% N 39% P_2O_5 0% K_2O 20% S 19% N 9% P_2O_5 0% K_2O 20% S 23% N 20% P_2O_5 0% K_2O 7% S	Composed of 40% MAP and 60% Ammonium sulphate. Good for forage crops, e.g. legumes. In-row applications for grains.
Ammonium nitrate-sulphate	$(NH_4NO_3)_x{\cdot}(NH_4)_2SO_4$	S	30% N 0% P2O5 0% K2O 15% S	(x=1..3)
Ammonium sulphate nitrate (ASN)	$(NH_4)_2SO_4/NH_4NO_3$	P	26% N 35% SO_3	

Ammonium phosphate-nitrate	$(NH_4)_3PO_4$	S	27% N 12% P_2O_5 0% K_2O 4.5% S	
Potassium sulphate (SOP)	K_2SO_4	P	0% N 0% P_2O_5 50%-53% K_2O 17%-18% S / 45% SO_3	Completely water soluble. Lower salt index than KCl. Used on soils sensitive to Cl, e.g. avocado. Has gray or pink colors.
Potassium-magnesium sulphate (K-mag/Sul-Po-Mag)	$K_2SO_4(2MgSO_4)$	P	0% N 0% P_2O_5 22%-30% K_2O 11% Mg / 10% MgO 22% S / 42% SO_3	Minor effect on soil pH. Can supply both Mg and S. Useful when low Cl is required. Has tan or pink colors. Granular in nature.
Kieserite	$MgSO_4$	S	50% SO_3 25%-28% MgO	
Zinc sulphate	$ZnSO_4$	S	35.5%-36.5% Zn 14%-17.5% S	Most commonly used dry zinc material. Water soluble form of zinc. Effective in granular form. Availability decreases as soil pH increases.
Zinc ammonium-sulphate	$(NH_4)_2Zn(SO_4)_2.2H2O$	S		Commonly used in liquid fertilizers. Most effective in band applications. Cheaper than chelate forms of zinc.
Ferrous sulphate	$FeSO_4$	S	20% Fe 12%-18.8% S	Water soluble. Most used inorganic Fe source. Stabilizes iron chlorosis.
BORON (B)				
Disodium octaborate (anhydrous)	$B_8Na_2O_{13}$	M	25.83% B	
Sodium tetraborate (anhydrous)	$B_4Na_2O_7$	M	21.50% B	Solid crystalline or amorphous.
Disodium octaborate tetrahydrate	$Na_2B_8O_{13}.4H_2O$	M	20.96% B	Powder.
Boric acid	BH_3O_3 or H_3BO_3 or $B(OH)_3$	M	17.48% B	White or colorless solid crystalline powder.
Sodium tetraborate pentahydrate	$Na_2B_4O_7.5H_2O$	M	14.85% B	Mild white alkaline salt.
Sodium tetraborate decahydrate (borax)	$Na_2[B_4O_5(OH)_4]\cdot 8H_2O$	M	11.34% B	White or colorless crystalline powder.
COPPER (Cu)				
Cuprous oxide	Cu_2O	M	89% Cu	
Cupric oxide	CuO	M	75% Cu	
Copper sulfate monohydrate	$CuSO_4.H_{20}$	M	35% Cu	
Copper acetate	$Cu(CH_3COO)_2.H_2O$	M	32% Cu	
Copper ammonium phosphate	$CuNH_4PO_4.H_2O$	M	32% Cu	
Copper sulfate	$CuSO_4.5H_2O$	M	25% Cu	
Copper chelate (chelated copper EDTA)	Na_2Cu.EDTA	M	13% Cu	EDTA - Ethylene Diamine Tetra Acetic Acid

IRON (Fe)				
Iron sulphates	$FeSO_4$	M	14%-23% Fe	Percentage by weight.
Iron chelates (chelated iron - EDTA)	$C_{14}H_{20}FeN_3O_{10}$-	M	5%-10% Fe	
	$(K,Na)(Fe_3,Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$			
Greensand		M	5%-12% Fe	Contains mainly glauconite. But contains glauconitic siltstone and glauconitic sandstone.
MANGANESE (Mn)				
Manganous oxide	MnO	M	41%-68% Mn	Required in small quantities by plants. Critical to plant growth like macronutrients. Most common is manganese sulfate ($MnSO_4$). Highly water soluble and suited for soil or foliar application.
Manganese oxide	MnO_2	M	63% Mn	
Manganese carbonate	$MnCO_3$	M	31% Mn	
Manganese sulphate	$MnSO_4 \bullet 3H_2O$	M	26%-28% Mn	
Manganese chloride	$MnCl_2$	M	17% Mn	
Manganese chelates	MnEDTA	M	12% Mn	
Manganese frits		M	10%-25% Mn	
MOLYBDENUM (Mo)				
Molybdenum trioxide	MoO_3	M	66% Mo	
Ammonium molybdate	$(NH_4)6Mo7O_24 \bullet 4H_2O$	M	54% Mo	
Sodium molybdate	$Na_2MoO_4 \bullet 2H_2O$	M	39% Mo	
ZINC (Zn)				
Zinc oxide	ZnO	M	50%-80% Zn	
Zinc sulphate (basic)	$ZnSO_4$	M	55% Zn	
Zinc sulphates (hydrated)	$ZnSO_4 \bullet xH_2O$	M	22%-36% Zn	
Zinc chelates (chelated Zinc - EDTA)	$CxH_{12}N_2O_8Zn.2Na$	M	6-15% Zn	Cx represents the Zn content of the particular chelated zinc being utilized.
Ammoniated zinc complexes	$(NH_4)_2Zn(SO_4)_2 \bullet xH_2O$	M	10% Zn	
Other organics (polyflavonoids)		M	5%-10% Zn	

