FERARI

FERTILIZER RESEARCH & RESPONSIBLE IMPLEMENTATION

Book of Abstracts

IDENTIFICATION OF EVIDENCE-BASED RESPONSIBLE FERTILIZER USE IN GHANA: 2022 FERARI IN-PERSON COORDINATION CONFERENCE

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Book of Abstracts

Identification of Evidence-Based Responsible Fertilizer Use in Ghana: 2022 FERARI In-Person Coordination Conference

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PREFACE

This Book of Abstracts on identification of evidence-based responsible fertilizer use in Ghana was developed to provide an overview of key research about fertilization strategies as related to improving soil health in Ghana. The abstracts are called for in FERARI's first in-person coordination meeting in Ghana, delayed by the COVID-19 pandemic. The conference is bringing together various stakeholders under the FERARI program to discuss the past three years of project implementation and the way forward. Largely, the research has been done by the M.Sc. and Ph.D. student researchers and the researchers from the various associated institutions and universities. In most cases, the abstracts were written with data generated through experiments and surveys conducted under the FERARI program. The abstracts focus on nutrient transfer from soils, chemical interactions within the soil system, economics/agribusiness and sustainability of soil fertility management, nutrient management and enhanced crop yield, and stakeholder analysis of soil health.

The Book of Abstracts was coordinated by researchers in the FERARI program and its collaborative researchers. These coordinators have in-depth knowledge on the fertilizer sector and crop fertilization, with records of publication on soil health, crop production, and farm economics. The Book of Abstracts provides some evidence on FERARI's objectives of training a new generation of fertilizer scientists and provides recommendations on how to improve crop productivity through the use of balanced fertilization.

This Book of Abstracts provides evidence for the need to improve soil fertility, especially through the use of macronutrients and micronutrients. It is the first of its kind under the FERARI program, and we expect that it will raise the awareness of our audience of the significant impact the program is making to improve upon existing fertilizer research. Overall, the abstracts on the experimental data highlight the impacts of various fertilizer types, rates, and application methods on crop yields, particularly for maize, rice, and soybean. The socioeconomic results also highlight the major challenges confronting the fertilizer sector in Ghana and some strategies for addressing these.

ABOUT FERARI

FERARI is a public-private program in Ghana that integrates on-the-ground implementation to develop the fertilizer value chain with transdisciplinary research by Ph.D. and postdoctoral researchers, supervised by internationally renowned universities and to build the research capacity of the involved institutions. FERARI activities will run from 2019 to 2024 and are co-funded by OCP, Mohammed VI Polytechnic University (UM6P), IFDC, and other institutions.

The overall objective of the program is to develop the evidence base showing the need for a systematic approach to support widespread adoption of balanced fertilizers by farmers in the less developed markets of sub-Saharan African countries, specifically Ghana, as a means to improve their food and nutrition security. The sub-objectives are to:

- Develop on-the-ground experience in pre-competitive activities to create appropriate market conditions for balanced fertilizers and their widespread adoption by farmers.
- Convert tacit knowledge into formal knowledge to allow more effective science-based up- and out-scaling of practical approaches.
- Train highly qualified Ph.D. and postdoctoral researchers to enter the international research and implementation field after graduation.
- Strengthen the transdisciplinary scientific capabilities of the involved institutions.

For more information, visit: https://ifdc.org/projects/fertilizer-research-and-responsible-implementation-ferari/

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Multilocational Evaluation of Rice Response to NPK and Micronutrient Application in the Guinea Savannah Ecology of Ghana

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Background

Rice is the second most important cereal staple in Ghana after maize, with per capita consumption of 32 kilograms per annum. It is cultivated in almost all 16 regions of Ghana under mostly rainfed and some irrigated conditions. Although rice consumption has quadrupled over the past decades, local production is estimated to meet only 40% of Ghana's demand. This could be due to low yields compared to the world average. The country imports to meet the deficit, costing millions of dollars. There is a need to improve the productivity of rice. This may require the use of improved varieties, good agronomic practices, and fertilizer. Balanced application of macro- and micronutrients has been found to positively improve crop yields elsewhere. The objective of this study was to evaluate the effect of NPK and micronutrients applied on rice in northern Ghana.

Methodology

Twenty-six trials on rice were established on farmers' fields in 10 districts/municipalities in the Northern and North East regions of Ghana. The experimental design used was the randomized incomplete block design, with the communities as replications. Three varieties of rice – AGRA rice, CSIR Malimali, and Savanna – were used for the trials. The spacing adopted was 0.2 m x 0.2 m. The treatments evaluated were NPK 60-40-40, NPK 120-40-40, NPK 120-40-40 + Soil [Zn+S], NPK 120-40-40 + Foliar [Zn+S+Fe], NPK 90-60-60, and control (no fertilizer). Data were collected on plant height, biomass, number of panicles per plant, number of unfilled spikelets per plant, panicle length, panicle weight, and 1,000-seed weight. The data were subjected to analysis of variance, and treatment means were separated using the least significant difference test.

Key Findings

Treatment effects were significant for all traits measured. NPK with micronutrient application significantly influenced the plant height and grain yield as compared to NPK with no micronutrients (Figures 1A and 1B). Varietal effect across locations was significant for plant height, biomass, number of panicles per plant (Figure 1C), panicle length, panicle weight, and 1,000-seed weight (Figure 1D). Application of NPK 120-40-40 + soil-applied Zn+Fe produced the tallest plants, which significantly differed from plants that received NPK 60-40-40 alone (Figure 1A). Grain yield ranged from 2.20 metric tons per hectare (t/ha) to 4.51 t/ha for the control plot and the plot treated with NPK

120-40-40 and foliar-applied Zn+S+Fe, respectively, with a mean of 3.74 t/ha (Figure 1B). The application of micronutrients significantly increased grain yield of rice compared to NPK 120-40-40 and NPK 60-60-60 with no micronutrients.

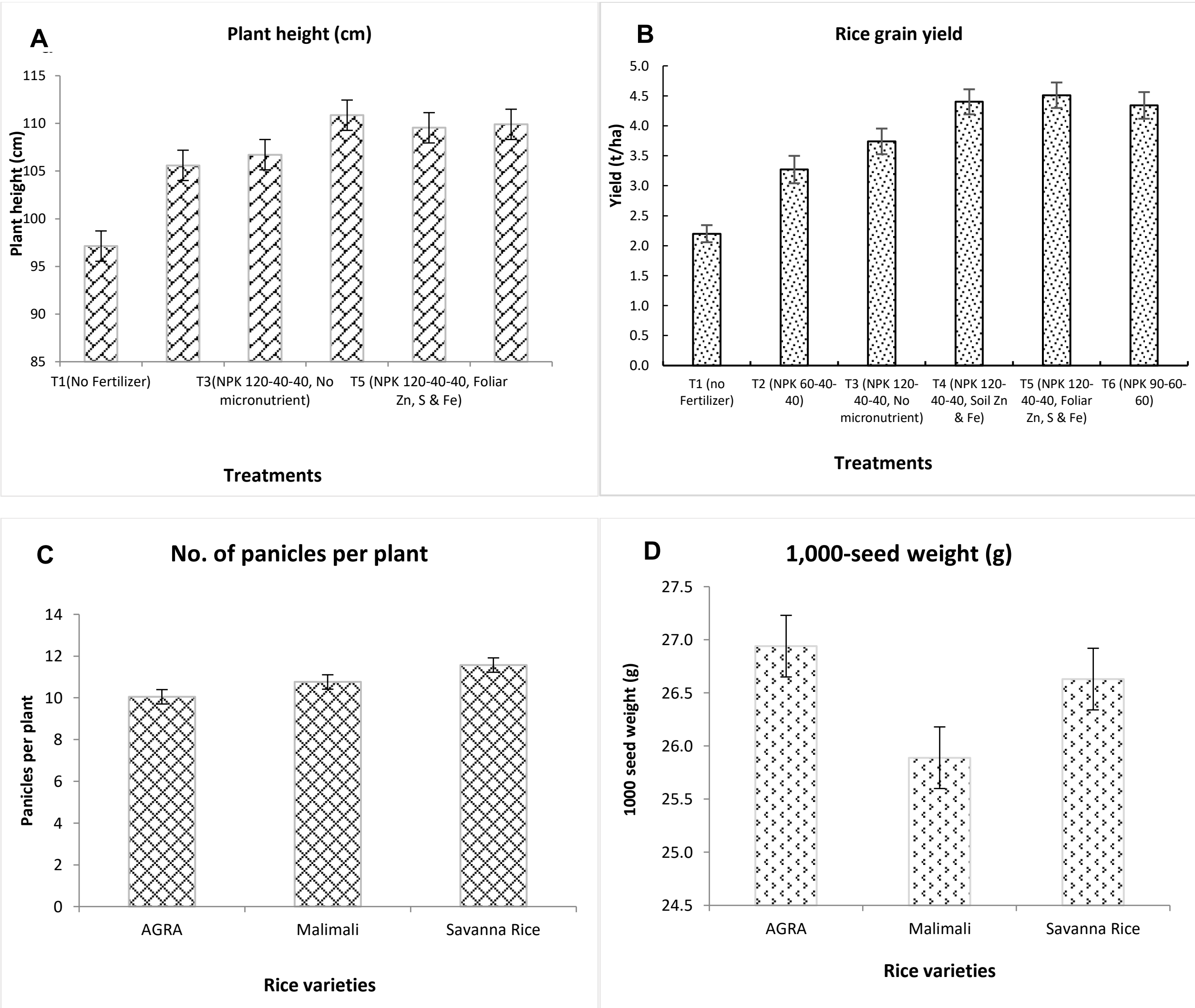
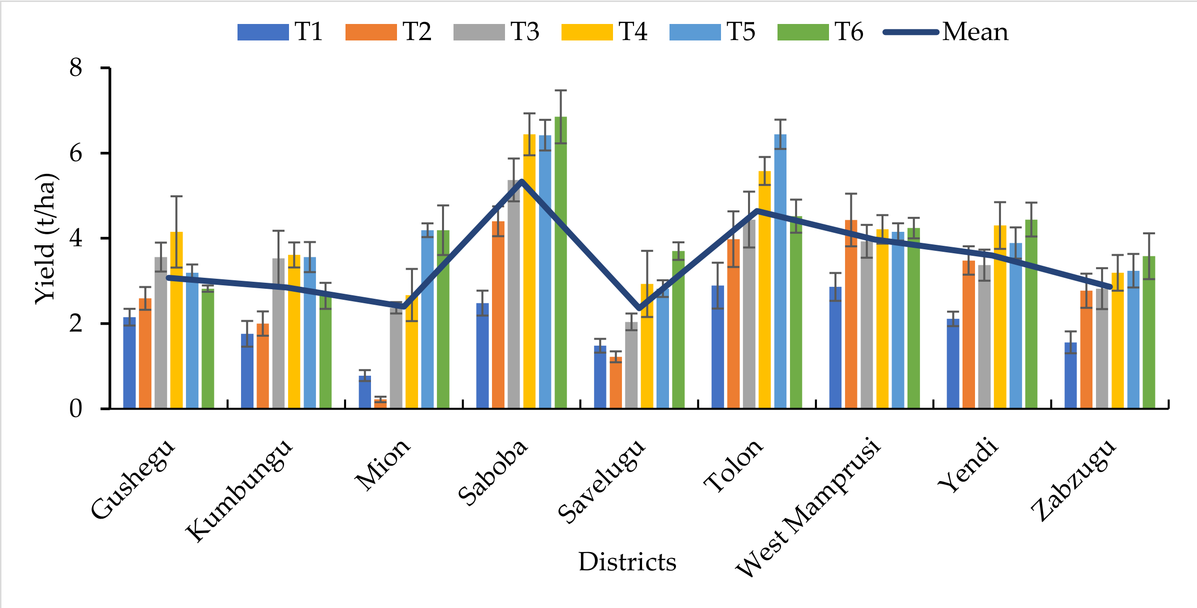


***Figure 1.** Effect of various nutrient treatments on (A) plant height and (B) rice grain yield and effect of variety on (C) number of panicles per plant and (D) 1,000-seed weight.*



T1 = control; T2 = NPK 60-40-40; T3 = NPK 120-40-40; T4 = T3 + soil Zn, Fe; T5 = T3 + foliar Zn, S, Fe; and T6 = NPK 90-60-60.

Figure 2. Effect of different nutrient treatments on rice grain yield in the districts.

Conclusion and Recommendations

Across locations, treatment effects were significant for all parameters measured in the rice trials. The application of micronutrients significantly influenced the number of rice panicles and grain yield as compared to NPK with no micronutrients. Rice varietal effect across locations was significant for plant height, biomass, number of panicles per plant, number of unfilled spikelets per plant, panicle length, panicle weight, and 1,000-seed weight. AGRA rice had the highest grain yield across locations though not significantly different from CSIR-Malimali and Savanna rice. The significant treatment x location effect suggests that site-specific fertilizer recommendation is imperative for improved rice production in northern Ghana.

Sulfur and Phosphate Rock Inclusion in NPK Formulations for Maize Production on a Feralic Lixisol in Northern Ghana

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Background

It has long been proposed that sulfur inclusion in fertilizer regimes would enhance maize growth and productivity. In Ghana, maize (*Zea mays* L.) is the major cereal produced, occupying about 1.5 million hectares. Production has increased over the past decades and maize now accounts for 50-60% of total cereal production. Maize production in Ghana was reported to be 3.0 million metric tons in 2020.

Sulfur is one of the 16 elements required for crop production. Plants need sulfur to make important metabolic components, including glutathione, proteins, and amino acids, as well as sulfolipids for crop growth. Ghana's Guinea Savannah zone has limited productive lands. Nutrient depletion in the region is growing, hence the need to research the relative productivity of sulfur inclusion in fertilizer formulation on growth and yield of maize.

Methodology

The study was conducted at Gbalahi between May 2020 and July 2021. The experimental site is located at latitude 000° 45.767' W and longitude 09° 26.226' N. The experiment was laid out in a randomized complete block design, with four replicates. The Wang Daata maize variety was used. The treatments for maize consisted of N(PR)KS 60-20-25-10, N(P+PR)KS 60-20-25-10, NPKS 60-20-25-10, NPK 60-20-25, NPS 60-20-10, NKS 60-25-10, PKS 20-25-10, PS 20-10, PK 20-25, and no fertilization (control), where PR is phosphate rock. Sampling for growth and yield data was carried out at 3 weeks after planting (WAP) to 13 WAP, at harvest, and also after harvest. Five plants on each plot were randomly tagged, taking into consideration the border effect of each plot. Data was taken on daily rainfall, plant height, leaf number, leaf area index, leaf chlorophyll content, biomass, grain-filling duration, and grain yield.

Key Findings

Nitrogen omission negatively impacted the 5th and 6th leaf chlorophyll content (Figures 1 and 2), thus reflected in lower biomass and grain yield. This result confirms the importance of N in chlorophyll formation. The aboveground biomass yield (Figure 3) and grain yield (Figure 4) after harvest significantly increased when maize was treated with NPKS 60-20-25-10 compared to the control. This is an indication that the nutrients were released to the plants and used for photosynthesis, resulting in better plant growth and development. These results on yield conform to those of Duncan et al. (2018), who hypothesized that interactions between N, P, K, and S would boost grain yield. When there was no K, sole NPS resulted in similar performance as NPKS, although NKS did not result in such performance, showing a complementary effect of P and S for maize growth in such soils.

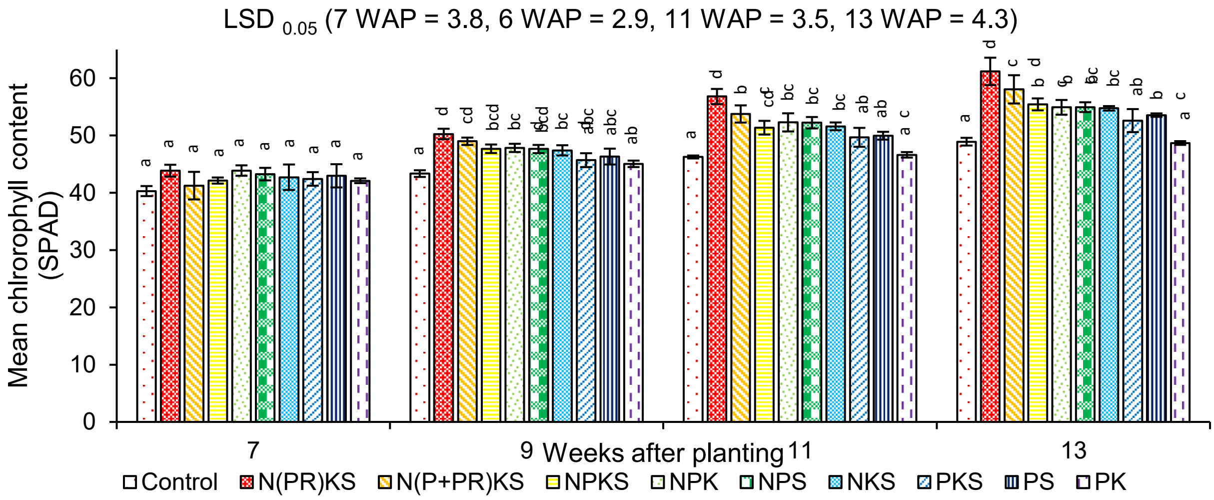

Figure 1. ***Effect of primary nutrients and sulfur inclusion/omission on 5th leaf chlorophyll content (SPAD units) of maize grown on a feralic lixisol in northern Ghana.***

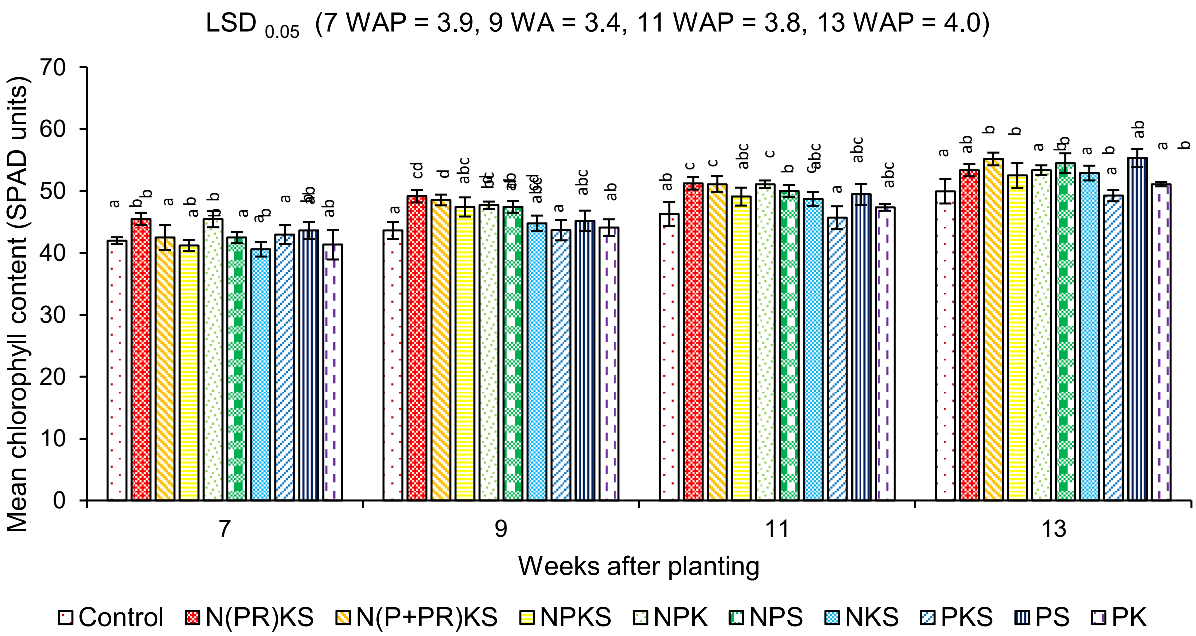

Figure 2. ***Effect of primary nutrients and sulfur inclusion/omission on 6th leaf chlorophyll content (SPAD units) of maize grown on a feralic lixisol in northern Ghana.***

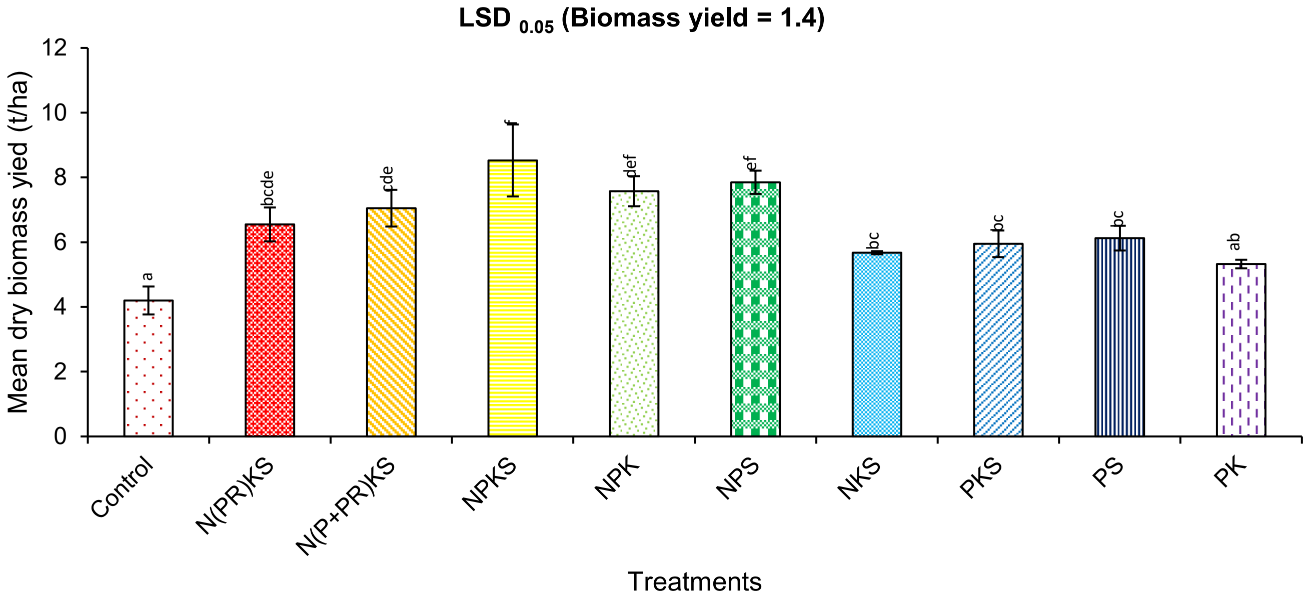

Figure 3. Effect of primary nutrients and sulfur inclusion/omission on maize dry biomass yield at harvest.