L. CRITICAL RELATIVE HUMIDITY CHART

Critical relative humidities of pure salt and mixtures at 30°C (86°F)

	Calcium nitrate	Ammonium nitrate	Sodium nitrate	Urea	Ammonium chloride	Ammonium sulfate	Diammonium phosphate	Potassium chloride	Potassium nitrate	Monoammonium phosphate	Monocalcium phosphate	Potassium sulfate
Calcium nitrate	46.7											
Ammonium nitrate	23.5	59.4										
Sodium nitrate	37.7	46.3	72.4									
Urea	–	18.1	45.6	72.5								
Ammonium chloride	–	51.4	51.9**	57.9	77.2							
Ammonium sulfate	–	62.3	–**	56.4	71.3	79.2						
Diammonium phosphate	–	59*	–	62*	–	72*	82.5					
Potassium chloride	<22	67.9**	66.9**	60.3	73.5	71.3**	70*	84				
Potassium nitrate	31.4	59.9	64.5	65.2	67.9	69.2	–	78.6	90.5			
Monoammonium phosphate	52.8**	58	63.8	65.2	–	75.8	78*	72.8**	59.8	91.6		
Monocalcium phosphate	46.2	52.8	68.1	65.1	73.9	87.7	78*	–**	87.8	88.8	93.6	
Potassium sulfate	76.1	69.2**	73.3**	71.5	71.3	81.4	77*	81	87.8	79	–**	96.3

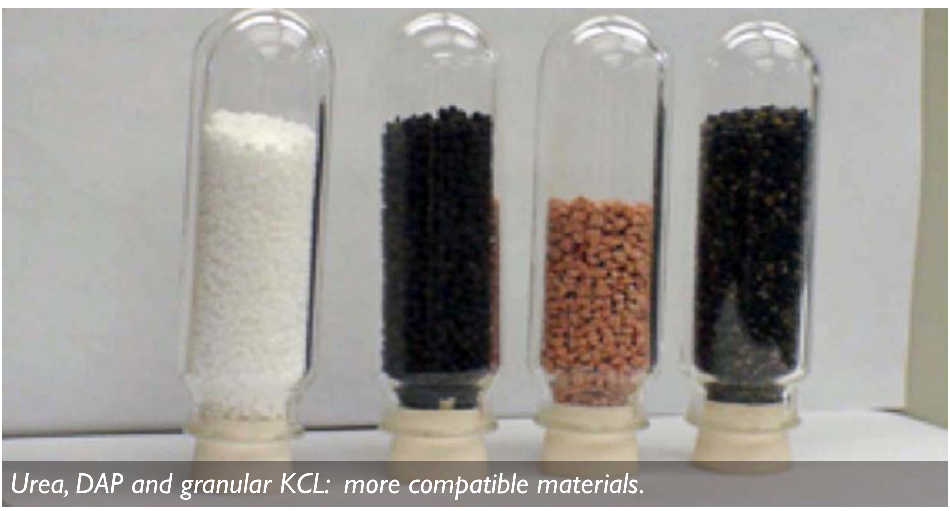
* *Approximate values obtained by Tennessee Valley Authority (TVA, Ref. 3). Other data are from literature.*
** *Unstable salt pair; the value given is for the stable pair.*

M. JAR TEST DIAGRAMS AND EXAMPLES OF PARTICLE SIZE DISTRIBUTION

Jar test diagrams.

DAP and coarse KCL: segregation.

DAP and granular KCL: no segregation.



Urea, DAP and granular KCL: more compatible materials.

Source: CFI, 2013

N. HOW TO DETERMINE SGN AND UI USING THE GRAPH METHOD

The size distribution is plotted on graph paper, per cent cumulative (by mass) versus particle size. The normally smooth distribution curve is approximated by drawing straight line segments between adjacent data points, as shown in the graph below.

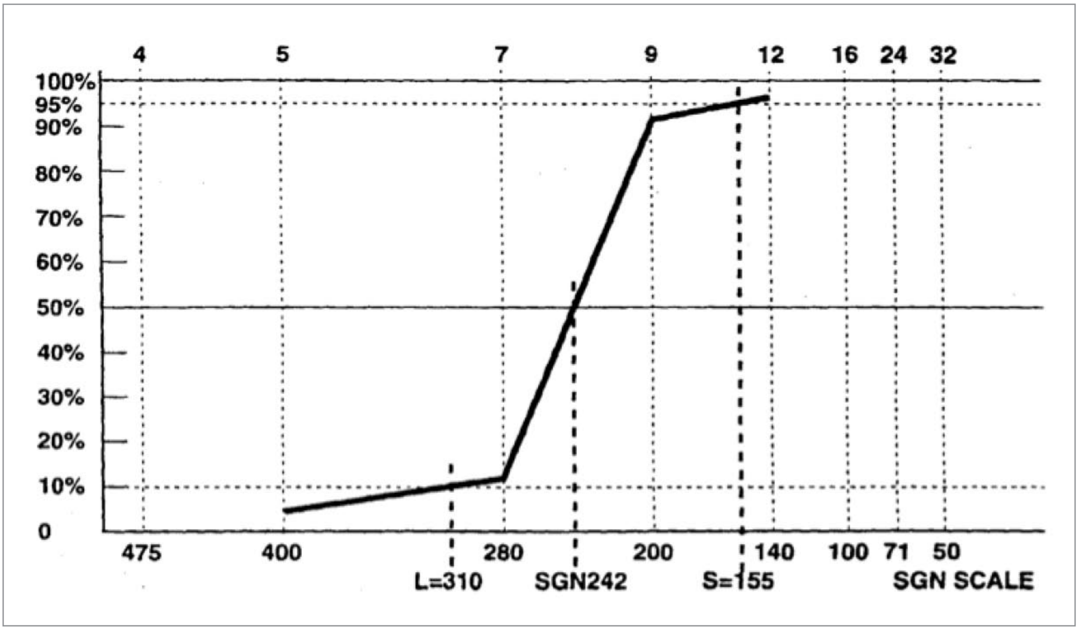
From the point where the cumulative data line crosses the 50% horizontal line, draw down a vertical line to the SGN scale for direct reading of the SGN value. SGN = 242 in this example.

From the point where the cumulative data line crosses the 95% horizontal line, draw down a vertical line to the SGN scale for direct reading of the small Particle Dimension, S = 155 in this example.

From the point where the cumulative data line crosses the 10% horizontal line, draw down a vertical line to the SGN scale for direct reading of the large Particle Dimension, L = 310 in this example.

$$UI = (100\ S)/L \text{ or, for the example: } (100 \times 155)/310 = 50$$

Figure 9. *Tyler Mesh number*



Source: CFI, 2013

O. HOW TO DETERMINE SGN AND UI USING THE MATHEMATICAL METHOD

The determination of SGN and UI would be simple if the screen tests showed exactly 10, 50, and 95% cumulatively retained on three different sieves. For example, 50% on the 2.36 mm sieve would immediately convert to SGN 236. Similarly, 10% on the 2.80 mm sieve and 95% on the 1.40 mm sieve would mean that UI = 50%, since UI = S/L x 100.

The screen test results, however, are rarely exactly 10, 50, or 95% on a particular sieve. To determine SGN, S and L, we must resort to a mathematical method called linear interpolation. The straight segments used in linear interpolation approximate the smooth S shape of the true size-distribution curve.

If we have, for example, 46% retained on 2.80 mm and 68% retained on 2.36 mm, we know that SGN is between 280 and 236. We calculate the mathematically exact value with the interpolation formula:

$$[a\,(CRA - k)] / (CRA - CRB) + b$$

Where k = 50 since we are calculating SGN

a = aperture difference = 280 - 236 = 44

b = aperture of the sieve retaining a proportion greater than k = 236

CRA = Cumulative Retained Above k = 68

CRB = Cumulative Retained Below k = 46

SGN = [44(68 - 50)]/ (68-46) + 236 = 272

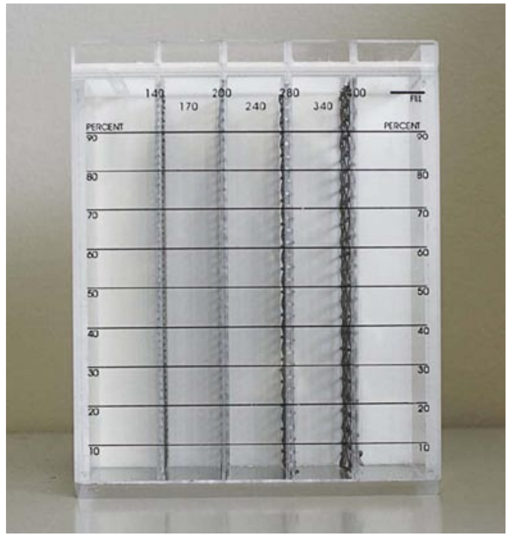
The same interpolation formula is used for the determination of L and S, the dimensions of the "large" and the "small' particles, corresponding to the 10 and 95% levels of the cumulative distribution curve. The coefficient k is always 10 for L and 95 for S, while the other values depend on the screen test results. For example, 92% retained on 1.70 mm and 97% retained on 1.40 mm correspond to:

$$S = [30(97 - 95)] / (97 - 92) + 140 = 152$$

The best accuracy is obtained when consecutive standard sieves are used. Testing with every second or third sieve often affects the SGN estimate and always lowers the UI estimate. See Table H-1, for a list of standard screens.

Source: CFI, 2013

P. THE SGN SCALE AND HOW TO DETERMINE SGN USING THE SGN SCALE METHOD



The Size Guide Number (SGN) Scale is an instrument designed for simple screen tests of fertilizer samples. It is a book-size acrylic box fitted with five sieves. It directly produces a size histogram of the sample tested, from which the SGN can be estimated.

The control sample of a fertilizer blend is truly representative only if the blending materials have been selected to minimize the risk of segregation in mixing and handling. Particle size is the most important factor in the selection of non-segregating materials. Particle size is commonly identified by the median dimension in millimeters times 100, or SGN. For example, if the screen test indicated that a sieve of 2.40 mm opening would retain exactly one half of the sample, the average particle size would be 2.40 mm, or SGN 240.

Who can use the SGN Scale?

- The blender manager, to select size-compatible materials.
- The blender operator, to prevent segregating blends.
- The control official, to identify the increased risk of poor results.
- The basic manufacturing plants for process control.
- The marketing staff, for promotional activities.