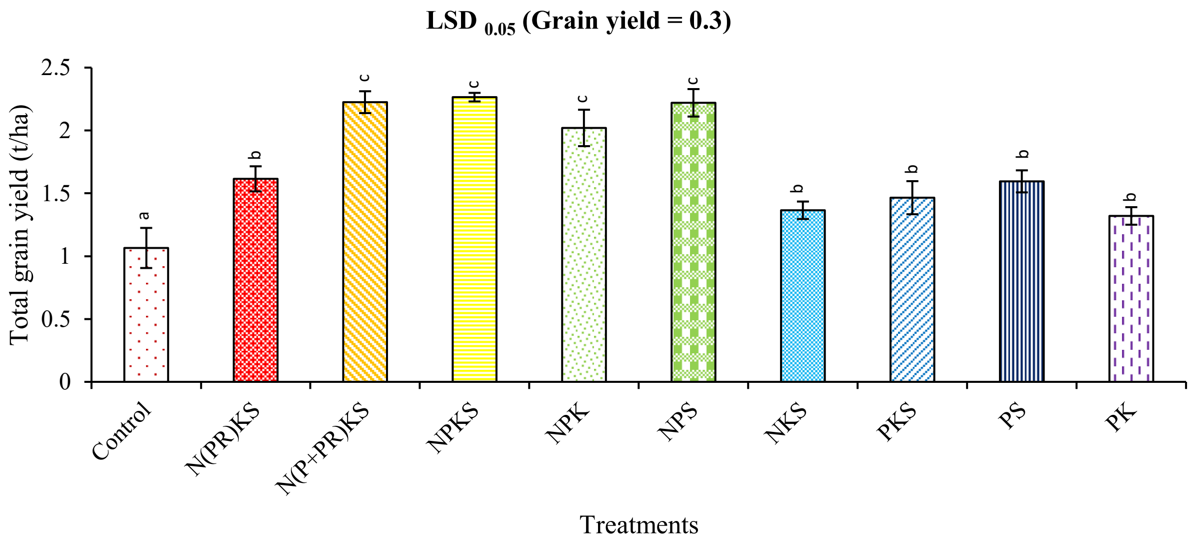

Figure 4. Effect of primary nutrients and sulfur inclusion/omission on maize grain yield at harvest.

Conclusion and Recommendations

The use of NPKS at a rate of 60-20-25-10 kg/ha improved maize vegetative growth and grain output (2.3 t/ha) as compared to yield of 2.0 t/ha with NPK. Furthermore, PR had a considerable impact on maize biomass and yield. This treatment supplied the plants with the right amount of nutrition, hence profoundly affecting their progressive vegetative growth and yield. Thus, the study affirms the significant role of sulfur inclusion in maize production.

Effects of Phosphate Rock, Sulfur, Boron, and Zinc Inclusion in NPK Formulation for the Improvement of Growth and Yield of Maize (*Zea mays* L.) at Gbalahi, Northern Ghana

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Background

Maize is an important cereal crop that is used as food due to its nutritional benefits for humans and livestock. The continuous cropping in northern Ghana, however, has led to the depletion of inherent soil nutrients, which has resulted in poor growth and low yield. It has been suggested that inclusion of macro- and micronutrients in fertilization will increase maize yield. Balanced fertilization that combines sulfur (S), zinc (Zn), and boron (B) with NPK fertilizers may boost yields in comparison to sole NPK fertilization. As a result, agronomic biofortification of maize with the use of fertilizers that contain the proper rates of S, Zn, and B could be more productive. Maintaining acceptable levels of S and micronutrients in the soil solution for optimal nutrient transfer to the sink ensures progressive growth during the reproductive stage and increase yield.

Methodology

A field trial was conducted at Gbalahi in the Tamale metropolis of Ghana from July to November 2021 to evaluate the performance of grain yield of maize. The experiment was laid out in a randomized complete block design, with four replications.

The experimental plots were laid at 5 m x 5 m, with 2 m between replications and 1 m between treatment plots. The maize variety used was Wang Daata. The treatments used were control, N(PR)KS, N(P+PR)KS, NPKS, NPK, NPS, NPS 14-31-0-9S-1Zn-1B, NPK 11-22-21+5S+0.7Zn+0.5B, and NPK 20-20-10+3S. Each formula was applied at a P_2O_5 rate of 60 kg/ha, and N was topdressed to achieve an N rate of 120 kg/ha. Growth data were collected at two-week intervals on plant height, 5th and 6th leaf chlorophyll content, and leaf length. Yield data were collected on biomass weight and grain yield. The data were analyzed using ANOVA and means separated at 5% probability using the least significant difference.

Key Findings

The omission of S, Zn, and B and zero fertilization significantly decreased biomass and grain yield when compared to balanced fertilization (Figure 1). Higher biomass yield was recorded for NPK 11-22-21+5S+0.7Zn+0.5B application and lowest with control 1 (without fertilizer treatment). NPK 11-22-21+5S+0.7Zn+0.5B produced the highest grain yield (4.2 t/ha) compared to control 1 with the lowest yield (1.0 t/ha) (Figure 2). These results show the importance of S, Zn, and B addition in plant growth and development. The addition of S to NPK performed second best, with yield levels of around 3.5 t/ha.

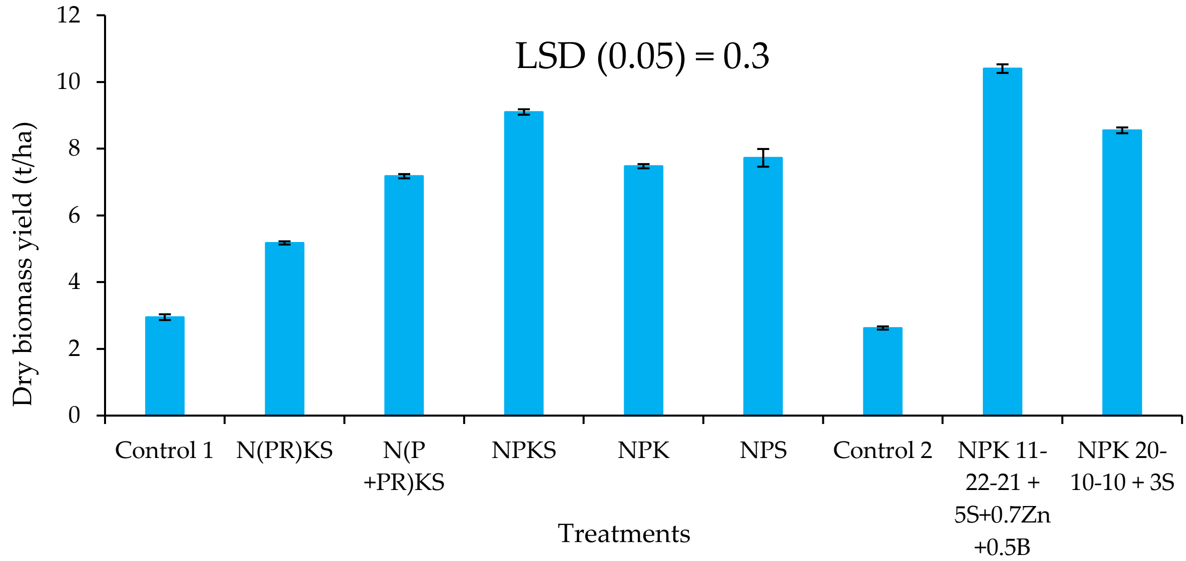

***Figure 1.** Effect of secondary (sulfur) and micronutrient omission/inclusion on dry biomass yield of maize at Gbalahi in Tamale metropolitan area.*

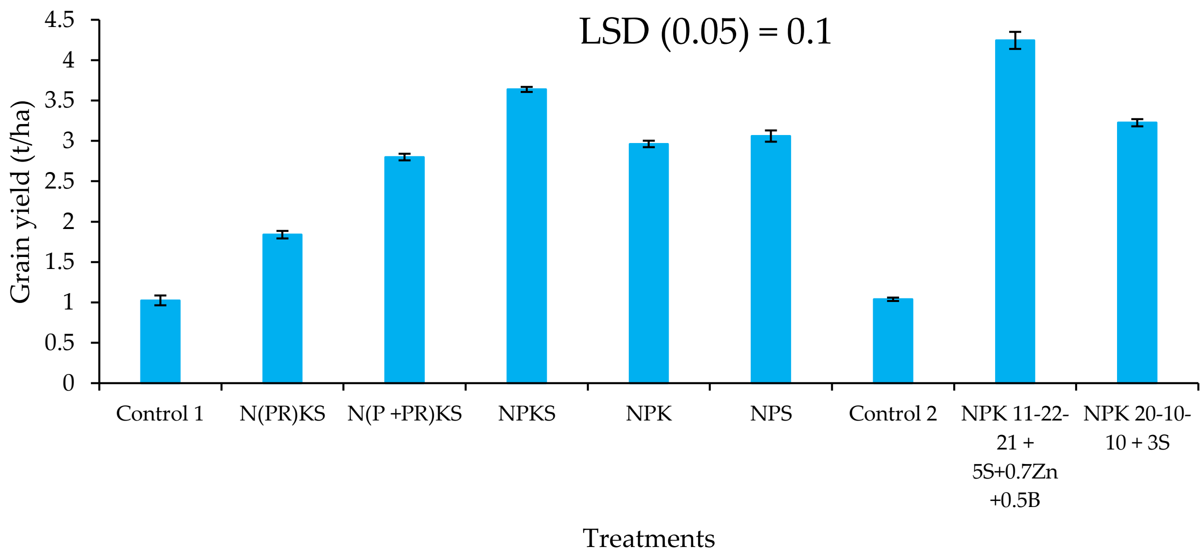

***Figure 2.** Effect of secondary and micronutrient omission/inclusion on grain yield of maize.*

Conclusion and Recommendations

The findings of this study show that maize benefits from inclusion of S, Zn, and B in an NPK fertilizer formulation, as it boosts biomass accumulation and grain yield. Thus, fertilizer recommendations should not only include NPK fertilizers, but also take into consideration secondary and micronutrients in a comprehensive and balanced fertilizer formulation to ensure higher maize productivity in northern Ghana.

Influence of Sulfur, Zinc, and Phosphate Rock in Briquette and Granular NPK on Growth and Yield of Maize (*Zea mays*)

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Background

Briquettes are formed by passing granular fertilizer through machines that compress it into briquettes. Fertilizer briquettes have been tested and slowly accepted for rice paddies in countries such as Bangladesh, Vietnam, the Philippines, Ghana, and Burkina Faso.

Maize is not only an important food crop for humans, but it is also an important component of animal feed and a raw ingredient for many industrial goods. About three-quarters of maize consumption comes from domestic production, implying that maize as a cash crop has a massive global appeal. It is used in the preparation of roughly 24 food products in Ghana, accounting for 30.8% of total food expenditures by all families. As a result, maize has a great potential for addressing serious food security issues, and it could play a key part in future attempts to reverse Ghana's declining trend in per capita food production.

Methodology

An trial was laid as a single factor experiment using a randomized complete block design, with four replications, and each replication contained nine plots, for a total of 38 plots. The size of each plot was 25 m^2, with an alley of 1.0 m between plots and 2.0 m between blocks.

Table 1. Amounts of fertilizer products applied per plot (kg/ha)

Treatments	Type	NPK	PR	P	K	S	Zn
Control		0	0	0	0	0	0
NPK-23-10-5	Briquette†	80-40-40	0	0	0	0	0
NPK-23-10-5+P+S+K	Briquette	80-40-40	0	8.3	8.3	8.3	0
NPK-23-10-5(PR+P)+K+S	Briquette	80-40-40	12.5	4.2	8.3	8.3	0
NPK-23-10-5(PR+P)+K+S+Zn	Briquette	80-40-40	12.3	4.1	8.2	8.2	0.8
NPK-23-10-5	Granular	80-40-40	0	0	0	0	0
NPK-23-10-5+P+S+K	Granular	80-40-40	0	8.3	8.3	8.3	0
NPK-23-10-5(PR+P)+K+S	Granular	80-40-40	12.5	4.2	8.3	8.3	0
NPK-23-10-5(PR+P)+K+S+Zn	Granular	80-40-40	12.3	4.1	8.2	8.2	0.8

† Weight of each briquette is 2.2 grams.

Key Findings

Maize Grain Yield

The fertilizer treatment on maize grain yield was significant (=0.032). Plants treated NPK 23-10-5+PR+K+S+Zn briquettes registered a high yield of 3,661 kg/ha, and plants without fertilizer treatment recorded lowest yield of 2,032 kg/ha. A higher yield was obtained with the briquette fertilizer treatments because nutrients were more available to the maize plants throughout the growing period. Therefore, the increase in maize yields from the fertilizer briquette treatments could be attributed to the apparent slow release of nutrients in synchrony with the maize nutrient demand. Yet, since the actual weight of briquettes was 2.2 grams on average, instead of the anticipated 3.4 grams, total nutrient application rates with briquettes was significantly lower.

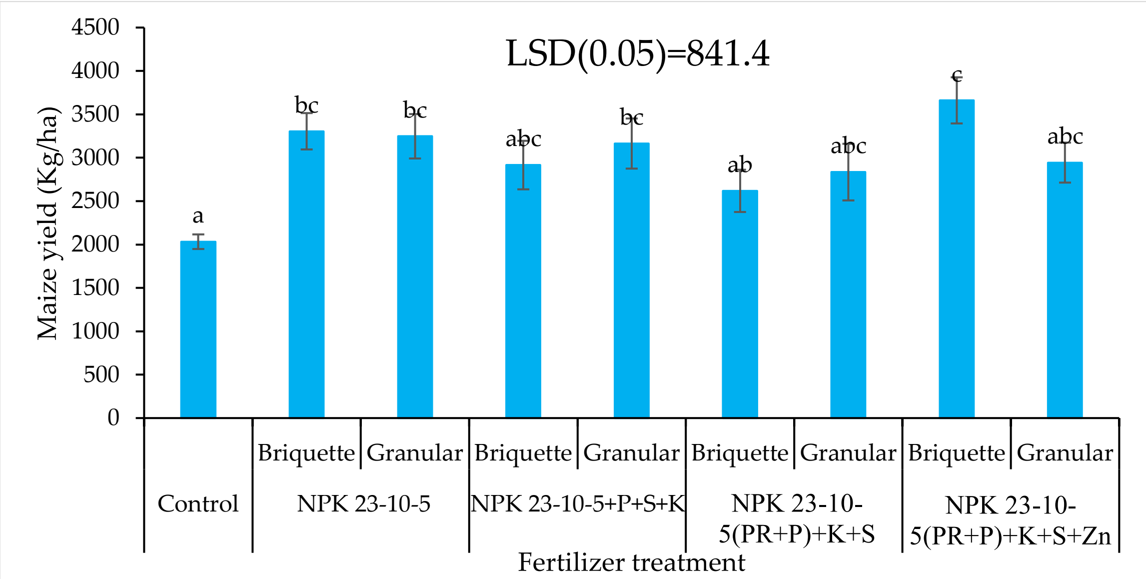

Figure 1. Effect of fertilizer treatment on maize yield.

Conclusion and Recommendations

The average maize yield with the NPK 23-10-5+PR+P+K+S+Zn briquette treatment was higher than the average maize yield of granular NPK 23-10-5+PR+P+K+S+Zn. In general, the briquette treatment plots performed better than the granule treatment plots except for the NPK 23-10-5+PR+P+K+S treatment, for which yield was higher with the granular treatment than the briquette treatment. However, the trial should be repeated in the next season at a different location to determine the best fertilizer recommendation for farmers.

Inclusion of Phosphate Rock, Sulfur, Boron, and Zinc in NPK Formulation for Improvement of Soybeans Growth and Yield

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Background

Soybean (*Glycine Max* [L.] Merrill) is an important food crop. It plays a significant role in natural ecosystems, where its ability to fix atmospheric N_2 in conjunction with rhizobium makes it a good colonizer of low-nitrogen environments. Sulfur, boron, zinc, and other nutrient deficiencies in soils are some of the contributing factors to low yield in soybean. Sulfur and the micronutrients have several roles in soybean growth and productivity, aiding cell formation, cell wall and vascular tissue formation, enzyme activation, nodule number and plant height, flower development, and seed set. Phosphate rock (PR) increases the soil's available P and increases carbon accumulation, which in turn improves soil quality. Though sulfur, boron, zinc, and PR have beneficial effects on crops, evaluation of the effect of their inclusion in NPK formulations for soybean production has received little attention in the nutrient poor soils of northern Ghana. This study aims to evaluate the effect of S, B, and Zn inclusion in fertilizer formulation on growth and yield of soybean.

Methodology

Gbalahi, a suburb of Tamale Metropolis in Ghana's Northern Region, was the site of the experiment during the 2021 farming season. The site lies on longitude 09° 26.226' N and latitude 000° 45.767' W. The experiment was set up in a randomized complete block design, with four replicates. Each experimental plot was 5 x 5 m. Alleys were 2 m and 1 m between replications and plots, respectively. Treatments are as presented in Table 1. Five plants on each plot were randomly tagged, taking into consideration the border effect of each plot. Data were taken on plant height, chlorophyll content, leaf area, days to 50% flowering (budding), stem girth, 1,000-seed weight, and grain yield.

Table 1. Fertilizer treatments used to evaluate the effect of boron, zinc, sulfur, and phosphate rock on soybean growth and yield. NPK was targeted at rate of 100-50-50 kg/ha.

Code	Treatment/ Fertilizer	PR	Urea	TSP	MOP	Ammonium Sulfate	NPK 11-22-21+5S+0.7Zn+0.5B	NPK 20-10-10+3S
						(g)		
T1	Control							
T2	N(PR)KS	389.1	50.3		125.5	103		
T3	N(P+PR)KS	250	50.3	86	125.5	103		
T4	NPKS		50.3	249.1	125.5	103		
T5	NPKS		97.8	249.1	125.5			
T6	NPS		50.3	249.1		103		
T7	Control							
T8	NPK 11-22-21+5S+0.7Zn+0.5B						520.8	
T9	NPK 20-10-10+3S							1,145.8

Key Findings

Treatments containing S and micronutrients significantly increased 6th leaf chlorophyll content compared to the control treatments (Figure 1). The application of NPS gave higher grain yield of 2.8 t/ha compared to zero fertilized plants (Control 1 and 2) which gave lower grain yields of 1.3 t/ha and 1.6 t/ha respectively (Figure 2). Treatments containing Sulphur significantly improved vegetative growth and grain yield of soybeans compared to the zero fertilized plants.

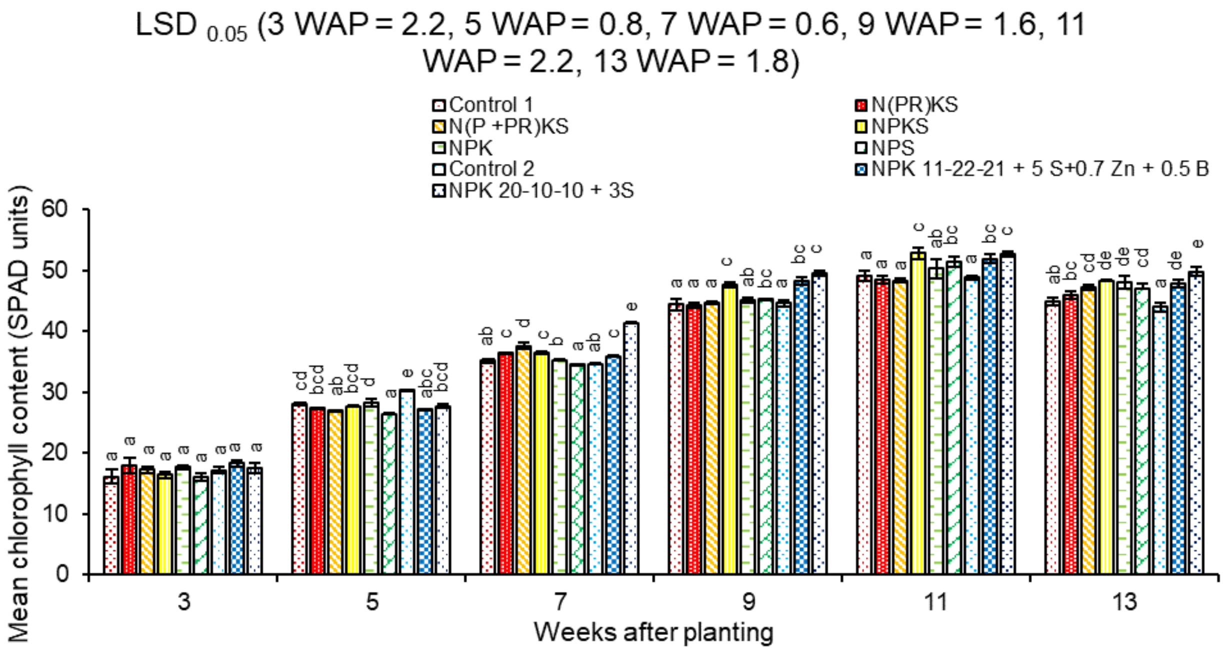

Figure 1. Effect of primary nutrients, sulfur, and micronutrient (boron and zinc) inclusion on fifth leaf chlorophyll content (SPAD units) of soybean.

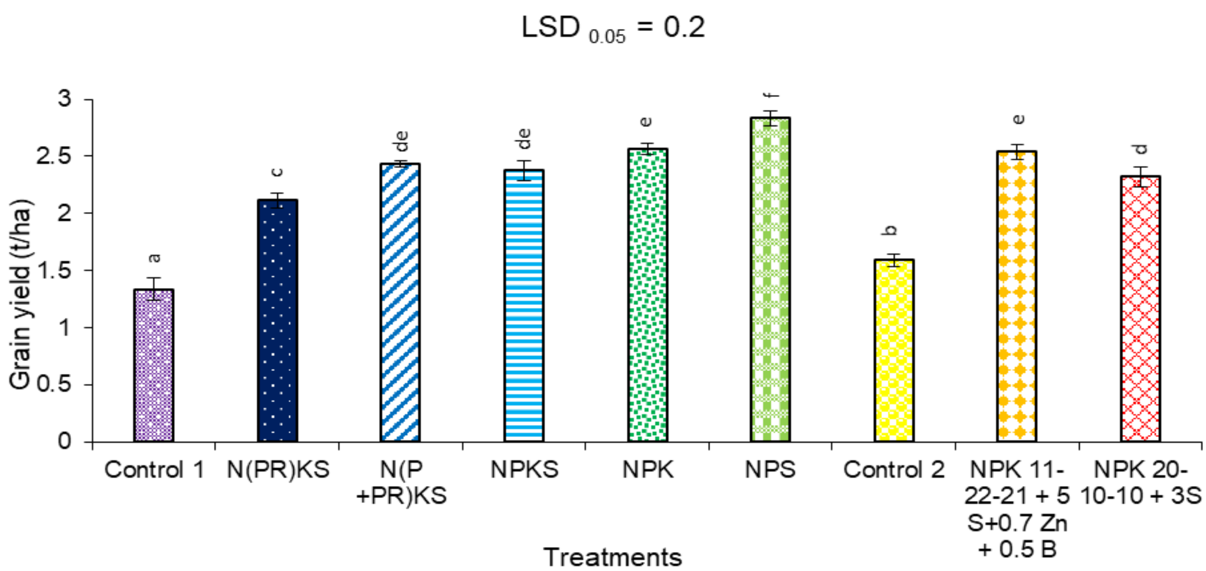

Figure 2. Effect of primary nutrients, sulfur, and micronutrient (boron and zinc) inclusion on the grain yield of soybean.

Conclusion and Recommendations

Treatments containing Sulphur and micronutrients increased vegetative growth and grain yield compared to the control as it supplied soybean with balanced nutrition. Therefore, Sulphur, boron and zinc should be considered in NPK fertilizer formulation for higher productivity of soybean particularly in areas of low soil fertility.

Soybean Varietal Response to NPK Fertilizer and Micronutrients Application

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Background

Soybean (*Glycine max* [L.] Merr.) is largely cultivated in the Savannah belt as an important crop for food, feed, and soil fertility improvement. Over 80% of the soybean crop production in Ghana occurs in the Guinea Savannah ecology, which is characterized by inherently poor soils. Average soybean yield observed in this ecology of 0.8 t/ha is low compared to the national average of 1.65 t/ha, which is still lower than potential yield (2.8 t/ha) reported elsewhere. This is mainly due to the cultivation of poor varieties and low input use. Though several improved varieties of soybean have been developed for cultivation in the Guinea Savannah ecology of Ghana, information on their response to mineral fertilizer application remains scanty. This study was carried out to test the effect of specially formulated fertilizer on the growth and yield performance of soybean in the Guinea Savannah ecology of Ghana.

Methodology

The experiment was carried out at CSIR-Savanna Agricultural Research Institute, Nyankpala, in the Guinea Savannah agroecological zone. The experimental design was a split plot. Three soybean varieties constituted the main plot, while eight treatments (seven fertilizer combinations plus the control [no fertilizer]) constituted the sub-plot. The soybean varieties (Afayak, Favour, and Jenguma) were planted at a spacing of 0.75 m x 0.05 m. All recommended crop management practices for soybean were carried out throughout the growth of the crops. NPK fertilizers were applied as a single dose at 3 weeks after planting. Data were collected on plant height (cm), stem diameter (mm), SPAD chlorophyll meter reading (SCMR), nodule count, number of pods/plant, stover weight (kg/ha), grain yield (t/ha), and 1,000-seed weight (g). Combined analysis of variance (ANOVA) was carried out using GenStat software (12^{th} edition), and the least significant difference (LSD) at 5% probability was used for mean separation.

Key Findings

Highly significant varietal effect was observed for plant height (Figure 1A), stem diameter, chlorophyll content, number of nodules/plant, and grain yield (Figure 1B). Treatment effect was also significant for plant height, stem diameter, chlorophyll content, and grain yield. The variety × treatment interaction effect was significant for only plant height and grain yield (Table 1). Afayak (59.56 cm) had significantly taller plants than Favour (56.39 cm) and Jenjuma (56.28 cm). Across treatments, grain yield followed this order: Afayak (1.43 t/ha) >Jenguma (1.24 t/ha) > Favour (0.91 t/ha). Afayak treated with NK+DAP+inoculant+foliar-applied zinc produced the greatest grain yield (1.75 t/ha).

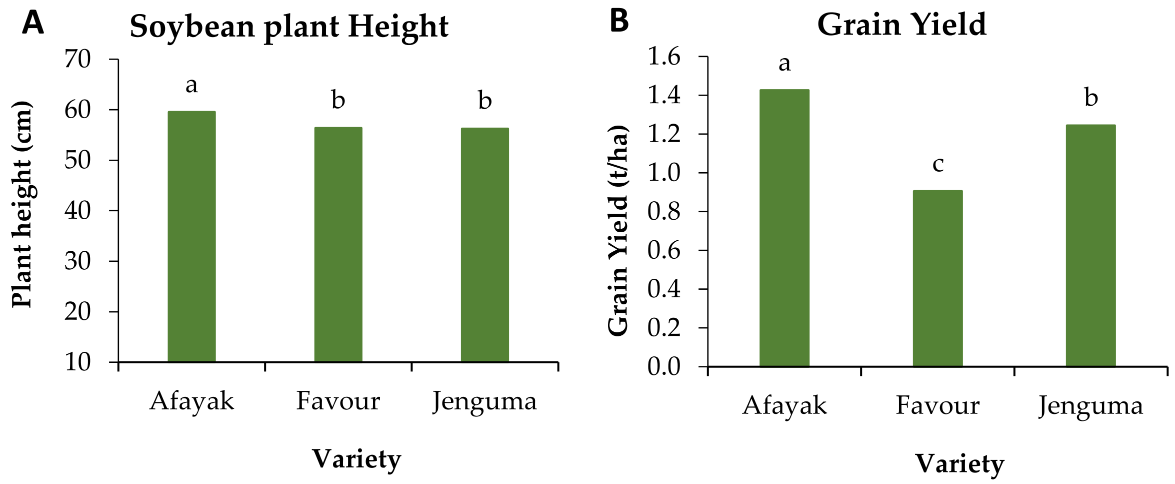

Figure 1. Effect of variety on (A) plant height and (B) grain yield of soybean.

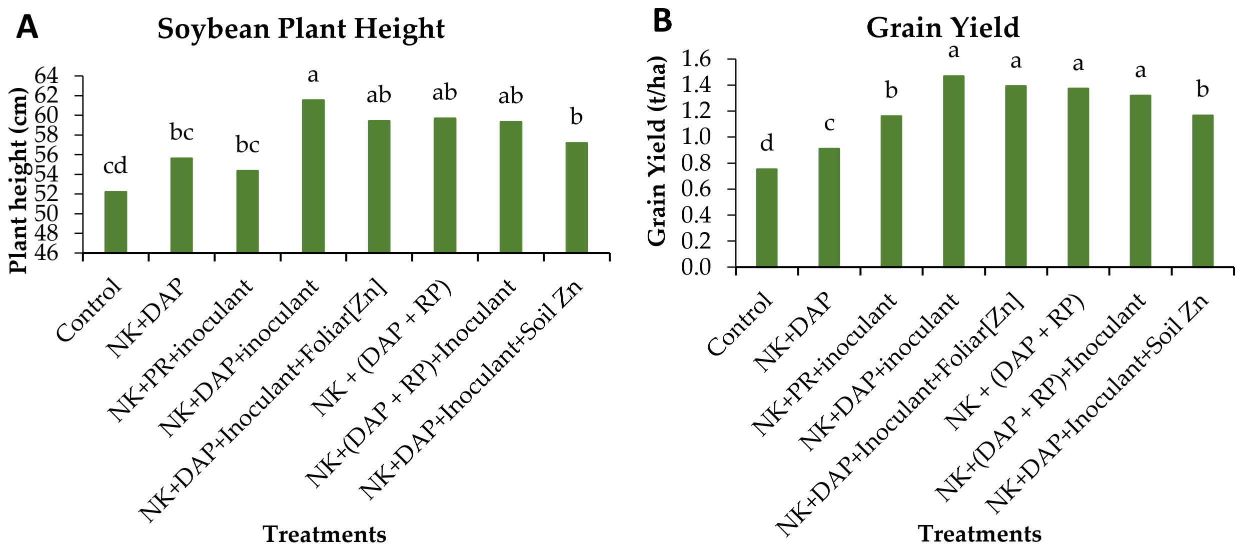

Figure 2. Effect of treatment on (A) plant height and (B) grain yield of soybean.

Table 1. Variety x treatment effect on grain yield (t/ha) of three soybean varieties.

Treatments	Varieties			Mean
	Afayak	Favour	Jenguma	
Control	1.00	0.44	0.82	0.75
NK + DAP	1.03	0.62	1.08	0.91
NK + PR + inoculant	1.47	0.75	1.26	1.16
NK + DAP + inoculant	1.60	1.39	1.42	1.47
NK + DAP + inoculant + foliar Zn	1.75	1.10	1.32	1.39
NK + (DAP + PR)	1.53	1.40	1.18	1.37
NK + (DAP + PR) + inoculant	1.42	0.85	1.68	1.32
NK + DAP + inoculant + soil Zn	1.61	0.71	1.17	1.16
Mean	1.43	0.91	1.24	

LSD (0.05) Variety = 0.09 t/ha; LSD (0.05) Treatment = 0.14 t/ha; LSD (0.05) Variety x Treatment = 0.25 t/ha.

Conclusion and Recommendations

Soybean varietal response was significant for plant height, stem diameter, chlorophyll content (SCMR), number of nodules/plant, and grain yield. Treatment effect was also significant for plant height, stem diameter, SCMR, stover yield, and grain yield. Variety × treatment interaction effect was significant only for plant height and grain yield. Afayak produced the highest grain yield, followed by Jenguma and Favour. The highest grain yield was obtained following the application of NK+DAP+inoculant, which was significantly greater than plots treated with NK+DAP+inoculant+soil-applied Zn. The study revealed that different soybean varieties require different fertilizers and rates for improved growth and yield. It is therefore necessary to determine variety-specific application rates.

Foliar Application of Iron Compounds Improves Iron Content in Soybean and Rice Grain and Lettuce Biomass

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Background

Globally, more than 2 billion people suffer from iron (Fe) deficiency, and this is more common in children (6-23 months) and pregnant women from low- and middle-income countries, including Ghana.

According to the most recent Ghana Demographic and Health Survey, anemia prevalence among pregnant women is estimated to be 45-50%, with a higher number of cases being reported in northern Ghana. Also, most households in the northern Ghana, compared to other parts of the country, engage in crop production, yet food insecurity is still high at 22.6-48.7%, relative to the average of 11.7%. Ghana has also moved toward the use of fertilizer blends with micronutrients, particularly zinc, sulfur, boron, magnesium, and iron. Generally, Fe fortification is necessary in staple crops to address iron deficiency. The best target crops for fortification are rice and soybean, because the former is a key staple food consumed by half the world's population and the latter is a major source of edible vegetable oil and high in protein. Further, lettuce, which is one of the most widely consumed leafy vegetables, was selected for Fe fortification. Out of the three key approaches – conventional breeding, agronomic, and genetic engineering – foliar application (agronomic) is an easy and economical approach to supply nutrients directly to the foliage for improving the Fe status in the edible part of the plants.

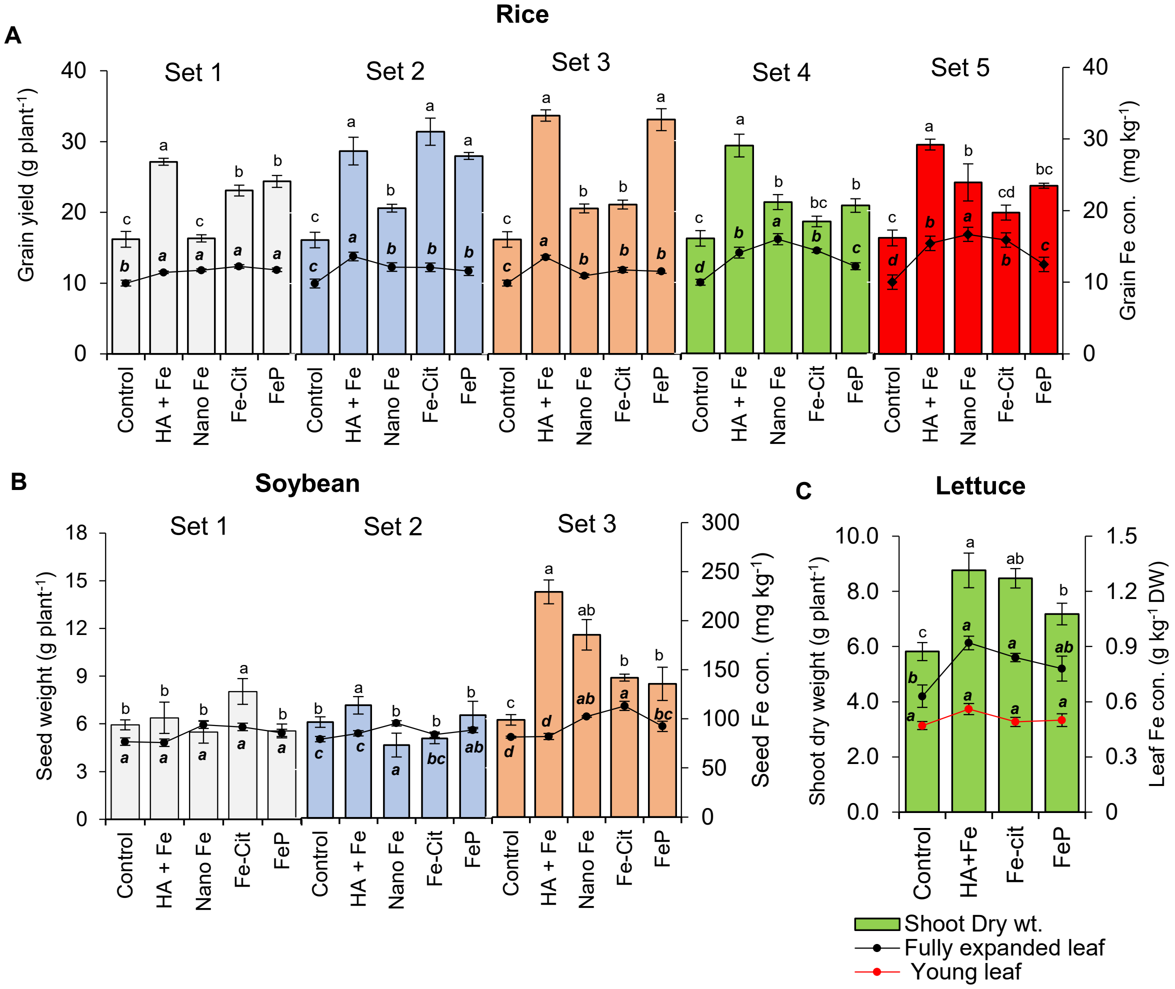
Methodology

Three different pot experiments were conducted on crops including rice (var. MAS946-1), soybean (var. DS-2614), and lettuce (*Chinese yellow*) under natural conditions in their respective growing seasons. Soil (0-30 cm) was collected from the field and sieved. The recommended dose of fertilizers (N, P, and K) was added, and pots were filled with 15 kg of soil in each. Soybean seeds were sown directly in the pots, while rice and lettuce seedlings were transplanted. One healthy plant per pot was maintained for all crops. Foliar applications of Fe citrate (4mM) (Fe-Cit), Fe phosphate (4mM) (FeP), humic acid (25 mg L^{-1}) with ferric chloride (2 mM) (HA+Fe), and nano-Fe (4 mM) were done on rice and soybean, while only the first three treatments were applied to for lettuce. The deionized water was used as control treatment. The pH of spray solutions, including the control, was maintained at 6.0, and 0.1% surfactant (Triton X100) was added before spraying. In rice, the first three sets received a single spray at tillering (set 1), anthesis (set 2), and grain-filling stage (set 3), while sets 4 and 5 received two sprays (at anthesis and grain-filling stage) and three sprays (at all three growth stages), respectively. In soybean, a single foliar spray was applied to set 1 and set 2 plants at flowering and pod-filling stages, respectively, while two foliar sprays were applied to set 3 plants at both growth stages. In lettuce, a foliar spray was done

30 days after transplanting, and the observations on shoot biomass and Fe concentration in fully expanded and young leaves were recorded on the 6th day post foliar application.

Key Findings

In all three crops, Fe foliar application significantly ($p < 0.05$) improved the yield and Fe status as compared to control (Figure 1). Averaged over different sets, the maximum increase in grain yield was recorded with HA+Fe in both rice (>83%) and soybean (52%) as compared to their respective controls (Figure 1A, B). Similarly, in lettuce, maximum shoot biomass on a dry weight basis was obtained with HA+Fe application (Figure 1C). Averaged over different Fe treatments, the maximum increase in grain yield was observed in set 2 (single spray at anthesis) in rice, while in soybean, set 3 (two foliar, each at flowering and pod-filling) showed the maximum increase as compared to control.



Data analysis was carried out using one-way ANOVA. Means with the same letter are not significantly different at $p < 0.05$.

***Figure 1.** Effect of foliar iron application on grain yield and Fe concentration in (A) rice (sets 1, 2, and 3 – single sprays at tillering, anthesis, and grain-filling stages, respectively; set 4 – two sprays each at anthesis and grain-filling; and set 5 – three sprays at all three stages), (B) soybean (sets 1 and 2 – single sprays at flowering and pod-filling stages; and set 3 – two sprays at both growth stages), and (C) shoot dry weight and leaf iron concentration of lettuce.*

In both soybean and rice, the number of sprays was directly related to the seed or grain Fe concentration; the more sprays, the higher the seed Fe concentration (Figure 1). Grain Fe concentration in rice increased by more than 20% on average across all sets and in all Fe treatments as compared to control. However, the highest increases were recorded with HA+Fe and nano-Fe. Nano-Fe foliar application in set 4 and set 5 resulted in maximum increase in rice grain Fe concentration (>60%) among all treatments and sets. Likewise, in soybean, the maximum increase in seed Fe concentration was observed with nano-Fe (>23%), followed by Fe citrate (21%). In lettuce, Fe concentration increased significantly in the fully expanded leaves (>22%) but not in young leaves.