Procedure

1. Transfer a representative sample of approximately 200 mL to the right end of the compartment of the SGN scale.

2. Close the SGN Scale and rotate it to bring the sample in the top position. Shake, long enough to finish sifting.

3. Return the box to the horizontal position, to view the label in each compartment and to estimate the SGN. Remember that SGN is the scale value which divides the sample in two equal halves. As an example, if 50% of the sample is on the left of a line halfway between 200 and 280, this gives SGN 240. If 50% of the sample is on the left of a line eight tenths of the interval 200-280, this gives SGN 264.

Source: CFI, 2013

Q. INDICATIVE CHECKLIST FOR BLENDING AND BAGGING OPERATIONS

1. Check if the raw materials required to satisfy the nutrient guarantees are available.
2. Check if the formula grade is correct.
3. Check if all weighing scales are reset to "zero".
4. Load raw materials (macro nutrients and micronutrients – if applicable), till bins are full.
5. Start blending process.
6. Visually inspect movement of materials from hoppers to mixer.
    i. Are there lumps?
    ii. Is there too much dust?
    iii. Is a bag connected to the fines discharge hopper?
7. Start bagging process after the product hopper is full.
8. Start bag stitching process.
9. Check bag weights manually at intervals.
10. Start palletizing process.

R. INDICATIVE CHECKLIST FOR PLANT MAINTENANCE

1. Removing Obstructions:
   a. Remove cover sheet.
   b. Check the gate's full range of motion.
   c. Turn on isolator.
   d. Power plant back up.
   e. Open manual shutoff valve.
2. Releasing jammed screw conveyor (if applicable):
   a. Close manual shutoff valve fully.
   b. Switch off the plant.
   c. Switch the plant to local mode.
   d. Change motor drive direction and frequency to run the plant in reverse.
   e. Run screw repeatedly in reverse and forwards to release the jam.
   f. Open manual shut off valve.
   g. Reset motor driver settings.
3. Purging products left in hoppers:
   a. Switch the plant off, switch the plant to local mode and switch the direction and frequency of the motor drive to enable the belt run backwards.
   b. Place a purge collection bag at the tail of the conveyor and ensure someone is controlling the bag to avoid bag collapse and overfilling of purged product.
   c. Start the conveyor and open the bin to be purged manually.
   d. When done, return all motor settings to normal.
4. To purge products through the bagging machine:
   a. Switch the bagging setting to manual.
   b. Move the stitching conveyor to make space for bulk bags if a large amount of product is to be purged.
   c. Startup bagging equipment and open the bin to purge.

d. Repeat till purging completed, remove bulk bag and replace stitching conveyor.

5. Loading micro hoppers:
   a. Pause the plant.
   b. Fill the micro hoppers. Do not feed the micro hoppers while plant is blending.
   c. Startup the plant and continue blending.

6. Cleaning motor fans:
   a. Remove the fan cowl.
   b. Blow out the fan.
   c. Check for unobstructed movement of the fan.

S. INDICATIVE CHECKLIST FOR PLANT SAFETY

1. Safety Precautions and Signs
   a. The plant should have adequate access for installation, operations, and maintenance.
   b. Safety harness should be worn when working at height on the plant.
   c. Adopt the "Look before you Leap" approach in the vicinity of the plant.
   d. Install standard information and warning signs and labels on and around the plant area.
   e. Ensure the information and warning signs are not removed unnecessarily.
   f. Do not reach into or over any part of the plant while its running.
   g. Follow proper "Lock-Out" procedures when cleaning, servicing, or maintaining the plant.
2. Inspection
   a. Carry out an adequate visual inspection before starting the plant.
   b. Look out for foreign objects or loosely hanging parts before running the plant.
   c. Critically observe the plant for its mechanical, electrical and instrumentation readiness before operating it e.g., look out for worn, touching, or rubbing mechanical parts, lose or hanging electrical wires, error signs on the computer systems, display screen or PLC board.
   d. Make sure the plant is ready for production by ascertaining that all the raw materials, material and labor resources, electrical supply, compressor etc. are present.
3. Access
   a. Cat ladders, step ladders and access platforms should be provided alongside the plant and utilized, according to standard practice, for works at height.
   b. Due to the corrosive nature of the product, these components for access heights can be rusted and their structural integrity lost. Therefore, care should be taken to maintain them regularly.
   c. Lock Out/Tag Out signs should be visibly installed and adhered to especially during any kind of maintenance.
   d. Work from platforms around the hoppers and not directly in or on them.
   e. Only trained and authorized personnel should work in service hatches located on different parts and interconnection points of the plant.
   f. Avoid the underside of the pulley guards on the troughing conveyors because it is open.

g. Do not touch rollers and pulleys while the plant is powered up.

h. Only trained and authorized personnel should touch electrical and instrumentation panels, displays and touch screens.

4. PPE

a. Hardhats should be worn to prevent head injury.

b. Dust masks or respirators should be worn to prevent dust inhalation and breathing difficulty.

c. High visibility clothing should be worn to prevent accidents due to moving vehicles.

d. Safety boots should be worn to prevent leg and foot injury.

5. Magnet

a. Install a permanent plate magnet over the under-bin conveyor so external metallic objects are removed from the product.

b. Keep medical, electronic, and personal devices that can be affected by strong magnetic fields away from the plant to prevent malfunction or outright damage.