Conclusion and Recommendations

The results of these experiments revealed that foliar Fe application not only improved the Fe status of crops in the edible part but also enhanced their yields if the right Fe compounds were applied at the right growth stage. In comparison to other Fe compounds, HA+Fe exhibited the highest grain yields in both rice and soybean, as well as the highest shoot biomass in lettuce. Additionally, the results showed that, in both rice and soybean grains, Fe content increases as the number of foliar sprays increases. However, grain yield did not show any relationship with the number of sprays. Thus, we recommend that foliar application of Fe along with humic acid should be followed, as it enhances grain and biomass yield in rice, soybean, and lettuce crops, while nano-Fe increases the Fe concentration in the seed of rice and soybean.

Foliar Application of Phosphorus, Sulfur and Micronutrients of Zinc and Iron on Growth and Yield of Rice (*Oryza sativa* L.) under Rainfed and Irrigation in the Guinea Savannah Ecology of Ghana

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Background

Rice (*Oryza sativa* L.) is a widely cultivated cereal crop in varied environments. It is grown for its high-quality grains that are high in carbohydrates. Rice production has employed more than 20 million African farmers, and it is estimated that rice provides a living for roughly 100 million people in Africa. A field experiment was carried out at two locations during the 2020 farming season to examine the relative responses of rice to soil P and foliar P. This sought to determine whether foliar P application could compensate for a lower soil-applied P rate and whether foliar Zn, Fe, and S applications might boost rice grain output.

Methodology

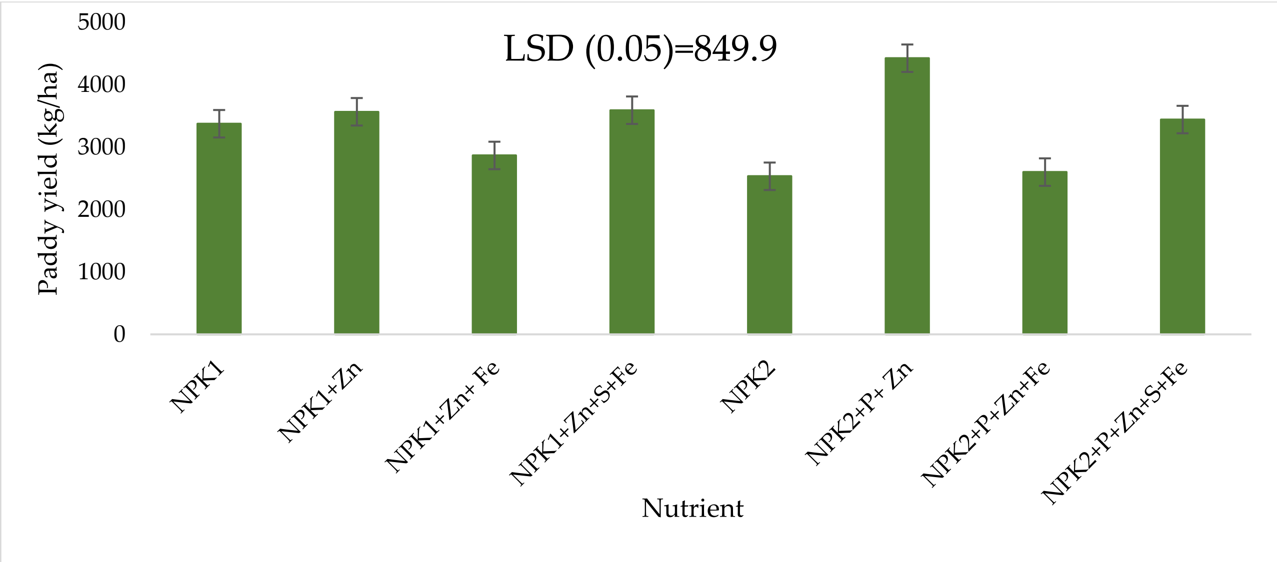
The field study was a 2 x 8 factorial experiment laid out in randomized complete block design, with three replications. The two locations were Nyankpala and Botanga under rainfed lowland and irrigation ecologies, while the eight nutrient formulations were as indicated in Table 1. Alleyways of 1 m and 2 m were given between adjacent treatment plots and blocks, respectively. Each plot measured 5 m x 5 m, and a total of 24 plots were seeded per location. The test crop was the AGRA cultivar, which has a maturity period of 125-130 days.

Table 1. Nutrients as formulated from various combinations of NPK, P, S, Zn, and Fe using the addition model.

	Basal Application			Topdressing			
	Soil Applied (kg/ha)			Foliar Applied (kg/ha)			
Treatment	N	P	K	TSP	Zn ($ZnSO_4$)	Fe ($FeSO_4$)	S (KSO_4)
NPK_1	120	40	40	0	0	0	0
NPK_1+[Zn+S+Fe]	120	40	40	0	1	2	4
NPK_1+[Zn+Fe]	120	40	40	0	1	2	0
NPK_1+[Zn]	120	40	40	0	1	0	0
NPK_2	120	20	40	0	0	0	0
NPK_2+[P+Zn+S+Fe]	120	20	40	4	1	2	4
NPK_2+[P+Zn+Fe]	120	20	40	4	1	2	0
NPK_2+[P+Zn]	120	20	40	4	1	0	0

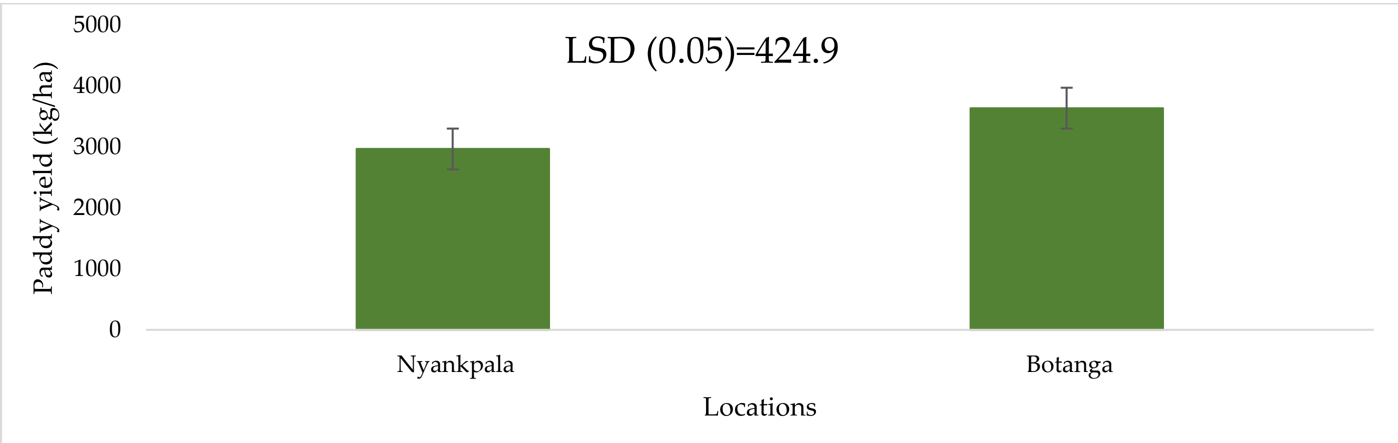
Key Findings

Foliar application of P, S, and micronutrients Zn and Fe resulted in a highly significant difference in paddy production among treatments and locations. The results of the treatment of micronutrients revealed a significant increase in paddy productivity. NPK_2+P+Zn had the maximum production of 4,425 kg/ha, which was equal to that of NPK_1+Zn+S+Fe. In both experiments, foliar nutrient application with Zn, S, and Fe enhanced yield components and rice grain yield. Botanga had the maximum paddy production of 3,635 kg/ha under irrigation, while Nyankpala had the lowest paddy output of 2,965 kg/ha under rainfed conditions.



Bars represent SEM.

Figure 3. Nutrient effect on paddy yield under both irrigated (Botanga) and rainfed (Nyankpala).



Error bars represent SEM.

Figure 2. Location effect on paddy yield under rainfed and irrigation.

Conclusion and Recommendations

The results of this study demonstrate that foliar treatment of the key micronutrients evaluated (Zn+S+Fe, Zn+Fe, Zn, P+Zn+S+Fe, P+Zn+Fe, and P+Zn) increased rice output in both rainfed and irrigated fields. Micronutrients might be extremely important, as an adequate supply could help to ensure higher grain yield and improved economics of production. In addition, application of micronutrients in conjunction with macronutrients could further improve grain yield, with the NPK_2+P+Zn formulation providing the best option. Results showed foliar P increased rice growth and yield response compared to soil-applied P, while irrigation ecology enhanced terminal parameters more than rainfed. Rice yield increased with application of S and micronutrients Zn and Fe, whereas foliar P application compensated for lower soil-applied P. Grain yield was improved by a combination of micro- and macronutrients. Overall, in rainfed and irrigation ecologies, higher responses in rice production would be best supported by four treatments: NPK_2+P+Zn, NPK_1+Zn+S+Fe, NPK_1+Zn, and NPK_1+Zn+Fe. As such, farmers could improve rice production with the inclusion of foliar application of Zn, S, and Fe in their fertilization program. Finally, foliar fertilization could be a viable agricultural strategy for increasing grain Fe and Zn concentrations.

Effects of Soil and Foliar Application of Phosphorus, Sulfur, and Zinc on Grain Yield of Maize in the Guinea Savannah Agroecological Zone of Ghana

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Background

Maize (*Zea mays* L.) is a member of the Pocaea family, and after rice and wheat, it is the world's third most significant cereal crop. Maize is the number one food security staple crop in Ghana and provides a source of income for many people in northern Ghana. For the growth of plants such as maize, micronutrients are required in very small quantities and are involved directly or indirectly in improving photosynthesis, respiration, protein synthesis, and reproduction. One of the strategies to boost crop yields is to provide optimal levels of mineral nutrients through the soil or foliarly. This study, therefore, analyzed the effect of soil and foliar application of macro- and micronutrients on the maize yield in the Guinea Savannah zone of Ghana.

Methodology

The experiment was conducted at University for Development Studies Farming for the Future Garden in Nyankpala, Tolon District. The study design comprised 10 treatments in a randomized complete block design, with four replications. Each block consisted of 10 experimental units, with a plot measuring 5 m × 5 m with an alley of 1 m between plots and 2 m between blocks. The treatments consisted of only soil-applied nitrogen (N), phosphorus (P), and potassium (K), or soil and foliar-applied P, sulfur (S), and zinc (Zn) in different combinations. NPK 23-10-5, phosphorus (triple superphosphate), S (K_2SO_4), and Zn fertilizer were used ($ZnSO_4$). NPK and muriate of potash (MOP) were applied directly to the soil as a basal treatment 2 weeks after sowing, while urea was used as a topdressing 7 weeks after sowing. Further, 7 weeks after planting, foliar applications of P, S, and Zn were also applied to the respective treatments.

Key Findings

From Figure 1, the application of Zn and S to the crop through foliar application significantly increased grain yield over when they were applied through soil. Yield with the application of Zn through the soil was significantly higher than with the sole application of NPK. The use of Zn and S to improve grain yield has also been reported in the literature.

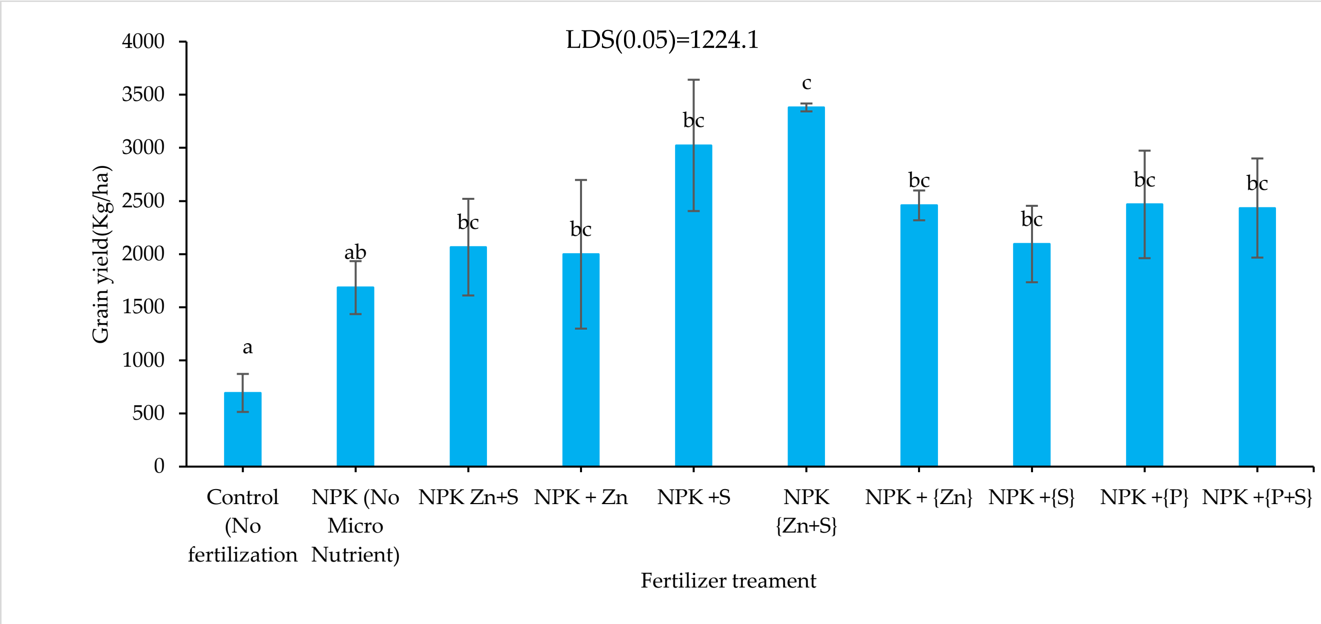

Figure 1. Grain yield under various treatments.

Conclusion and Recommendations

Based on one year of data, foliar application of Zn and S had a great influence on maize grain yield as compared to soil application of Zn and S. The trial needs to be repeated in a subsequent season, preferably also at different locations, to get the best recommendation of fertilizers to farmers.

Agronomic Characteristics of Soybean (*Glycine max*) under Foliar Fertilizer Treatment

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Background

Legumes such as soybean have been recognized as "soil improvers." Soybean is beneficial in managing *Striga hemonthica* in Ghana's Savannah zone. It is a non-host plant to *Striga*, but produces chemical substances that stimulate germination of Striga seeds. Many epidemiological studies on the effects of soybean consumption and cancer, heart disease, and menopausal syndrome prevention have also been conducted. Zinc deficiency is known to affect one-third of the world population, and one of the possible solutions is agronomic biofortification. However, there is little research on zinc biofortification in soybean in Ghana. Field investigations were therefore carried out in two consecutive cropping seasons, i.e., 2020 major season (April to July) and minor season (September to December), in the Semi-Deciduous Forest zone of Ghana to evaluate the impact of zinc application on the productivity of soybean.

Methodology

The field experiments were conducted at three locations: Horticulture Department (06.67768° N, 001.56643° W), Plantation Crops and Experimentation Section (06.68313° N, 001.55128° W), and Agricultural Research Station (ARS), Anwomaso (06.69826° N, 001.52038° W) of Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. The experiment was laid out in a randomized complete block design, comprising seven and nine treatments in the major and minor seasons, respectively. The treatments were: control, NPK, phosphate rock + inoculant, diammonium phosphate + inoculant, NPK + inoculant, NPK + inoculant + foliar Zn, diammonium phosphate + phosphate rock, diammonium phosphate + phosphate rock + inoculant, NPK + inoculant + soil Zn in the minor season. The phosphate rock + inoculant and diammonium phosphate + inoculant treatments were not included in the major season. The treatments were replicated four times in each season with the soybean variety Jenguma.

Key Findings

Leaf area and leaf area index in the minor season were influenced by soil-applied zinc at 6, 8, and 10 weeks after sowing. The number of nodules produced under both foliar and soil-applied zinc were similar in both the major and minor seasons. Similarly, the number of days to 100% maturity were similar among all treatments in both cropping seasons. Applied fertilizer types produced a similar harvest index ($p > 0.05$) in both seasons. With respect to yield components, the number of pods per plant and 1,000-seed weight showed significant differences among the fertilizer types in the minor season but not in the major season. In the minor season, NPK + inoculant + soil-applied Zn significantly outperformed the NPK treatment in 1,000-seed weight. Grain yields obtained under both soil and foliar-applied zinc were below the potential yield of soybean. Economic analysis performed showed that none of the treatments had value-cost ratios greater than 2.

Table 1. Grain yield (t/ha) results for site-specific locations.

Treatments	Minor Season			Major Season		
	Horticulture	Plantation	ARS	Horticulture	Plantation	ARS
Control	1.81	1.11	0.88	0.68	0.84	0.91
NPK	1.96	1.05	0.90	0.84	0.89	1
PR + inoculant	2.22	1.34	1.26	ND	ND	ND
DAP + inoculant	1.94	1.4	1.18	ND	ND	ND
NPK + inoculant	1.89	1.26	1.12	0.68	0.86	1.19
NPK + inoculant + foliar Zn	2.12	1.29	1.36	0.82	0.93	1.04
(DAP + PR)	1.58	1.1	1.47	0.72	1.15	1.01
(DAP + PR) + inoculant	2.14	1.27	1.32	1.02	0.79	0.97
NPK + inoculant + soil Zn	1.74	1.05	1.33	0.70	0.85	1.12
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	25.1	24.1	24.7	37.1	18.4	18

NS = Not significant; ND = Not determined.

Table 2. Concentration of zinc (mg kg^{-1}) in grains of soybean.

Treatment	Horticulture	Plantation	ARS
Control	26.87	26.27	24.86
NPK	27.19	27.44	25.14
NPK + inoculant	30.18	27.10	21.22
NPK + inoculant + foliar Zn	27.98	23.43	23.34
DAP + PR	27.42	22.58	21.50
DAP + PR + inoculant	31.31	22.36	25.64
NPK + inoculant + soil Zn	29.07	26.88	20.25
LSD (5%)	NS	NS	NS
CV (%)	16.8	16.2	18.9

ND = Not significant.

Conclusion and Recommendations

The seemingly no effect of the foliar-applied zinc could stem from its one-time application at 90% plant cover, among other factors. Based on the results of the study, the following recommendations are made:

- Given that foliar Zn applications did not achieve many results, it is recommended that its application be done twice within the growth cycle of the plants at a higher rate.
- A better understanding of the processes involved in the nutrient pathway once it reaches the leaf surface and the subsequent movement into the leaf and transport to the tissue should be explored.
- Different fertilizer formulas had no effect on soybean performance (at the three sites) and were also not economically viable. To avoid economic loss and crops channeling nutrients to vegetative production, it is advisable to use less of the nutrient formulations in soybean production.

Effect of Foliar Application of Some Macro- and Micronutrients on the Yield of Maize

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Background

For some time now, the farming methods used by farmers have been negatively affected by components such as climate, declining soil fertility, and inadequate application of external inputs and constant monocropping. One of the most effective ways of replenishing and correcting depleted soil nutrients is through the application of mineral fertilizer. Therefore, providing ideal quantities of mineral nutrients in addition to the use of balanced macro- and micronutrient doses to crops is one way to improve crop yields. Micronutrients are needed in small amounts to directly or indirectly enhance photosynthesis, respiration, protein synthesis, and reproduction. Fertilizers supplied through soils are subjected to leaching, fixation, surface runoff, erosion, volatilization, and extremely high or low pH and render nutrients unabsorbable by plants. Foliar application of fertilizer therefore supplies nutrients directly to the stomata and cuticle of the leaves, which saves time and increases yield.

Methodology

The experiment was designed as a multi-location study comprising eight treatments. The eight treatments were evaluated in a randomized complete block design, with three replications. Each block consisted of eight plots each measuring 5 m × 5 m, with an alley of 1 m between plots and 2 m between blocks. The experiment was conducted at the experimental field of University for Development Studies, Nyankpala (9°24'39"N, 0°59'2" W 170 m) and Kpaliga (9°26'44"N, 0°57'58"W 170 m) in the Northern Region of Ghana.

Table 2. Amounts of treatments applied (kg/ha).

Treatments	Soil Basal Application		Topdressing				
			Soil Applied		Foliar Applied		
	NPK (23-10-5)	MOP	Urea	TSP	Zn ($ZnSO_4$)	Fe ($FeSO_4$)	S (KSO_4)
NP_1K	400.00	40.16	60.88	0.00	0.00	0.00	0.00
NP_1K+[Zn+S+Fe]	400.00	40.16	60.88	0.00	3.08	6.80	13.96
NP_1K+[Zn+Fe]	400.00	40.16	60.88	0.00	3.08	6.80	0.00
NP_1K+[Zn]	400.00	40.16	60.88	0.00	3.08	0.00	0.00
NP_2K	200.00	60.24	160.88	0.00	0.00	0.00	0.00
NP_2K+[P+Zn+S+Fe]	200.00	60.24	160.88	11.80	3.08	6.80	13.96
NP_2K+[P+Zn+Fe]	200.00	60.24	160.88	11.80	3.08	6.80	0.00
NP_2K+[P+Zn]	200.00	60.24	160.88	11.80	3.08	0.00	0.00

Key Findings

Application of nitrogen in a split form has the ability to broaden the leaf surface area to receive the foliar-applied micronutrients. However, increasing nitrogen at basal application and reducing it at topdressing (NP_2K treatments) stands a better chance of broadening the leaf surface area (Figure 1). The general progression of leaf area index could be attributed to the adequate supply of macronutrients.

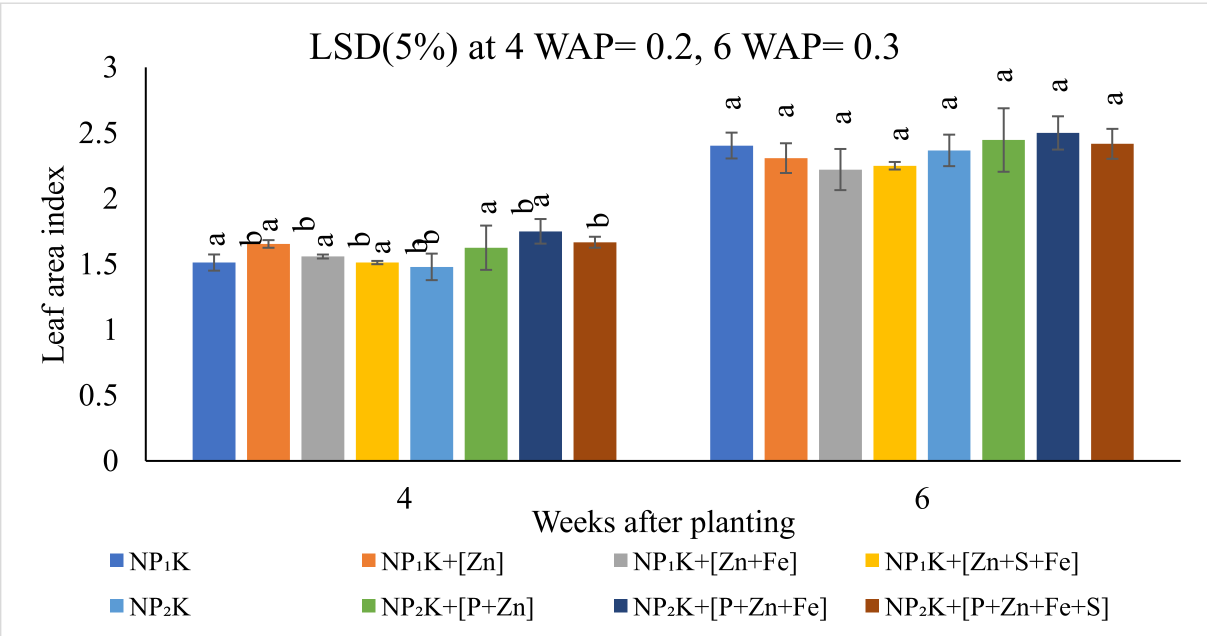

Figure 4. Influence of fertilizer treatments on leaf area index at 4 and 6 weeks after planting.

NP_2K+[P+Zn+Fe] produced the highest grain yield. There was no significant difference among the treatments containing zinc. According to Leach and Hameleers (2001) and Subedi and Ma (2009), maize is a crop of high response to zinc, which could have been the cause of this result (Figure 2).

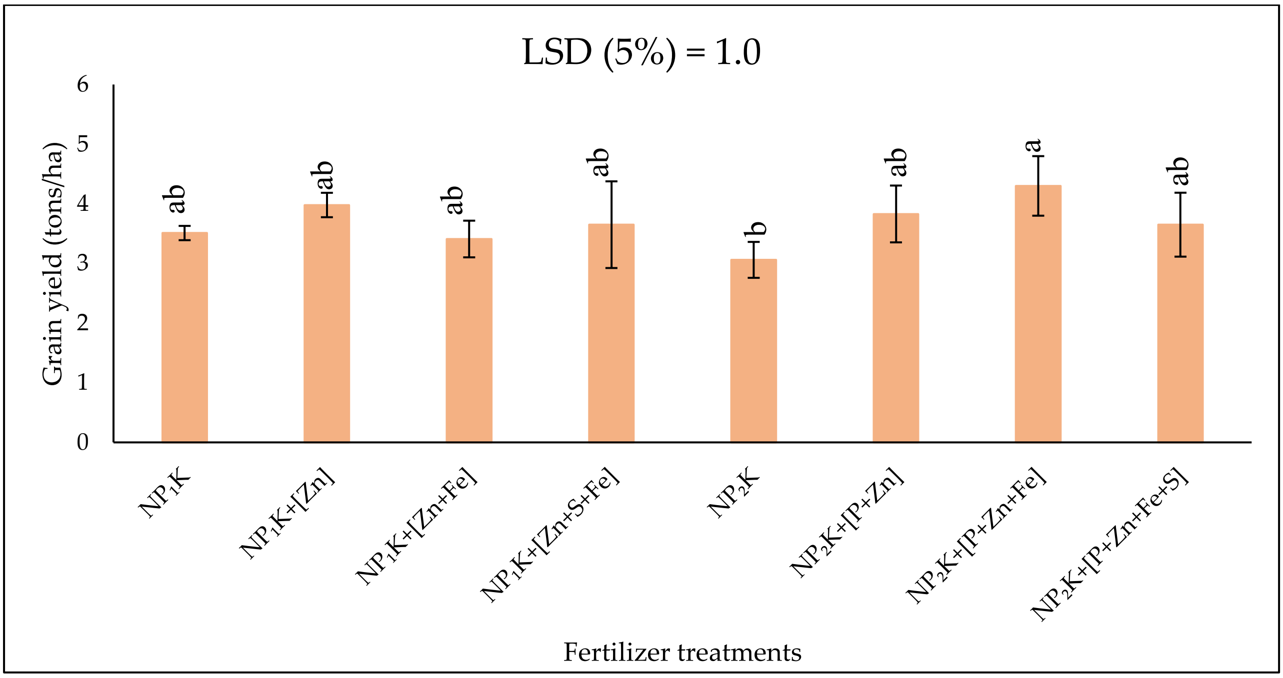

Figure 5. Effect of fertilizer treatments on grain yield.

Conclusion and Recommendations

During the experiment, the highest plant height was recorded from plants treated with NP_2K+[P+Zn+Fe]. A similar trend was observed in SPAD values, leaf area index, and grain yield. Treatments containing zinc generally performed better in all the growth and yield parameters. Maize plants therefore responded better to foliar application of phosphorus, zinc, and iron. The outcome of this study is from one growing season, hence the need for further studies to establish the findings.

Comparative Effect of Different Briquette Fertilization on Maize Yield and Growth

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Background

Constraints to maize output are determined by many complex interacting factors. In the Guinea Savannah zone of Ghana, continuous land use coupled with opposing long dry seasons has led to rapid decomposition of soil organic matter and loss of soil fertility. Fertilizers are critical components of the production system for supplying nutrients that are essential for the proper growth and development of maize. Balanced nutrition is an essential component of nutrient management and plays a significant role in increasing crop production. For the major processes of development and yield formation in maize, the presence of micro- and macronutrients in a balanced form is essential. One practical and cost-effective nutrient management strategy is the incorporation of some micronutrients, such as zinc, boron, sulfur, magnesium, and phosphate rock, with NPK fertilizers (briquettes) to reduce nutrient losses and improve fertilizer efficiency in a deep placement technology.

Methodology

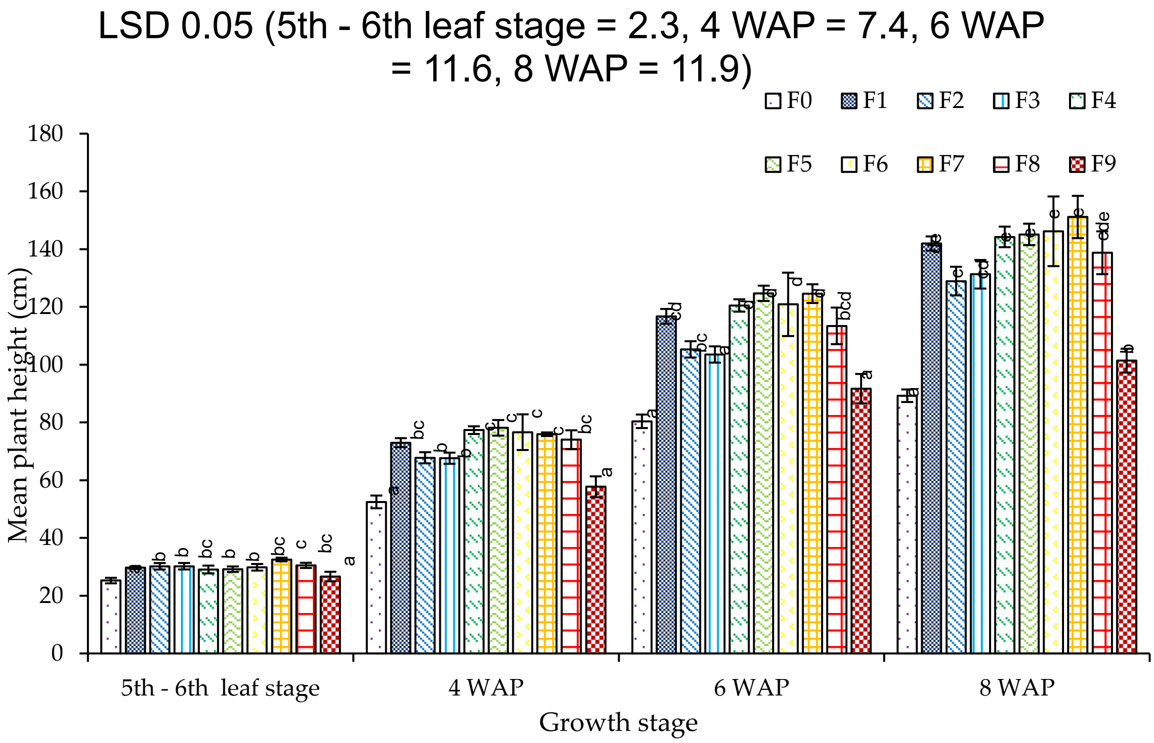
The trial was conducted at two locations, Nyankpala and Kudula, in the Guinea Savannah zone. The experiments were laid out in a randomized complete block design, with four replications, with nine treatments and one control. Plot sizes of 5 m x 5 m were used. Alleys between replications and between plots were 2 m and 1 m, respectively. The treatment (briquette) combinations were: T0 = control, T1 = NPK, T2 = NPK 23-10-5, T3 = NPK 20-10-10+3S, T4 = NPK 23-10-5+P+S+K, T5 = NPK 15-20-20+0.7Zn, T6 = NPK 12-30-17+0.4Zn, T7 = NPK 11-22-21+5S+0.7Zn+0.5B, T8 = NPK 23-10-5+(RP+P)+K+S+Zn, and T9 = urea. A planting spacing of 0.75 m x 0.45 m was used. The basal application was done 12 days after planting. Briquette fertilizer was placed in holes about 7-10 cm deep beside the base of the plant and covered. Various agronomic practices were carried out equally.

Key Findings

The application of the treatments had a significant interactive influence on maize growth parameters. Plant parameters varied between treatments from 4 weeks after planting (WAP) to 8 WAP. At the 5^{th} to 6^{th} leaf stage, plants had nearly identical heights, leaf chlorophyll content, and leaf area for all treatments. There were significant differences ($p < 0.001$) between the treatments from 4 WAP to 8 WAP.

Plant Height

The application of the treatments had a significant interactive influence on maize height at the two locations. The variation in plant height increased between treatments from 4 WAP to 8 WAP. At 2 WAP, which is prior to fertilizer treatment application, the plant heights were statistically similar ($p > 0.001$). Moreover, the plant heights increased substantially after the fertilizer treatments were applied, and they were significantly different among the fertilizer regimes (Figure 1). The differences in plant height between the fertilizer treatment regime increased with growth and peaked at 8 WAP. Experimental plots treated with NPK briquette formulation 11-22-21+5S+0.7Zn+0.5B registered the highest plant height among all the treatments in each week, except at 6 WAP, where NPK 15-20-20+0.7Zn registered the highest plant height. The experimental plot with no fertilization (control plot) had the lowest plant height among all the treatments throughout the weeks after treatments were applied to the plants (Figure 1).

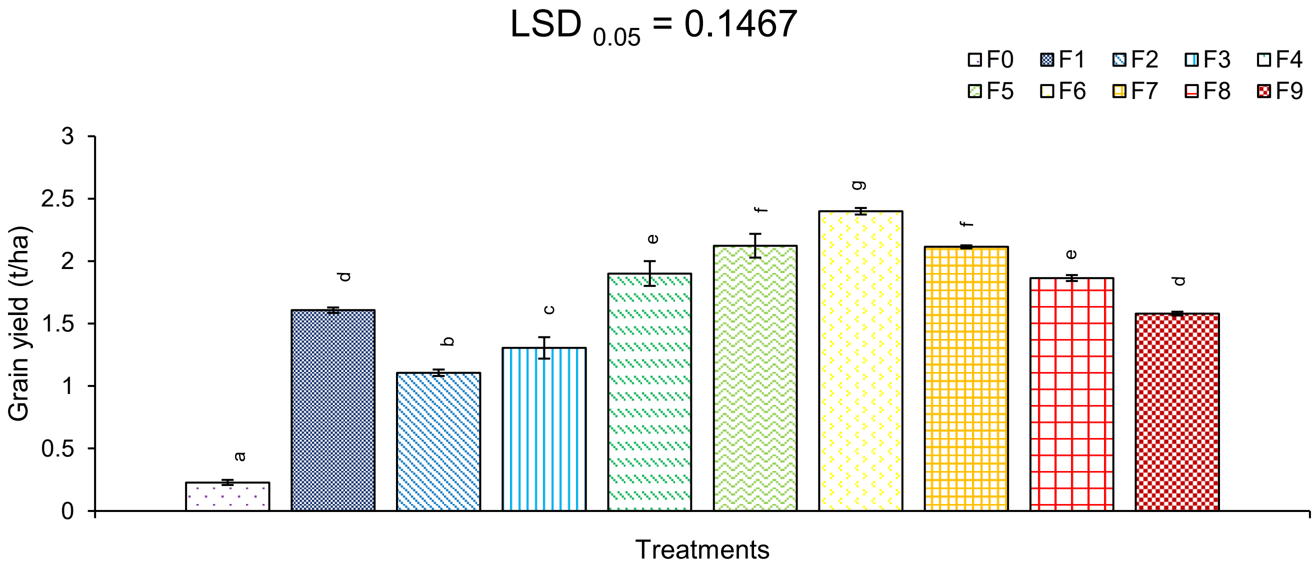


F0 = control, F1 = NPK, F2 = NPK 23-10-5, F3 = NPK 20-10-10+3S, F4 = NPK 23-10-5+P+K (farmer-managed A), F5 = NPK 15-20-20+0.7Zn, F6 = NPK 12-30-17+0.4Zn, F7 = NPK 11-22-21+5S+0.7Zn+0.5B, F8 = NPK 23-10-5+(PR+P)+K+S+ZN (farmer-managed B), and F9 = urea.

Figure 1. Effect of primary, secondary, and micronutrient formulation rates on plant height in northern Ghana.

Grain Yield

The total grain yield was significantly ($p < 0.001$) influenced by application of primary, secondary, and micronutrients (Figure 2). At harvest, the application of NPK 12-30-17+0.4Zn recorded the statistically greatest mean yield of 2.4 t/ha. NPK 15-20-20+0.7Zn and NPK 11-22-21+5S+0.7Zn+0.5B were statistically similar in yield at 2.1 t/ha. NPK 23-10-5 recorded the next lowest, followed by the control plot with no fertilization recording the least grain yield.



F0 = control, F1 = NPK, F2= NPK 23-10-5, F3= NPK 20-10-10+3S, F4= NPK 23-10-5+P+S+K (farmer-managed A), F5 = NPK 15-20-20+0.7Zn, F6 = NPK 12-30-17+0.4Zn, F7 = NPK 11-22-21+5S+0.7Zn+0.5B, F8 = NPK 23-10-5+(PR+P)+K+S+ZN (farmer-managed B), F9 = urea.

Figure 2. Effect of primary, secondary, and micronutrient formulation rates on grain yield of maize at harvest in northern Ghana.

Conclusion and Recommendations

It was found from the study that the addition of zinc, sulfur, and boron to NPK in NPK 12-30-17+0.4Zn increased maize productivity in the Guinea Savanna. The use of NPK 12-30-17+0.4Zn improved maize vegetative growth and grain output (2.4 t/ha). Furthermore, phosphate rock had a minimal impact on maize biomass and yield. This treatment supplied the plants with the right amount of nutrition, hence profoundly affecting their progressive vegetative growth and yield. Omitting sulfur, zinc, and boron from maize fertilizer formulations can impair growth and production. Applying NPK 12-30-17+0.4Zn, NPK 15-20-20+0.7Zn and NPK 11-22-21+5S+0.7Zn+0.5B briquette fertilizer on maize stimulates vegetative growth and yield. Therefore, such formulations are recommended among the treatments for the studied area.

Effect of Zinc, Sulfur, Phosphate Rock, and NPK Briquettes on Growth and Yield of Maize (*Zea mays* L.) in the Guinea Savannah Ecology

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Background

Declining soil fertility is increasingly becoming a serious concern in the Guinea Savannah ecology. Most soils in this ecology lose their fertility because of frequent cultivation without nutrient replenishment. Application of improved inorganic NPK fertilizers known as optimized briquettes is feasible in contemporary soil fertility restoration for increased maize productivity. However, most available fertilizers are the traditional micronutrient- and secondary nutrient-deficient NPK. Continuous adherence to such fertilizers for profitable production of fertilizer-responsive crops, such as maize, is non-agribusiness in concept. In order to promote maize productivity to meet contemporary demand, fertilizer formulation reviews are imperative. Adoption of optimized fertilizer briquette technology could be a sustainable option. The objectives of this research were to: (i) optimize nutrients in briquette form for maize growth and yield and (ii) ascertain which nutrients (zinc [Zn], phosphate rock, phosphorus, potassium, and sulfur) when added to NPK briquettes will contribute to improved maize growth and yield.

Methodology

The research was conducted at two locations – Kpalga in Kumbungu District and Nyankpala in Tolon District in Northern Region – in the Guinea Savannah ecology during the 2021 rainy season. Trials were laid in a randomized complete block design, with eight fertilizer treatments and one control per replication, replicated four times at each location. Data on maize growth parameters and yield were taken, and the least significant difference (LSD) test was used to determine the effect on maize growth and yield. Mean values were tabulated against all parameters that showed significant fertilizer effects and compared. The effectiveness of all nine treatments was scored from first to last, i.e., 1 through 9, as per significant parameters obtained from ANOVA.

Key Findings

This research found treatments without PR performed relatively better in maize vegetative growth parameters, including leaf area index (LAI), fresh biomass, and plant height, in the order NPK+P+S > NPK+P+S+K (Figure 1). However, these treatments that showed superiority in related vegetative growth parameters did not exhibit similar superiority in grain yield. The added potassium was irreflexive in both growth and yield traits. In terms of grain yield, this research ranked performance of the various treatments in descending order as follows: NPK+PR+P+S (2,602 kg/ha) > NPK+PR+P+K+S+Zn (2,455 kg/ha) > NPK+P+S+K (2,406 kg/ha) > NPK+PR+P (2,312 kg/ha) > NPK+PR+P+K+S (2,294 kg/ha) > NPK+P+S (2,209 kg/ha) > NPK (2,140 kg/ha) > NPK+PR

(1,871 kg/ha) > control (1,358 kg/ha) (Figure 2). Almost consistently, control, NPK, and NPK+PR showed abysmal performance in both growth and yield potential.

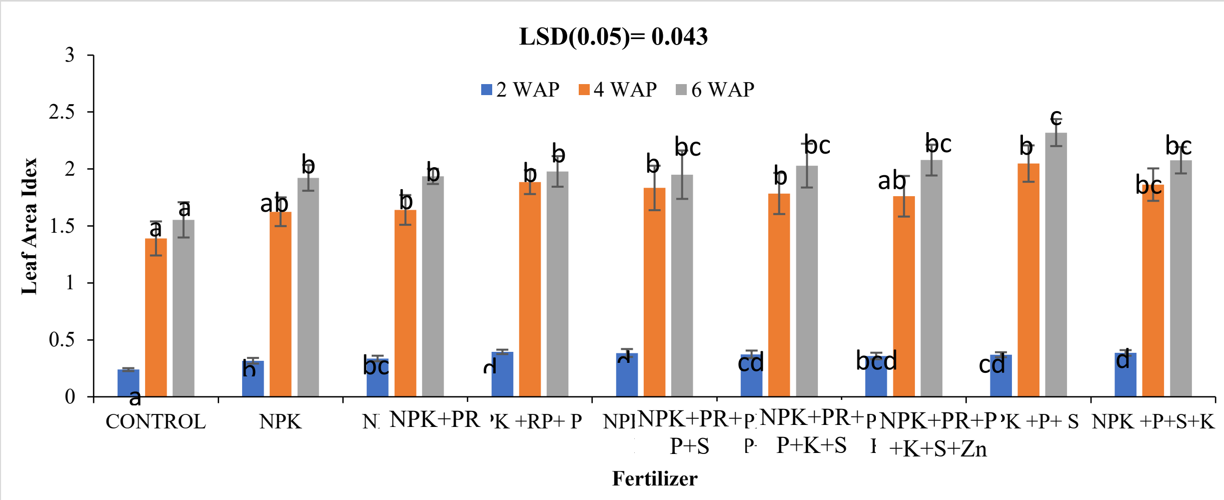

Figure 1. Effect of optimized NPK briquettes on leaf area index of maize.