6. Fire Hazard

a. Ensure the entire production facility adheres the local safety, health, environment, risk and quality laws and regulations.

b. Conduct a Hazard Identification and Risk Assessment exercise before starting the plant and after any operational changes are made.

c. Adequate care should be taken to keep flammable materials and ignition sources away from the plant and fertilizer raw materials.

d. Dry CO2 extinguishers should be installed in high-risk zones around the plant.

T. SAMPLING METHODS AND EQUIPMENT

Sampling Bags (≤50 kg)

The minimum conditions to be satisfied in ensuring the quantity of sample collected for testing fairly represents the total quantity contained in the (≤50 kg) bag are:

1. Determine what the sample is required for.
2. Establish the characteristics of the material e.g., its qualities, particle size and compatibility.
3. Ensure the sample is of adequate volume or mass for the analysis.
4. For a lot of 10 bags or less, samples of equal mass should be taken from each bag.
5. For a lot of 11 bags or more, samples of equal mass should be taken from each bag making up the square root of the total number of bags.
6. The minimum requirement is to sample any 10 bags from an entire lot.

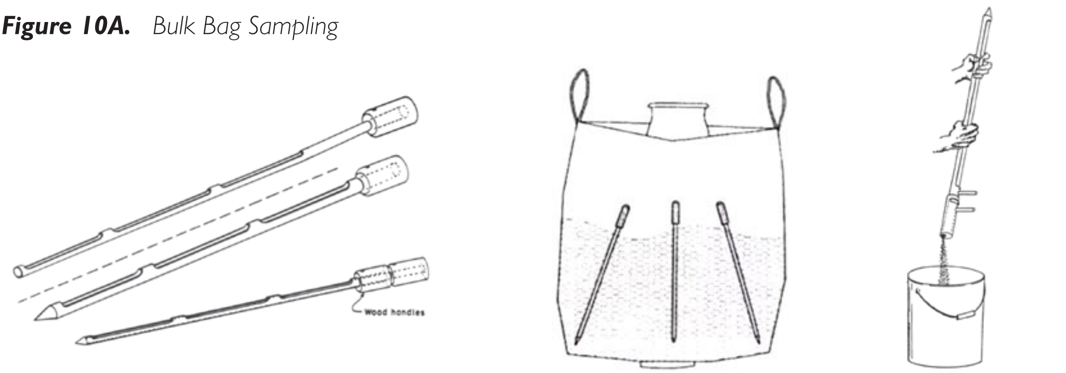
Sampling Bulk Bags (≥1 mt)

The minimum conditions to be satisfied in ensuring the quantity of sample collected for testing fairly represents the total quantity contained in the bag (≥1 mt) are:

1. Determine what the sample is required for.
2. Establish the characteristics of the material e.g., its qualities, particle size and compatibility.
3. Insert a double tube trier from the center of the open top through the bulk bag in a manner that collects samples from the entirety of the bag.
4. Angle the tube at about 30° towards the bottom outer end of the bag. Open the trier to enable the material to fill it. Close the trier and take it out of the bag.
5. Ensure the sample is of adequate volume or mass for the analysis
6. For a lot of 3 bulk bags or more, 4 samples of equal mass should be taken from each quadrant of the bag.
7. For only 2 bulk bags, divide the bag into 6 equal vertical segments and probe each part.
8. For only 1 bulk bag, divide the bag into 12 equal vertical segments and probe each part.

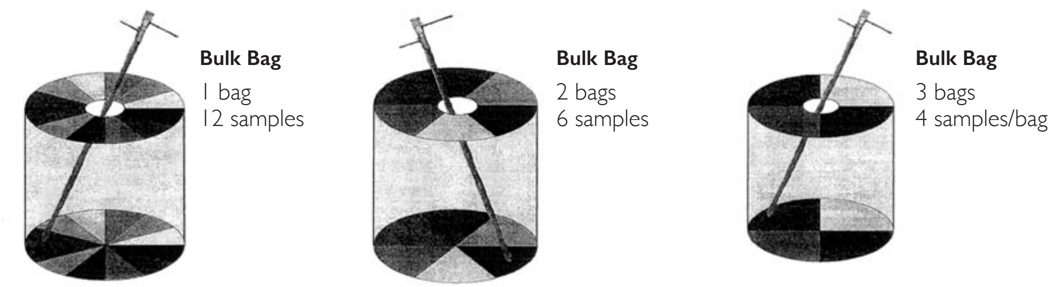
The results of several experiments carried out suggest that sampling results derived from both the techniques of stream cutting and sampling of bulk bags are identical. However, for a more accurate method, collect samples while the material is in motion i.e., when either the ≤50 kg or the ≥1 mt are being filled. As protocol, during sampling, the health and safety of the person collecting the samples should be taken into serious consideration.

Figure 10A. *Bulk Bag Sampling*



Source: International Fertilizer Association. IFA, 2017

Figure 10B. *Bulk Bag Sampling*



Source: International Fertilizer Association. IFA, 2017

Sampling Quantity

If a bag weighs less than 5kg, it is considered a sub-sample. If the final quantity of the sample is not sufficient, the number of selected bags can be increased. 50kg bags should be divided to get an adequate representative sample.

It is best to take samples while emptying the bag, though this may not always be possible. The recommendations regarding sampling quantity for bagged products are summarized below:

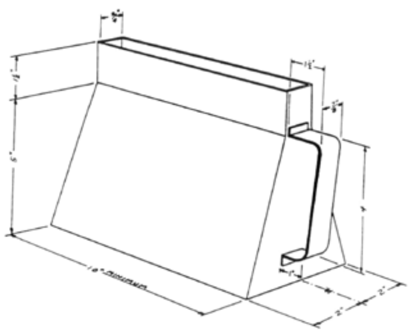
1. Less than 5 bags require a sample taken from each bag.
2. 4 to 11 bags of products require samples taken from 4 bags.
3. 10 to 400 bags of products require samples taken from a whole number above the square root of the number of bags.
4. More than 400 bags of products would require 20 bags of sample.

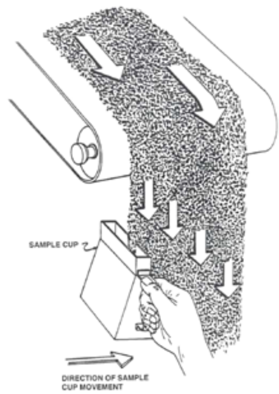
5. For product bays/bins, incremental samples are to be taken as listed below:
   a. Bay/bin sizes 25 tons or less require a minimum of 10 sampling units.
   b. Bay/bin sizes between 25 and 400 tons require sampling units of the nearest whole number above the square root of 4 times the number of tons present.
   c. Bay/bin sizes of more than 400 tons require 40 sampling units to be taken.

Sampling Equipment

The double tube trier, also known as the spear, is recommended for probe sampling. But the trier's dimensions must be suitable to the properties of the sample quantity and the size of its particles must be a minimum of 3x the particle size. Samples collected should be stored in airtight, moisture free and transparent containers to preserve the integrity of the samples. The success of the use of a sampling equipment is reliant on the material being free flowing in nature, thus, easy to penetrate without causing damage to the particles. For non-free flowing or not easily penetrable materials, other equipment, like a shovel or scoop, should be utilized to collect the samples.

Figure 11. *Example of a sampling cup and how it is used*





Source: Handbook of solid fertilizer blending, code of good practice for quality, 201

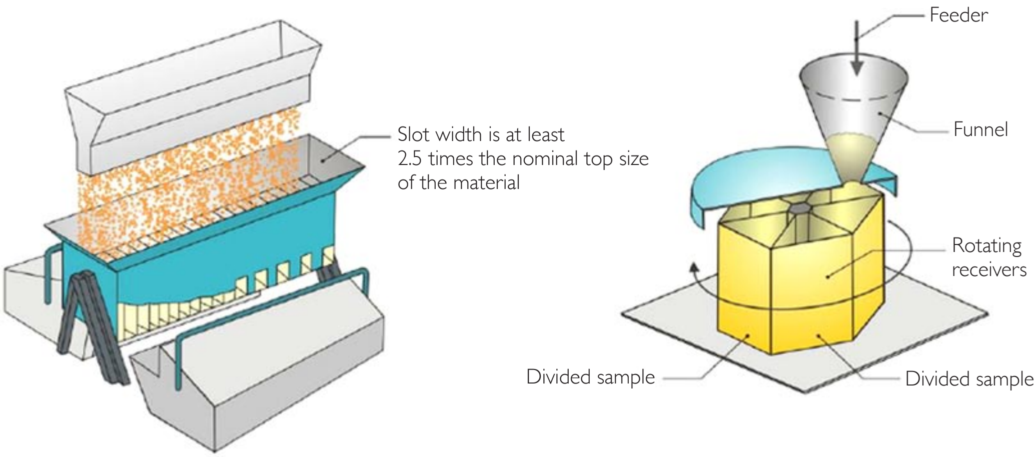
Figure 12. *Double Tube Trier in open and closed positions*

Source: International Fertilizer Association. IFA, 2017

Sample Divider

When sieve analysis is to be carried out on blends are being tested, rotary sample dividers are recommended. Riffle dividers are less appropriate for blended products but may be used for raw materials. When carrying out chemical analysis, crushing the samples is recommended before the sample is finally reduced while samples are not to be crushed for measurement of physical properties.

Figure 13. *Riffle Box and Rotary Sample Divider*



Example of riffle box **Example of rotary sample divider**

Source: Handbook of solid fertilizer blending, code of good practice for quality, 2016

U. GUIDELINES FOR STORAGE SIZES FOR VARIOUS PLANTS AND ANNUAL TONNAGE CAPACITIES

Table U1. *Indicative guidelines for storage.*

GUIDELINES FOR STORAGE SIZES REQUIRED FOR VARIOUS PLANT AND ANNUAL TONNAGE CAPACITIES

Component	Up to 30 mtph (30,000 mt/yr)	Up to 60 mtph (60,000 mt/yr)	Up to 100 mtph (100,000 mt/yr)	>100 mtph (>100,000 mt/yr)
Land	0.5 ha or 5,000 sq. m	≥ 0.5 ha but ≤ 1 ha Example: 0.75 ha	1 ha or 10,000 sq. m	≥ 1 ha Example: 1.5 ha or 15,000 sq. m
Main factory building	75% of land or 3,750 sq. m, or 45 m wide * 84 m long	75% of land or 5,625 sq. m, or 55 m wide * 100 m long	75% of land or 7,500 sq. m, or 65 m wide * 115 m long	75% of land or 11,250 sq. m, or 75 m wide * 150 m long
Raw material storage	30% of main bldg. or 1,500 sq. m, or 15 m wide * 20 m long * 5 no off	30% of main bldg. or 1,650 sq. m, or 15 m wide * 22 m long * 5 no off	30% of main bldg. or 2,250 sq. m, or 15 m wide * 30 m long * 5 no off	30% of main bldg. or 3,375 sq. m, or 20 m wide * 34 m long * 5 no off
Finished goods storage	10% of main bldg. or 375 sq. m, or 12 m wide * 15 m long * 2 no off	10% of main bldg. or 560 sq. m, or 13 m wide * 22 m long * 2 no off	10% of main bldg. or 750 sq. m, or 15 m wide * 25 m long * 2 no off	10% of main bldg. or 1,125 sq. m, or 20 m wide * 28 m long * 2 no off
Height of stockpile	for bulk, ≤ 6 m for bags, ≤ 5 m	for bulk, ≤ 6 m for bags, ≤ 5 m	for bulk, ≤ 6 m for bags, ≤ 5 m	for bulk, ≤ 6 m for bags, ≤ 5 m