At 6 weeks after planting, all treatments except NPK+P+S and control, which had the highest and lowest LAI at 2.320 and 1.553, respectively, including the most optimized treatment, i.e., NPK+PR+P+K+S+Zn were statistically similar. However, there was a significant difference between NPK and the NPK+P+S in terms of LAI.

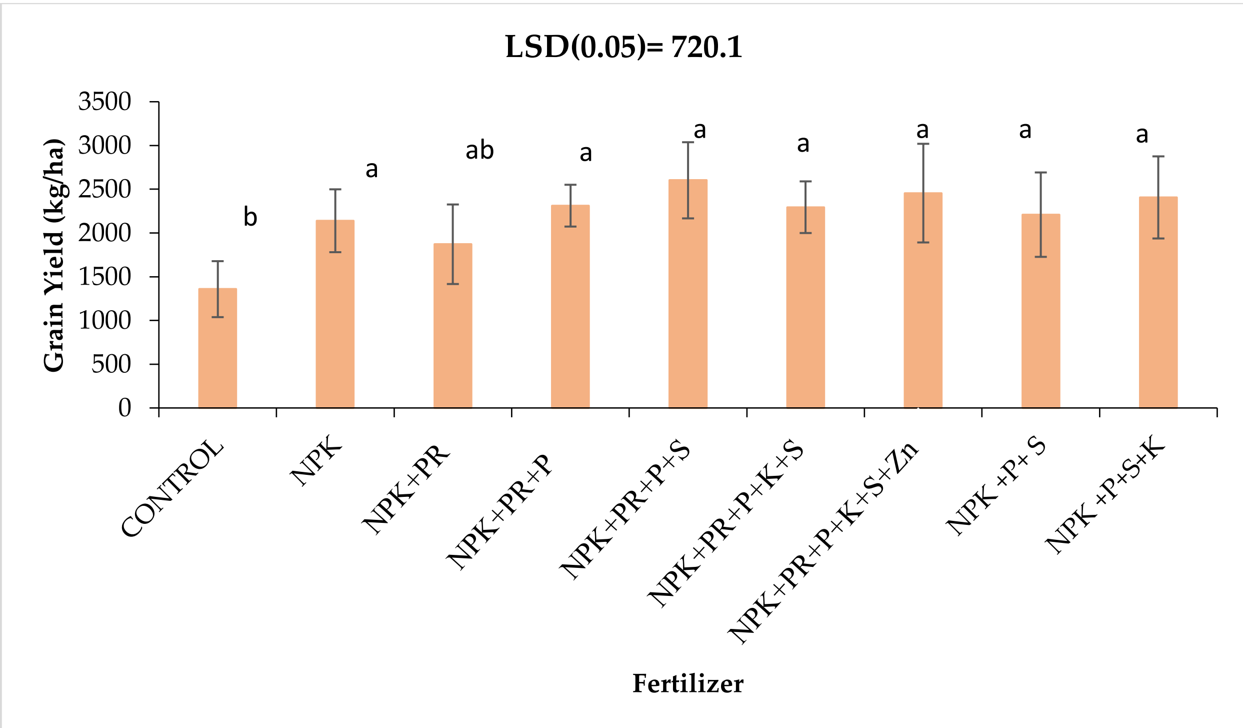

Figure 2. Effect of optimized NPK briquettes on grain yield of maize.

NPK and all other briquette treatments exhibited statistical similarity in grain yield. However, application of NPK+PR+P+S and control resulted in the highest and lowest grain yield of 2,602 kg/ha and 1,357.8 kg/ha, respectively. NPK+PR+P+K+S+Zn, which is more optimized in terms of elemental load, was next highest in grain yield at 2,455 hg/ha.

Conclusion

From this research, the optimized NPK briquette technology was shown to be an efficient and feasible soil fertility management option. Maize growth- and yield-related traits were shown to be responsive to optimized NPK briquettes. It is recommended that the application rate of Zn be increased in the same formulation in future research to determine whether that treatment, with the highest elemental load, could produce the highest grain yield per hectare. More effective binding materials could be developed and made available for fertilizer briquetting to improve handling and to meet the intended usage of NKP briquettes. Based on results from both locations, the development of NPK 23-10-5+PR+P+S optimized briquettes is recommended for adoption by farmers to contribute to profitable maize production and food security efforts in the Guinea Savannah ecology.

Effect of Granular NPK and Briquetted NPK on the Growth and Yield of Maize

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Background

Soils in northern Ghana are inherently poor, with low organic matter and low levels of nutrients, particularly nitrogen (N) and phosphorus (P). Low yields are recorded in maize as a result of low external inputs and poor crop management practices. Application of N, P, and potassium (K) at the right time, at the right place and in the proper balance has been found to increase yields of maize. However, soils in northern Ghana are prone to nutrient losses through leaching and runoff. One effective means to reduce nutrient losses and improve fertilizer efficiency is fertilizer deep placement (FDP) technology in the form of briquettes. Briquettes are large-size fertilizer particles that ensure the slow release of nutrients for uptake by plants. Studies have found briquetting to be more effective than broadcasting granular fertilizers, reducing N losses and improving nutrient uptake to enhance productivity. The objective of this study was to evaluate the growth and yield of maize as affected by briquetted and granular NPK fertilizer.

Methodology

The study was carried out at CSIR-Savanna Agricultural Research Institute, Nyankpala, in the Guinea Savannah agroecological zone in 2021. The experiment was arranged in a randomized complete block design, with four replications. Nine treatments, comprising eight fertilizer combinations plus the control (no fertilizer), were assessed for their effect on maize growth and yield parameters. Four pairs of fertilizer treatments consisting of NPK at a rate of 120-40-40 with or without micronutrients were tested in the form of briquettes and granules. The maize was planted using a spacing of 0.75 x 0.4 m. NPK fertilizers were applied in two splits at 2 weeks and topdressed at 6 weeks after planting. Data were collected on plant height, stem diameter, chlorophyll content (SCMR), cob diameter, cob length, grain yield, and 1,000-seed weight. Analysis of variance (ANOVA) was carried out using GenStat software (12th edition), and the least significant difference (LSD 5%) was used for mean separation.

Key Findings

Analysis of variance indicated a significant treatment effect for plant height, stem diameter, chlorophyll content (SCMR), cob diameter, cob length, grain yield, and 1,000-seed weight. Application of granular NPK 23-10-5+P+S+K and granular NPK 23-10-5(PR+P)+K+S+Zn produced significantly taller plants than plants treated with briquetted NPK 23-10-5(PR+P)+K+S and the control (Figure 1A). Plant height for plants fertilized with briquetted NPK 23-10-5 without micronutrients was similar to that of plants fertilized with granular NPK 23-10-5 without micronutrients. Grain yield ranged from 1.1 t/ha to 4 t/ha, with a mean of 3 t/ha. Plants fertilized with granular NPK 23-10-5 and granular NPK 23-10-5+P+S+K had the highest grain yield, which was significantly greater than all the other treatments and the control (Figure 1B).

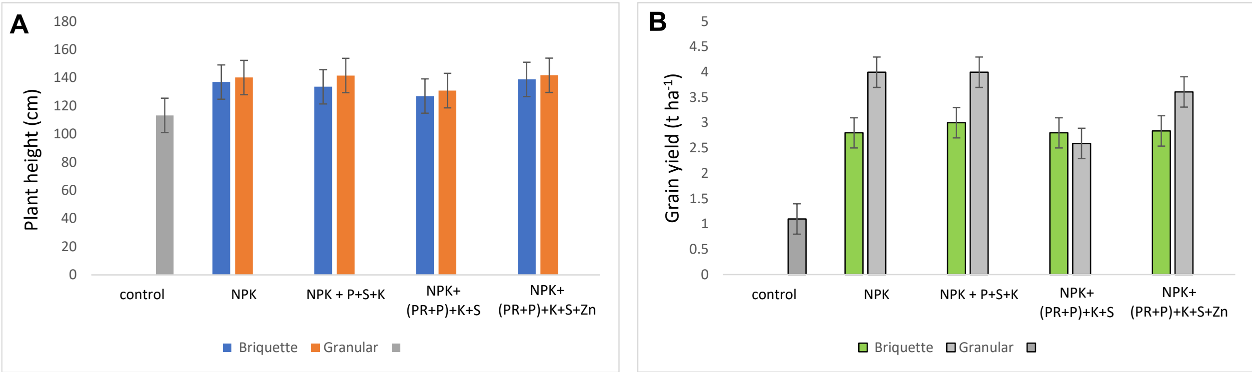

Figure 1. Effect of fertilizer application on plant height and grain yield of maize.

Conclusion and Recommendations

A significant treatment effect was observed for plant height, stem diameter, chlorophyll content (SCMR), cob diameter, cob length, grain yield, and 1,000-seed weight. Application of NPK 23-10-5 and NPK 23-10-5+P+S+K in the form of granules resulted in the production of the highest grain yield, which was significantly greater than the yield obtained from plots treated with each of the briquetted compound fertilizers. Briquetting did not have any significant effect on stem diameter, leaf area, cob diameter, or cob length compared to the granular fertilizer treatments. However, since the actual weight of briquettes was on average 2.2 grams instead of the anticipated 3.4 grams, the total application rates of nutrients in the briquettes was significantly lower. Since the results shown are from a single season's study, multi-locational trials should be conducted to validate these findings.

Comparative Performance of Granular and Briquette Fertilization in Maize Production at Kudula in Northern Ghana

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Background

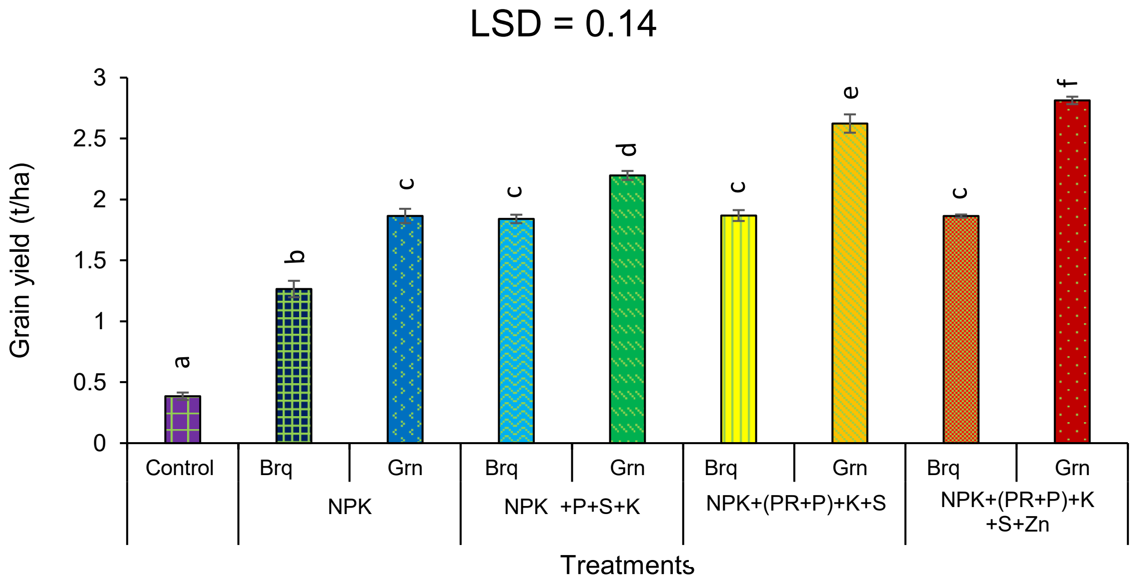
Maize is consumed directly in underdeveloped countries, where it is a staple food for over 200 million people. Agriculture in Africa faces a major problem in overcoming low crop output caused by reducing soil fertility due to nutrient mining and low input utilization. To prevent volatilization and runoff or leaching, fertilizers must be buried. There have been studies on briquette use, i.e., granular fertilizers compressed into small particles, for cereal fertilization in recent years. However, there have been few research studies that compare the relative performance of similarly formulated granular and briquette fertilizers on the same field. Findings from such a study are essential to inform the comparative performance of granular and briquette fertilizers in maize production systems.

Methodology

The experiment was conducted at Kudula in the Northern Region of Ghana during the 2021 cropping season. The maize variety used was Wang-Daata. A plot size of 5 x 5 m was used for this trial. Treatments were tested in a randomized complete block design, with four replications. Treatments included briquetted NPK 23-10-5, briquetted NPK 23-10-5+P+S+K, briquetted NPK 23-10-5+(PR+P)+K+S, briquetted NPK 23-10-5+(PR+P)+K+S+Zn, granular NPK 23-10-5, granular NPK 23-10-5+P+S+K, granular NPK 23-10-5+(PR+P)+K+S, granular NPK 23-10-5+(PR+P)+K+S+Zn, and a control plot with no fertilization. All fertilizer applications were done with the deep placement method. Five plants in each plot were randomly tagged, taking into consideration the border effect of each plot. Data on growth and yield parameters were analyzed at a 5% probability level.

Key Findings

Granular NPK+(PR+P)+K+S+Zn obtained a 51% increase in grain yield (0.9 t/ha) compared to the yield of the briquette (1.9 t/ha). Briquetted NPK+P+S+K, briquetted NPK+(PR+P)+K+S+Zn, granular NPK, and briquetted NPK+(PR+P)+K+S were statistically similar in yield. The control treatment had the lowest grain yield (0.4 t/ha) (Figure 1).



Brq = briquetted and Grn = granular.

***Figure 1.** Comparative maize grain yield of briquetted and granular fertilizers of similar formulation in northern Ghana.*

Conclusion and Recommendations

The findings demonstrated that granular fertilization may be more productive with the deep placement method than briquette fertilization for maize production. However, since the actual weight of briquettes was an average of 2.2 grams, instead of the anticipated 3.4 grams, total nutrient application rates of briquettes was significantly lower. These merits conducting trials at multiple locations to confirm findings of this study and to capture the spatial variability of the impact of the treatments on maize productivity.

Effectiveness of Neem Materials and Biochar as Nitrification Inhibitors in Reducing Nitrate Leaching in a Compost-Amended Ferric Luvisol

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Background

Nitrate produced after mineralization from compost may be prone to leaching, especially in tropical sandy soils, because of an increased rate of nitrification and the porous nature of such soils. Thus, during periods of heavy rainfall, nitrate may be leached, resulting in a low N use efficiency and some environmental issues as well. Inorganic nitrification inhibitors are costly and mostly unavailable in Ghana. The use of simple but effective local materials as nitrification inhibitors is therefore a priority area of research. Two such materials may be neem materials and biochar. Neem materials can control nitrate production by suppressing nitrifying bacteria due to the possession of antimicrobial properties. Biochar has also been shown to hold onto ammonium in the soil, temporarily making it unavailable to nitrifying bacteria. This work therefore seeks to determine the efficacy of some neem materials and biochar as nitrification inhibitors and their influence on nitrate leaching.

Methodology

In preliminary studies, (1) pot incubation was conducted for 60 days to estimate the nitrification rate after amendment with manure, compost, and NH_4Cl as the N sources (150 kg N /ha) in one set and neem seeds, bark, and leaves (1.25 µg azadirachtin/g) in another set, using nitrate concentrations. Azadirachtin extracted by methanol was determined using LC-MS. (2) Ammonium sorption and desorption capacities of sawdust, rice husk, and groundnut husk biochar were determined using various ammonium concentrations prepared from $(NH_4)_2SO_4$ solution. In the main studies, pot incubation with compost as the N source but treated with milled neem seeds or bark (1.25 µg azadirachtin/g) or sawdust biochar (20 t/ha) was conducted for 60 days, where nitrification inhibitions using nitrate concentrations were determined. A leaching experiment in columns packed first with subsoil and then topsoil with similar treatments and maize sown was then conducted to determine the amount of nitrate in leachates.

Key Findings

A high rate of nitrification was recorded in manure- and compost-amended soils, representing half the rate in the standard (NH_4Cl). The highest concentration of azadirachtin was recorded in the seeds (3.92 mg/g) and very low concentrations in the leaves (0.030 mg/g) and bark (0.049 mg/g). The sawdust biochar had the highest ammonium sorption and desorption capacity. These properties of neem seeds and sawdust biochar resulted in high nitrification inhibition in the soil.

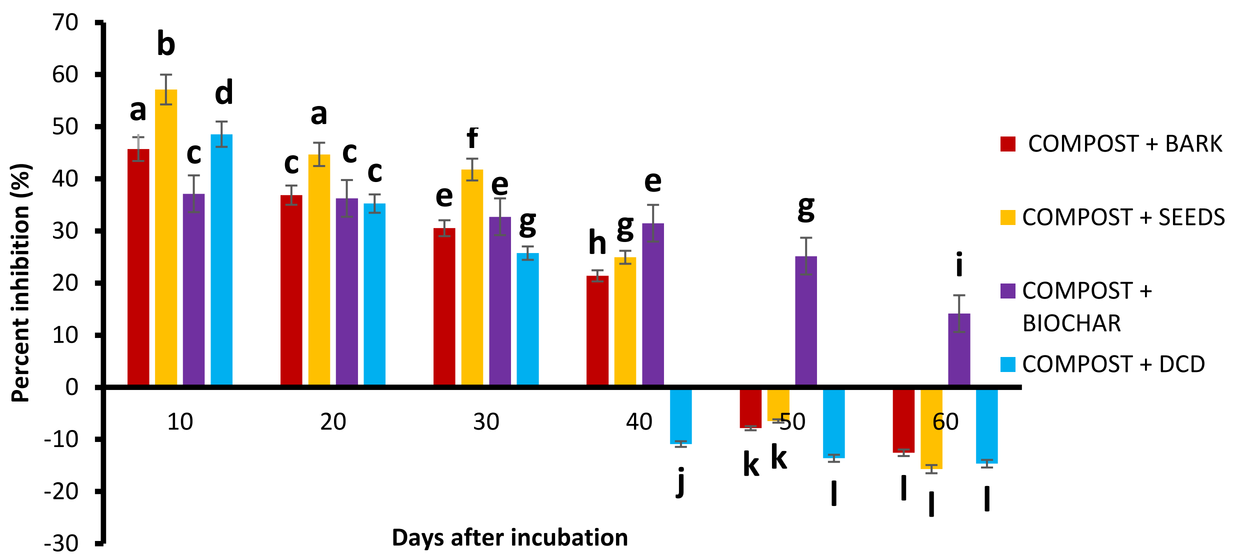

Figure 1. Percentage nitrification inhibition after amendment with time.

The high inhibition explains the average reductions of 72% (first leaching) and 63% (second leaching) nitrate leached from amended soils, subsequently resulting in better crop performance.

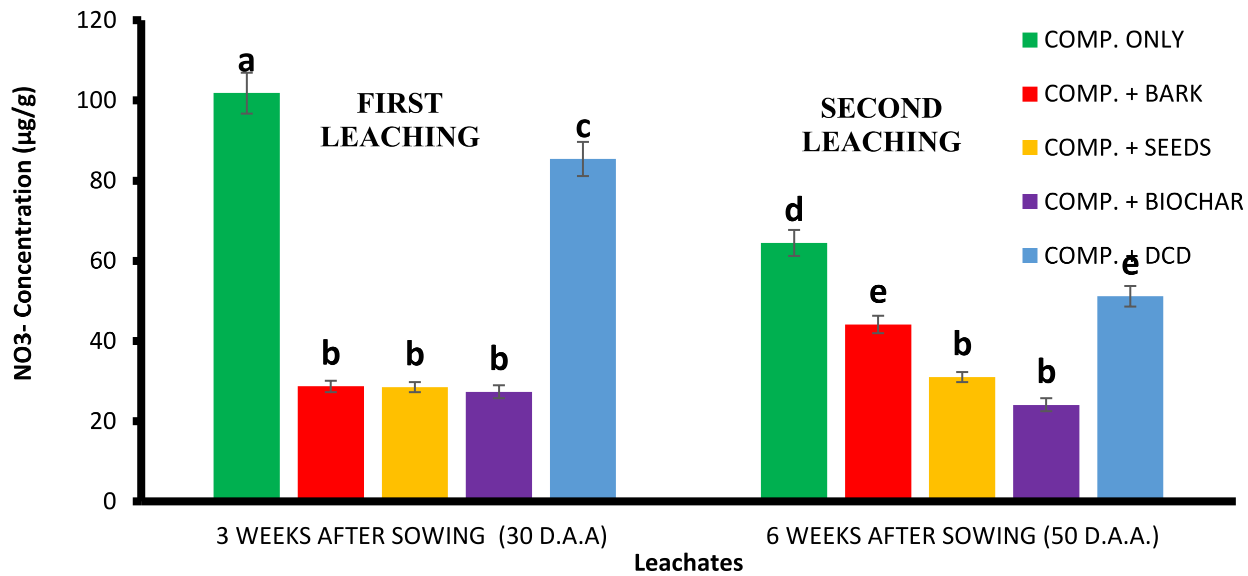

Figure 2. Nitrate concentration in leachates from first and second leaching.