Source: Innocent Matthews Consulting Ltd, 2022

V. TESTING METHODS AND EQUIPMENT

Chemical Analysis

National Standards, European Union (EC) Directives, European and International Standards and the Association of Official and Analytical Chemists (AOAC) analysis methods are standard reference test methods for most common chemical analysis used for fertilizer materials. Using these methods for routine process control and sampling is not essential, often automated methods are available. Although other methods can be explored, they must be benchmarked and evaluated against these recognized industry standards.

Physical Tests

The bodies mentioned above have existing guidelines on the test methods for numerous physical properties. However, it is recommended that blenders pay attention to test sieving and bulk density. Some laboratories have an accreditation for these special measurements. No standard methods are available for properties such as free dust and caking. For the sake of the naturally occurring segregation, sampling is a fundamental step for physical testing. Fundamentally, sampling is an important element for physical testing due to the occurrence of natural segregation. Another aspect to consider is the quantity needed for a final sample which has been proven may be more than 5 kg for physical testing.

TEST METHOD FOR SIEVE ANALYSIS

Principle

Use a mechanical sieving machine with one or more test sieves to dry sieve a sample fertilizer material.

Apparatus

- Weighing balance calibrated to weigh to the nearest 0.1 g.
- A 200 mm diameter stainless steel woven wire test sieves with a lid and receiver for the sieves.
- A sieving machine also known as a mechanical shaker. Should be able to apply horizontal and vertical motion to the material on the set of sieves.
- Stopwatch and soft brush.

Procedure for testing

In accordance with best practices, it is recommended to reduce the sample to approximately 250 g, most preferably ensuring the usage of a rotary sample divider or a riffle divider. Collect seven sieves to secure the range of particle size expected and arrange them in ascending order of aperture size on top of the receiver. Check the weight of the test sample and round up to the nearest 0,1 g. Secure sample with a lid and place on the sieve. Put the set of sieves along with the sample on the shaker and shake for up to 10 minutes. From the top, separate the sieves from the nest and weigh the retained quantity left on each sieve including the receiver. Round off the derived weight to the nearest 0,1 g. Using the brush, clean the remaining particles in the nest. Add up what is left on the sieve and receiver and ensure it is within 2.5 g of the original sample mass. Express the mass of each leftover as a percentage of the original mass and plot a table showing the cumulative percentage passing each sieve.

According to the handbook of solid fertilizer blending, code of good practice for quality, 2016, the percentage of material leftover in the receiver and on each sieve is derived from the equation, Xn = (mn/mt) *100, where mn is the mass on sieve n, mt is the total mass (m0 + m1 + …), and Xn is the mass percentage retained in sieve n. Also, the formula for the cumulative undersize is expressed as Cn = X0 + X1 + X2 + … + Xn-1, where Cn is the cumulative percentage undersize for sieve n.

TEST METHOD FOR LOOSE BULK DENSITY

Principle

Weighing a known volume of the fertilizer.

Apparatus

- A balance calibrated to weigh to the nearest 1g.
- A 60 mm diameter, 1 liter cylinder of known volume.
- A standard 25 mm diameter aperture funnel.

Procedure

1. Carefully place the sample unit of fertilizer in the funnel just as seen in the image of the equipment above. Ensure that the aperture is properly closed.
2. Check the weight of the empty barrel and place it right beneath the funnel.
3. Release the fertilizer to flow gently into the barrel and close the funnel after the barrel is full. Remove excess fertilizer with a spatula then weigh the barrel and the content in it.
4. Calculate the weight of the content as (m in kg).

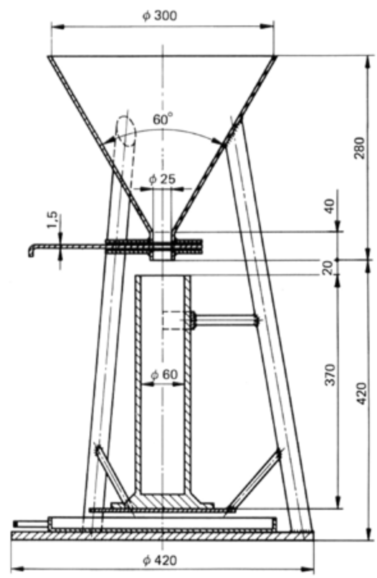


Figure 14. *Loose density measuring equipment*

Source: Handbook of solid fertilizer blending, code of good practice for quality, 2016

The formula for calculating loose bulk density is represented as:

$\rho = \frac{m}{V}$, where ***m*** = mass and ***V*** = volume.