Conclusion and Recommendations

- High potential nitrification rates exist in manure and compost amended soils hence, the need to consider possible ways of controlling nitrate leaching.
- The ratio of azadirachtin in neem seeds to leaves or bark is about 1:80.
- Sawdust biochar was the best among the three biochar types to be used for the purpose of ammonium sorption and desorption.
- For nitrification inhibition, neem leaves may not be appropriate because of the high mineralizable N.

- Neem seeds are recommended as a nitrification inhibitor in the soil within 40 days after amendment and may be used with short-duration crops, such as some cereals, vegetables, and legumes.
- For a longer period of nitrification inhibition in the soil, sawdust biochar is recommended and may be used with long-duration crops, such as tree crops.
- Neem seeds and sawdust biochar amendments are recommended for nitrate leaching reduction to result in higher crop performance.

Estimating Nitrogen Mineralization and Availability in Biochar-Manure Compost-Amended Soils using Alkaline Hydrolysis

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Background

The ability to predict the amount and timing of plant-available nitrogen (N) from organic amendments is germane for synchronizing N release with plant demand. This study compared the results from a recently proposed alkaline hydrolysis methods with: (i) long-term N mineralization under standard laboratory conditions, and (ii) actual N uptake from soils receiving biochar-manure composts (BMCs) of varied C:N ratios in a six-week greenhouse study. The alkaline hydrolysis procedure is based on direct steam distillation of BMC-soil mixtures treated with 1M NaOH or KOH, with the distillate collected in boric acid and analyzed for NH_4^+-N at 5-minute intervals for a total of 40 minutes.

Methodology

Nitrogen mineralization from the BMCs was measured in a 26-week incubation study following the procedure described by Stanford and Smith (1972). Duplicate samples of BMCs were placed in a leaching column, and at every leaching, 75 mL 0.05 M $CaCl_2$ and 25 mL of N-free nutrient solution was used. The leachate was then taken and distillation was done. The procedure described by Dodor and Tabatabai (2019) was used for the alkaline hydrolysis organic nitrogen. Briefly, 1 g of BMC was placed in distillation flask and 20 mL of 10 M NaOH or KOH was added. The mixture was direct steam distilled and the NH_3-N liberated was collected in 5 mL of 5% boric acid, which was changed successively every 5 minutes for a total of 40 minutes and titrated with 0.001 M HCl. The cumulative N mineralized/hydrolyzed was fitted to the first-order exponential equation to determine the potentially mineralizable N (N_0) and an analogous potentially hydrolyzable N (N_{max}) for the BMCs. Nitrogen uptake by maize was evaluated in a six-week pot experiment in the greenhouse.

Key Findings

Generally, N mineralization increased sharply during week 10, followed by a steady decrease thereafter until the end of the 26-week incubation period. The shapes, trends, and patterns of N mineralization for the other organic amendments were similar and fall between those shown in Figure 1.

The pattern of N hydrolysis by the two alkaline reagents in Figure 2 shows that there was an initial high rate of organic N hydrolysis by the two alkaline reagents, which declined to a low constant rate after 20 minutes of steam distillation.

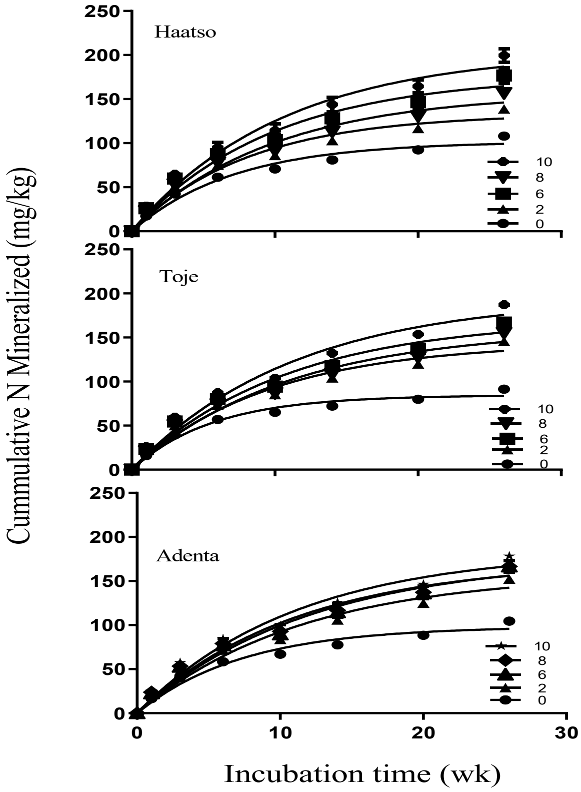

Figure 1. Pattern of the cumulative amount of N mineralized during the long-term incubation period in five of the soil-compost mixtures.

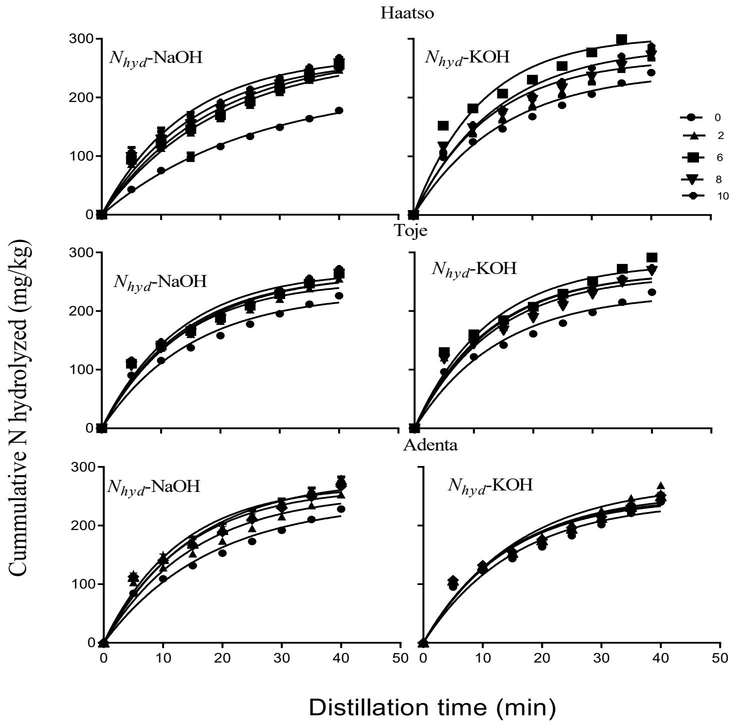

Figure 2. Cumulative N hydrolyzed with time of distillation using NaOH and KOH in five of the organic amendments.

The results showed that N_0 and N_{max} values differed among the BMCs, indicating that the chemical composition of the BMCs affected their reactivity and decomposability. Estimated N_{max} values were significantly correlated with N_0 (p = 0.023) and N uptake by maize (p = 0.005), indicating that Na OH hydrolyzable ON can be interpreted broadly for both N mineralization process and soil fertility assessment. Differences in the amount of N mineralization/hydrolysis may be because of differences in methods of hydrolyzing N, incubation conditions (e.g., temperature, duration), and/or the characteristics and composition of the amendment materials.

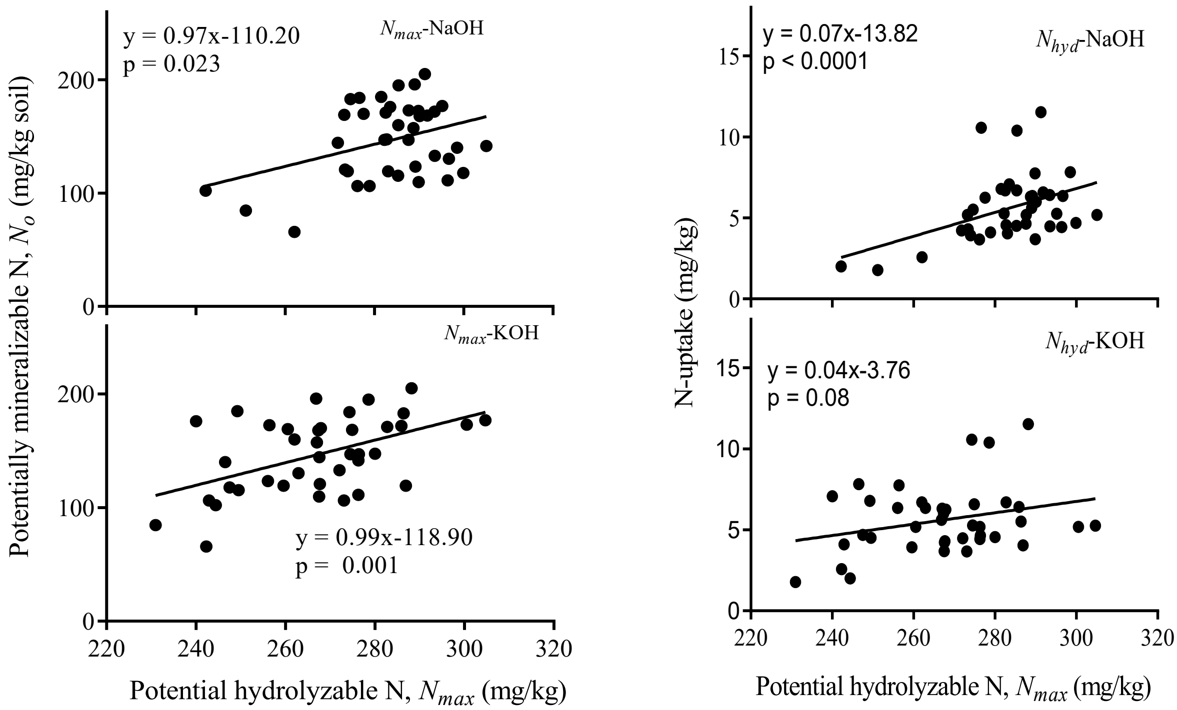

Figure 3. Correlation between N_0 and N_{max} values.

Conclusion and Recommendations

Since the alkaline hydrolysis procedure is relatively simple and offers a time-effective surrogate approach for predicting N mineralization and supplying capacity in BMC-amended soils, it should be considered as a rapid test for estimating N mineralization potential and availability in compost-amended soils.

Tillage Management and Soil Amendments Impact on Soybean Growth and Productivity in the Guinea Savannah Ecology of Ghana

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Background

Soybean contains high protein (42-45%) and oil (20-25%) content and has increasingly become an important cash crop in Ghana. Using appropriate soil management practices, such as conservation tillage and soil amendments, can help increase the yield of soybean for improved food and income security among farmers. Conservation tillage practices, such zero tillage with crop residues or organic matter, promotes better soil aggregation, improves soil water retention capacity, enhances soil carbon sequestration, increases soil microbiological properties, and reduces soil erosion. Soil amendments such as rhizobium inoculants and phosphorus fertilization also enhance effective nodulation and symbiotic nitrogen fixation process in soybean, thereby increasing yield. Therefore, this study was carried out to explore the effect of tillage and soil amendment practices on growth, symbiotic effectiveness, and yield of soybean.

Methodology

The experiment was conducted for two seasons (2020 and 2021) at the CSIR-Savanna Agricultural Research Institute located at Nyankpala in the Guinea Savannah agroecological zone of Ghana. It was laid out in a split-plot design and replicated four times. The main plot consisted of two tillage systems (conventional till and no till), while the sub-plot was made up of three soil amendments (rhizobium inoculant, phosphate rock, rhizobium inoculant + phosphate rock) and the control. At the R4 stage, 10 plants were sub-sampled from each plot and were assessed for nodulation. The plant biomass and nodules were subsequently oven dried and weighed to give the nodule and shoot dry weights. Data were also collected on the leaf area, leaf area index, plant height, pod load, and grain yield. Analysis of variance was carried out using GenStat software (12^{th} edition), and the least significant difference at 5% probability was used for mean separation.

Key Findings

Soybean grain yields under no tillage significantly increased yield by 29.7% and 23.7% compared to conventional tillage in 2020 and 2021, respectively (Figures 1 and 2). This could be due to improved soil water retention capacity and increased soil microbiological properties compared with conventional tillage. Application of rhizobium inoculant + phosphate rock resulted in the significantly highest grain yield for both the 2020 and 2021 cropping seasons (Figures 1 and 2). This indicates that phosphorus can enhance the development of more roots and nodules as a result of the application of the inoculants, which eventually supports biological nitrogen fixation for vegetative growth and increase in yields.

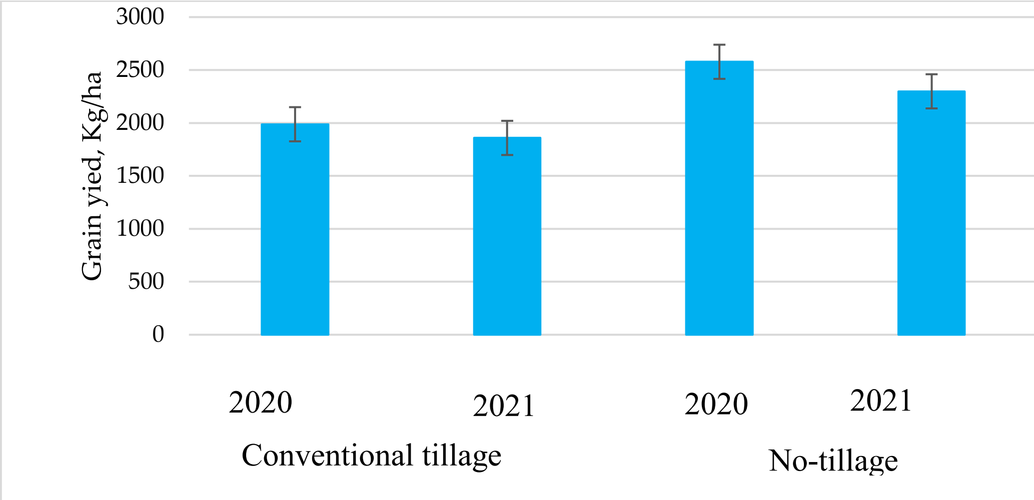

Figure 1. Effect of tillage systems on grain yield of soybean in 2020 and 2021 cropping season.

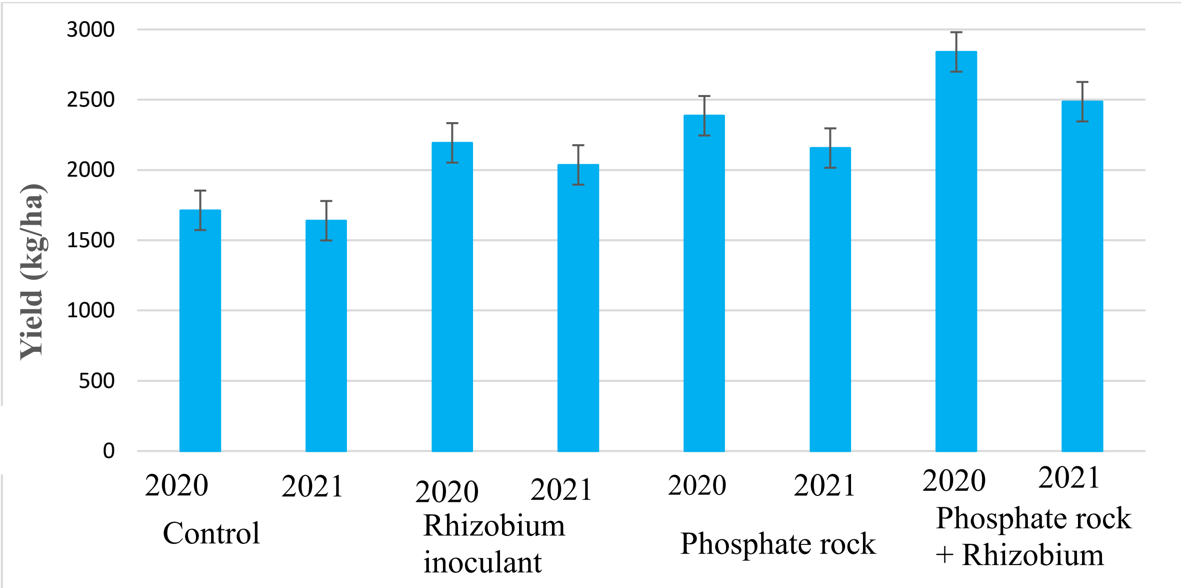

Figure 2 Effect soil amendments on grain yield of soybean in 2020 and 2021 cropping season.

Conclusion and Recommendations

Tillage systems and soil amendments significantly influenced most of the parameters measured in both 2020 and 2021 cropping seasons. The interaction effect between tillage systems and soil amendments was insignificant ($p > 0.05$) for all parameters measured except biomass, leaf area, number of plants established (two weeks after planting) in 2020 and plant height in 2021. Apart from leaf area and number of nodules per plant in both 2020 and 2021 cropping seasons, no-till resulted in high biomass, nodule weight per plant, number of pods per plant, and grain yield. Integration of rhizobium inoculation and phosphorus fertilizer application enhanced grain yield compared to rhizobium inoculation or phosphorus fertilizer alone. Therefore, adoption of no-till and integrated use of rhizobium inoculation and phosphorus fertilizer application by farmers is recommended to improve the growth and productivity of soybean.

Where Are the Fertilizers Going? An Emerging Picture of Soil Fertility Management Among Smallholder Farmers in Northern Ghana

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Background

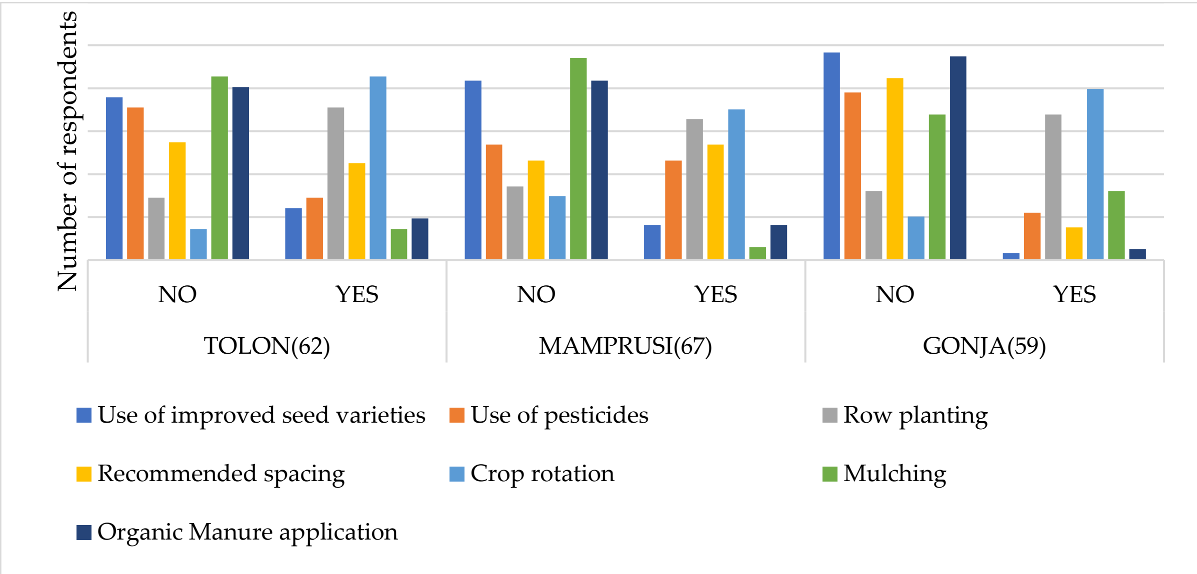
Fertilizers constitute important inputs for crop production. Their use is critical for enhanced crop yields and maintenance of soil fertility. Nonetheless, the use of fertilizers among smallholder farmers in the Northern Region of Ghana remains low due to high costs. Historically, the fertilizer application rate in the region has been below the Ministry of Food and Agriculture's recommended rate. More nutrients are mined from the soils than are replenished through organic and mineral nutrient sources. Maintaining the productive capacity of soils in smallholder farming systems is critical for sustaining the livelihoods of these farmers and their households and ensuring food security. This research seeks to understand the behavior and decision-making processes of smallholder farmers with respect to soil fertility management, and it is important in contributing scientific knowledge to addressing the implementation gaps reported in several agricultural interventions.

Methodology

In an exploratory study in 2021, 188 smallholder farmers from Gonja West, Tolon, and West Mamprusi districts were interviewed to obtain insight into their farming practices. The survey provided insight into farm structure, land use and history, farm management activities, and labor requirements. Farmers' perceptions and knowledge on soil fertility management and farmers' decisions on fertilizer use and application methods were also captured. Other key variables, such as farmers' access to extension services, membership in farmer-based organizations, farm investment, and production strategy, were also collected. Descriptive statistics in Stata and Microsoft Excel were performed to characterize the farmers according to implementation of good agronomic practices and the use of fertilizers. The initial results from the exploratory studies informed the design of an action research aimed at unraveling the optimal nutrient management and crop production strategies (organic manure, mulching, NPK, and improved maize varieties) for enhancing on-farm productivity.