TEST METHOD FOR ANGLE OF REPOSE

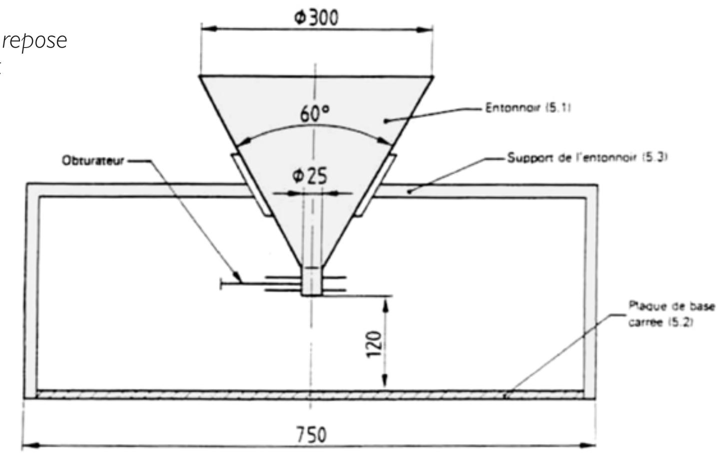
Principle

Measuring the diameter of a heap of known height and calculating the angle of the heap.

Apparatus

- Horizontal surface measuring 750 x 750 (mm) and four lines presenting an angle of 45° between and traced at the surface center.
- A standard 25 mm diameter aperture funnel placed 120 mm above the surface.

Figure 15. *Angle of repose measuring equipment*



Source: Handbook of solid fertilizer blending, code of good practice for quality, 2016

Procedure

5 kg fertilizer is placed in the funnel with a closed aperture. Fertilizer is allowed to flow freely unto the surface from a heap by opening the aperture. The flow is stopped when the heap reaches the bottom of the funnel. The four diameters on the plate are measured and the average diameter (d in mm) is derived. The value of the angle of repose is calculated using the following formula:

$$\alpha = \arctan\left(\frac{240}{\bar{d} - 25}\right)$$

Example

Examples of results of physical tests on fertilizers are given. The data set is realistic, but the physical properties will vary significantly for the same product contingent on its origin. The following results were obtained for three diverse fertilizers A, B and C using previously described measurement methods.

Table VI. *Example of data from the laboratory for physical testing of three fertilizers.*

	FERTILIZER		
SIEVING TEST	A	B	C
< 1.00 mm	0.1 g	0.5 g	8.2 g
1.00 to 2.50 mm	1.2 g	9.3 g	35.6 g
2.50 to 2.80 mm	5.3 g	19.9 g	45.2 g
2.80 to 3.15 mm	36.7 g	68.1 g	51.9 g
3.15 to 3.55 mm	115.2 g	79.6 g	46.8 g
3.55 to 4.00 mm	67.7 g	51.2 g	35.3 g
4.00 to 5.00 mm	15.9 g	13.2 g	21.7 g
> 5.00 mm	2.1 g	2.1 g	5.2 g
Total	**244.2 g**	**243.9 g**	**249.9 g**

Loose bulk density			
Weight of 1 litre (V=0.001 m^3)	1,000 kg	0.750 kg	0.950 kg
Angle of repose			
Average diameter base of the heap (d^)	400 mm	400 mm	325 mm

Determining the physical properties of these fertilizers is achievable by using the formulae:

	FERTILIZER		
SIEVING TEST	Weight (g)	Percentage (%)	Cumulative %
< 1.00	0.1	0.04	0.04
1.0 – 2.50	1.2	0.49	0.53
2.50 – 2.80	5.3	2.17	2.7
2.80 – 3.15	36.7	15.03	17.73
3.15 – 3.55	115.2	47.17	64.91
3.55 – 4.00	67.7	27.72	92.62
4.00 – 5.00	15.9	6.51	99.14
> 5.00	2.1	0.86	100,00
Total	244.2	–	–

Given the above test data, the mean particle size (d50) and the Granulometric Spread Index (GSI) can be determined. The d50 ranges between 3.15 mm and 3.55 mm, the d16 is slightly below 3.15 mm and the d84 ranges between 3.55 mm and 4.00 mm.

Therefore,

$$d_{16} = 2.80 + \frac{16 - 2.70}{17.73 - 2.70}(3.15 - 2.80) = 3.11 \text{ mm}$$

$$d_{50} = 3.15 + \frac{50 - 17.73}{64.91 - 17.73}(3.55 - 3.15) = 3.42 \text{ mm}$$

$$d_{84} = 3.55 + \frac{84 - 64.91}{92.63 - 64.91}(4.00 - 3.55) = 3.86 \text{ mm}$$

$$GSI = \frac{3.86 - 3.11}{2 \times 3.42} \times 100 = 10.96$$

	FERTILIZER		
SIEVING TEST	A	B	C
d16	3.11 mm	2.85 mm	2.34 mm
d50	3.42 mm	3.27 mm	3.04 mm
d84	3.86 mm	3.79 mm	3.83 mm
GSI	10.96	14.42	24.55
Loose bulk density (ρ)	1,000 kg/m³	750 kg/m³	950 kg/m³
Angle of repose (α)	32.6°	32.6°	38.7°

In conclusion, we will find that:

- Fertilizer A has very low GSI because its particles are similar in size.
- Fertilizer C has high GSI because it contains more tiny particles.
- Fertilizer B possesses low bulk density.
- Fertilizer C has a high angle of repose because it contains more particles that are angular in nature.

NB: The above example is an excerpt from the handbook of solid fertilizer blending, code of good practice for quality, 2016.

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