Key Findings

Most farmers (69%) interviewed had knowledge of soil fertility management techniques and used fertilizers. Access to fertilizers remained a challenge, with only 11% of fertilizer users having access to the inputs before planting. Farmers mostly evaluated the fertility of their soils by observing certain types of weeds, earthworm activity, soil color, the greenness of the vegetation cover after the first rains, and their crop yields from the previous year. The adoption of good agronomic practices varied across the Northern Region. Few farmers (14%) applied organic manure to their fields, while 17% implemented mulching, perceiving a high to very high effect on soil fertility and crop yields for both practices.



Conclusion and Recommendations

Soil fertility management among smallholder farmers remains a challenge. Although inorganic fertilizer use among farmers was high, the high cost of fertilizers contributed to fertilizer application below the recommended rate. Uncertainties associated with the climate also make the investments in inorganic fertilizers risky for farmers. Too little rain or moisture results in the scorching of plants when fertilizer is applied and too much rain could mean the loss of crop nutrition through leaching or erosion in poorly drained soils, which is usually the state of soils in the Guinea and Savannah agroecological zones of Ghana. This exploratory study uncovered farmers' knowledge and perception of soil fertility management and identified production strategies adopted by farmers for nutrient management. Mulching and organic manure application were perceived as soil fertility management practices with positive effects on crop yield and soil fertility.

Fertilizer Value Chain Development in Ghana: The Views of Actors

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Background

Agricultural productivity and sustainability in Ghana fall short of their potential despite several government efforts to develop the sector. This is partly attributed to inadequate and inefficient use of basic inputs, such as fertilizers and other soil amendments. Fertilizer value chain (FVC) actors are diverse and strive to reach farmers who are even more fragmented and generally operate in dispersed remote areas with poor infrastructural connections, resulting in access difficulties and high prices despite subsidies. Since farmers integrate services from multiple actors to make production decisions, there is a need for investigation into what major actors in the FVC regard as the main challenges in the chain and what joint efforts can be taken to proffer solutions. These suggested joint solutions can be knitted together as a foundation for FVC development. Against this backdrop, this study set out to understand the challenges in FVCs from the perspective of chain actors, and probe for their opinions on what solutions can address those challenges. Based on these, the study assessed the opinions of FVC actors on the ideal type of FVC that could increase fertilizer use among smallholder farmers and what actors can do individually or collectively; their willingness to participate in this ideal chain; and their potential contribution to it.

Methodology

The study used a qualitative data collection method involving key informant interviews to obtain in-depth information from various categories of FVC actors, numbering 42. Issues discussed in the interviews broadly pertained to actor roles, mode of operation, interconnections, and current market models to better understand the current chain. The study further determined how the different chain actors view and frame challenges at different levels of the FVC. Based on these, we elicited actors' opinions on and contributions to a hypothetically ideal FVC. These contributions include actors' suggested roles in the new chain, required collaborations, and the conditions under which they can undertake their new roles and collaborations. Thematic analysis based on resource integration and value co-creation ideas was used to provide a descriptive analysis of the opinions of FVC actors on the challenges and their suggested solutions and contributions to an ideal chain.

Key Findings

Challenges

The key challenges identified by most actors are high prices of fertilizer, low fertilizer quality, and untimeliness of access (Table 1). These lead to limited and inappropriate fertilizer use at high costs. Most of the actors attributed these challenges to bottlenecks in the FVC itself and unfavorable output market dynamics. Organizational and coordination lapses in the fertilizer chain, as well as infrastructural inadequacies, delay the arrival of fertilizer and stifle fertilizer application at the right time. In addition, long supply distances and the number of intermediaries (and their margins) in the supply chain contribute to high retail prices, leading to a high cost of using fertilizers. Along with untimely, inappropriate, and sometimes inadequate application, poor sustainability and general agronomic practices reduce the productivity potential of fertilizers used, while output market risks, particularly unstable prices, limit the return on farmer investments. All these factors discourage reinvestment. Also, there is a limited flow of formal credit into the FVC, especially to micro-level actors such as farmers and local retailers. Where credit is available, lending and repayment conditions are not conducive, and borrowing is not profitable.

Suggested Solutions

FVC actors proposed solutions in providing joint services where possible and introducing new services altogether to address identified challenges (Table 2). These ideas call for FVC development to address the issues holistically. Some of these FVC development solutions require new collaborations, new roles, new service/product delivery strategies, or new actors. For example, due to the vulnerability of smallholder farmers to climate risks, credit providers and other actors suggested the inclusion of crop insurance in credit packages. Already, informal partnerships mirroring value chain development ideas are utilized in a few individual transactions in the chain. This highlights the potential of such a strategy to be developed and invokes a need to investigate whether and how such solutions could be scaled up. Most of the actors are willing to subscribe to FVC development, given that it yields win-win outcomes. An overarching suggestion from non-farmer actors was working with farmer groups rather than with individual farmers due to the convenience. Also, it was found that many actors require capacity building to fully function in a new chain.

Table 1. Challenges in the FVC from chain actors' perspective.

Challenges in the FVC according to actors	High prices	Lateness in supply	Bad quality	Unavailability	Financial constraints	Low output prices	Lack of information on organic fertilizers	Lack of trust	Weak capacity of some actors
Fertilizer blending organizations					✓				
Input dealers (larger sellers and smaller local retailers)	✓		✓	✓	✓	✓		✓	✓
Credit sector (mainly rural banks)	✓	✓				✓	✓	✓	✓
Credit sector (commercial banks)	✓				✓				
Informal finance (local money lenders)	✓	✓				✓		✓	✓
Farm mechanization service providers					✓				✓
District MoFA officers	✓	✓	✓	✓	✓	✓	✓	✓	✓
Value chain development projects	✓						✓	✓	✓
NGOs	✓	✓			✓	✓	✓	✓	✓
Output buyers (aggregators, traders, processors, end user companies)	✓	✓		✓			✓	✓	
Farmers	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 2. Some suggested solutions for value chain development to address challenges in the value chain.

Suggested solutions for value chain development according to actors	Strengthen import capacities and arrangements with government to ensure timely availability	Provide joint input packages (fertilizer, seeds, extension, machine services)	Integrate technical support (e.g., via extension) to ensure sustainability and efficiency in fertilizer use	Create partnerships between credit suppliers and local input suppliers	Utilize buyer contracts to secure output prices	Strengthen the use of digital strategies for disseminating fertilizer access and use information	Form farmer organizations/ cooperatives to facilitate access to support services	Introduce crop insurance and warehousing/ storage services	Provide capacity building for some individual chain actors	Utilize multi-actor platforms for generating input for coordination and trust building
Fertilizer blending organizations	✓		✓		✓	✓				✓
Input dealers (larger sellers and smaller local retailers)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Credit sector (mainly rural banks)			✓	✓	✓		✓	✓	✓	✓
Credit sector (commercial banks)					✓					
Informal finance (local money lenders)				✓	✓		✓		✓	
Farm mechanization service providers		✓	✓	✓	✓		✓		✓	✓
District MoFA officers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Experts (value chain development projects)		✓	✓	✓	✓	✓	✓	✓	✓	✓
NGOs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Output buyers (aggregators, traders, processors, end user companies)		✓	✓	✓	✓		✓	✓	✓	✓
Farmers		✓	✓	✓	✓	✓	✓	✓	✓	✓

Conclusion and Recommendations

Given the findings of the study, the following key conclusions and recommendations are drawn:

- Most chain actors acknowledge the important contribution of downstream output market dynamics to set conducive preconditions for sustainable fertilizer use. Therefore, we recommend that a system-wide approach that integrates output markets should be adopted to develop the FVC.
- The FVC comprises contributions from multiple actors with different interests. We recommend that smallholder feedback on multi-actor contributions be prioritized in a FVC development design. The Fertilizer Platform Ghana is a good avenue for multiple actors to receive and deliberate on feedback in a farmer-centric manner.
- While actor collaborations are key to addressing some of the FVC issues, some actors require additional capacity building to properly function. For key individual actor groups whose capacities cannot be improved through chain partnerships, government and development partners with an interest in agricultural value chains can provide them with training and technical support.
- Since most actors prefer to work with farmer groups, farmer-based organizations should be strengthened to increase smallholders' ability to pull resources together and to facilitate vertical collaborations. Leaders of farmer-based organizations and cooperatives can be trained on group building strategies.
- Finally, we recommend service-oriented business solutions in the new chain. That is, products provided by participating actors should include services that enhance the productivity of the fertilizer.

Approaches for Increasing Phosphorus Use Efficiency: The Case of Chitosan, Tripolyphosphate, and Zinc

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Background

A significant leap in food production in sub-Saharan Africa can be achieved through intensification of agricultural production, rather than through extensification via increasing the land hectarage under cultivation. Agrochemicals such as fertilizers are critical inputs for agricultural intensification. Unfortunately, fertilizers such as phosphorus (P) are applied at only about 15% of the recommended rate in Africa, which, when combined with the inherent low use efficiency (<30%) of conventional P fertilizers, results in crop yield gaps in the continent. Accordingly, strategies are required to improve plant use efficiency of P fertilizers.

Methodology

Formulating P with biopolymers or essential metals, such as zinc, is considered critical for developing fertilizers with enhanced P use efficiency. To that end, an unusual P source, tripolyphosphate (TPP), was used together with chitosan biopolymer, with and without Zn fortification (ratio chitosan:TPP = 6:1 [Zn = 2% TPP]), to formulate P fertilizers following the facile wet chemistry procedure. The products were characterized and evaluated for their potential to prevent P leaching loss in soil and to support wheat growth and uptake of P into the plant, compared to conventional P (monoammonium phosphate [MAP]) and phosphate rock.

Key Findings

Composite P-fertilizer products were formulated from TPP using chitosan, with and without Zn (2% by weight of TPP) fortification (Figure 1). Compared to MAP (conventional fertilizer), the formulation without Zn reduced P leaching in soil by 86-97% over a 72-hour period, with 94% of the reduction occurring within 24 hours. Zn fortification of the chitosan-TPP composite maintained reduced P leaching of up to 94% throughout the study. Leaching losses from the products mimicked those of phosphate rock, which was no less than 99% lower than that of MAP at the peak leaching time. Relative to MAP, P uptake into wheat grain was 13% and 10% higher for the products without and with Zn amendment, respectively. Grain yields resulting from the products were 20% and 28% higher with the products without and with Zn, respectively, than that from MAP (Figure 1).

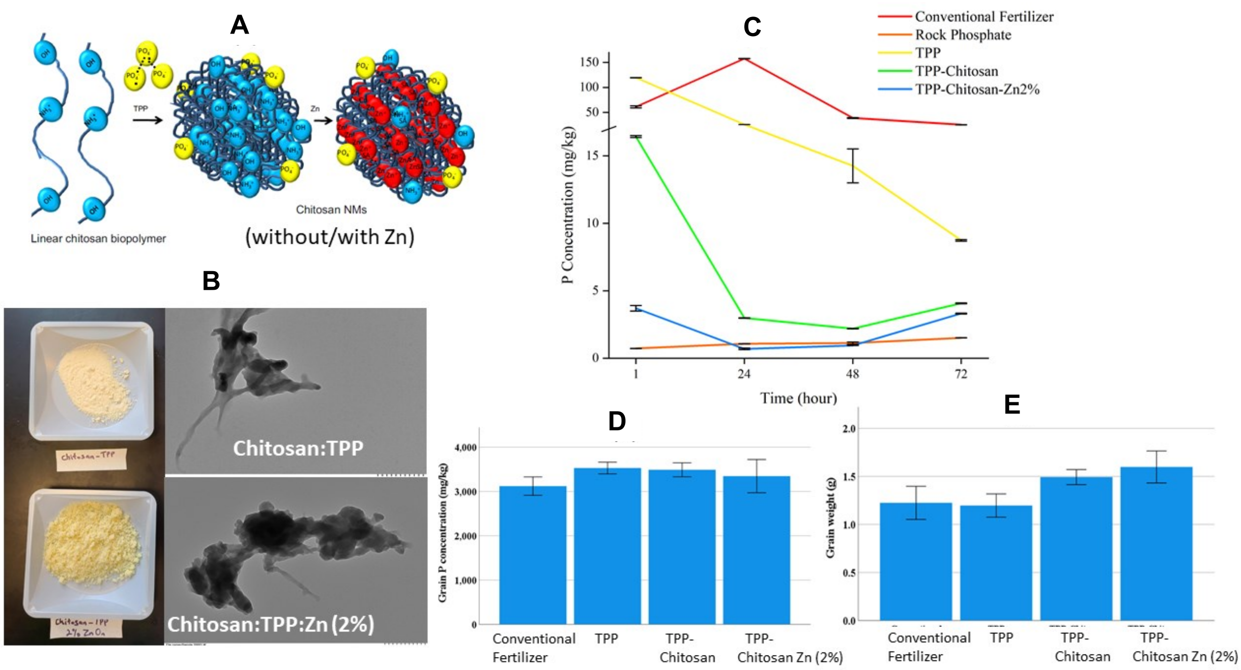

Figure 1. Development of chitosan:phosphorus:Zn (2%) fertilizers using tripolyphosphate and Zn oxide. (A) A facile conceptual depiction of the formulation chemistry; (B) the developed products (solid powders [left] and microscopic images [right]); (C) evaluation of effects on phosphorus leaching; (D) effect on P uptake by wheat grain; and (E) effect on plant reproductive performance (grain yield) by product, compared to conventional phosphorus fertilizer (MAP).

Conclusion and Recommendations

The findings indicate that chitosan-formulated P fertilizers can provide P for crop production while reducing P loss in the soil. Reduced P loss can provide residual soil P for future cropping. Viewed from a broader perspective, research on improving P use efficiency by using locally available natural resources, such as chitosan, and repurposing unusual P sources, such as TPP, can contribute to sustaining plant production in African settings, while minimizing the negative environmental and economic ramifications of nutrient use inefficiencies.

Light Use Efficiency Crop Model Effective for Identifying Driving Factors for the Maize Yield Gap in Ghana

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Background

Maize, the number one staple crop in Ghana, represents 50% of total cereal production and provides 25% of the country's caloric intake. However, observed yields are low at an average of 1.9 t/ha compared with an achievable yield of 5.5 t/ha. Bridging this high yield gap is necessary for the country to achieve food security. This study aims to quantify and explain the yield gap of maize using a light interception and utilization crop model (LINTUL-1). The use of LINTUL-1 allowed a simulation of the potential yield of maize and helped to analyze the yield gap calculation. The analysis also allowed identification of the relevant factors driving the yield gap to help prioritize research and interventions toward improved maize yield.

Methodology

Field experiments using 14 different fertilizer combinations were conducted in the Guinea Savannah and Transitional agroecological zones. The treatment with the highest yield was considered for LINTUL-1 calibration. The calibrated LINTUL-1 model was used to simulate the potential yield of maize in different experimental sites. To calculate the yield gap, the observed yield obtained in different treatments in the studied sites was subtracted from the simulated potential yield for the same sites. A multiple linear regression was fitted based on the AIC-stepwise selection method to identify the underlying factors (e.g., rainfall, soil variables, and fertilizer application) of the yield gap. In addition, using the weather data from different selected locations based on the land use map of the whole country, a potential yield map for maize in Ghana was developed.

Key Findings

From the estimated LINTUL-1, the simulated potential yield was between 5.5 t/ha and 6.9 t/ha (Figure 1), which is higher than the average observed yield of 2.2 t/ha. The average yield gap without fertilizer application was 72.8%, while it was 60.5% with fertilizer application. Soil organic matter, soil water-holding capacity, and pH are the major determinant of the yield gap (Table 1). Generally, the ability of soil to keep water is important due to the erratic rainfall in the studied area.

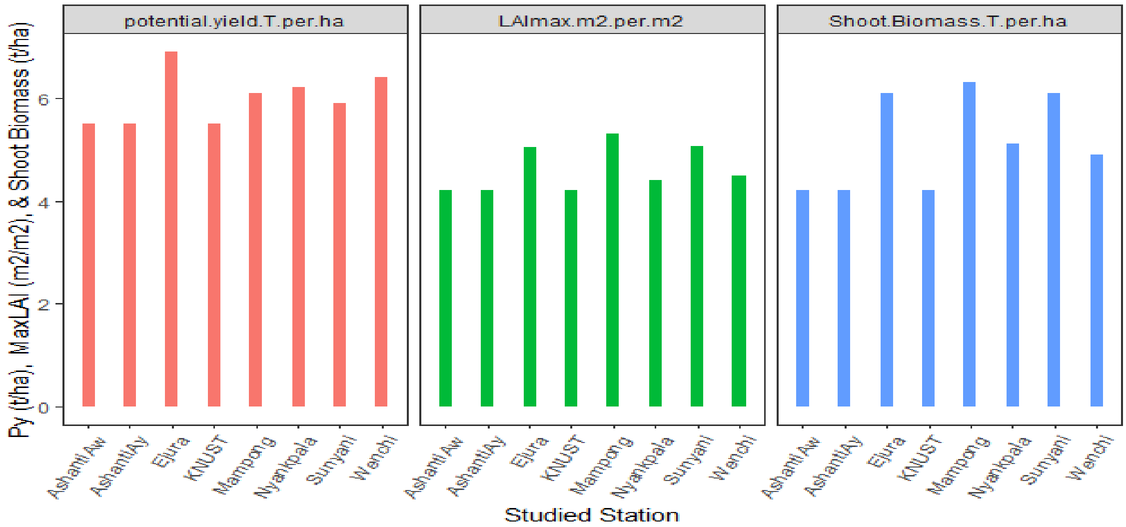

Figure 6. Simulated potential yield, maximum leaf area index, and shoot biomass using LINTUL-1 in eight different study stations.

Table 3. Factors influencing maize yield gap in the studied area.

Covariate	Estimate	Std. Error	T Value
Root zone depth	-36.83***	4.35	-8.47
Precipitation	-12.44***	0.86	-14.46
Nitrogen applied	-12.73***	1.69	-7.53
Sulfur applied	-15.58*	8.31	-1.88
Iron applied	103.65**	39.31	2.64
Phosphate rock	3.59**	1.57	2.28
Soil pH	565.67***	132.51	4.27
Organic matter	-1364.61***	154.46	-8.83
Soil phosphorus	-2.92***	0.71	-4.1
Water-holding capacity	-302.03***	119.11	-2.54

Note: ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Conclusion and Recommendations

Simulation of the potential yield using LINTUL-1 quantified the yield gap of maize in the study area. Even with the application of fertilizer, the average yield gap was huge, around 3.6 t/ha, i.e., 60.5% of the potential yield. This highlights that the low availability of nutrients in the soil is not the only constraint resulting in the low yield of maize. Instead, edaphic and weather factors were also found to be vital limiting factors for maize yield. For instance, increasing soil organic matter and soil water-holding capacity by 1% could reduce the yield gap by 1.3 t/ha and 0.3 t/ha, respectively. Since maize is produce under rainfed conditions in Ghana, a further study using the LINTUL-2 model for water-limited yield is necessary to provide more precise explanation of observed maize yield gap variability.

Evaluating the Effects of Macronutrients and Zinc (Soil- and Foliar-Applied) Combinations on Grain Yield of Soybean (*Glycine max* L. merr.)

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Background

Soybean contains roughly 35-40% protein and is mostly farmed for human use, with crop leftovers being fed to farm animals or left on the ground to replenish soil nutrients. Studies have revealed that the low soybean yields in sub-Saharan Africa may be related to poor-performing cultivars and a lack of long-term rhizobia inoculant and fertilizer use. In particular, phosphorus (P), along with organic matter, is said to be inadequate in soils for growth and development. P fertilizer products with various rates of P release could prevent P fixation in soils and could deliver P to the soybean crop timelier. Also, zinc aids in nitrogen metabolism, the synthesis of the amino acid tryptophan, starch metabolism, plant flowering, and fruit set. These physiological processes suggest that soybean yields could be improved through the application of macro- and micronutrients.

Methodology

The experiment was carried out during the 2021 farming season on the Planting for the Future Garden experimental field of the University for Development Studies, Nyankpala, in the Guinea Savannah agroecological zone of Ghana. The experimental fields were laid in a randomized complete block design, with seven fertilizer treatments and one control, which were replicated four times. The treatments used were: (i) control + inoculant (without treatment), (ii) NK + DAP + inoculant 1, (iii) NK + PR + inoculant, (iv) NK + DAP + inoculant 2, (v) NK +DAP + inoculant + Zn (foliar-applied), (vi) NK + DAP + RP + inoculant 1, (vii) NK + DAP + PR + inoculant 2, and (viii) NK + DAP + inoculant + Zn (soil-applied). Data collected were subjected to analysis of variance, and treatment means were compared using the least significance difference (LSD) at 5% probability level ($p < 0.05$).

Key Findings

The availability of nitrogen, phosphorus, and potassium nutrients in the soil is crucial for growing soybean, since it has high impact on the plant's growth and output. All the growth and yield parameters of soybean in the study were significantly affected by the fertilizer combinations. There was a significant grain yield difference between control and all the treatments except NK + PR + inoculant, which was insignificantly different from the control.

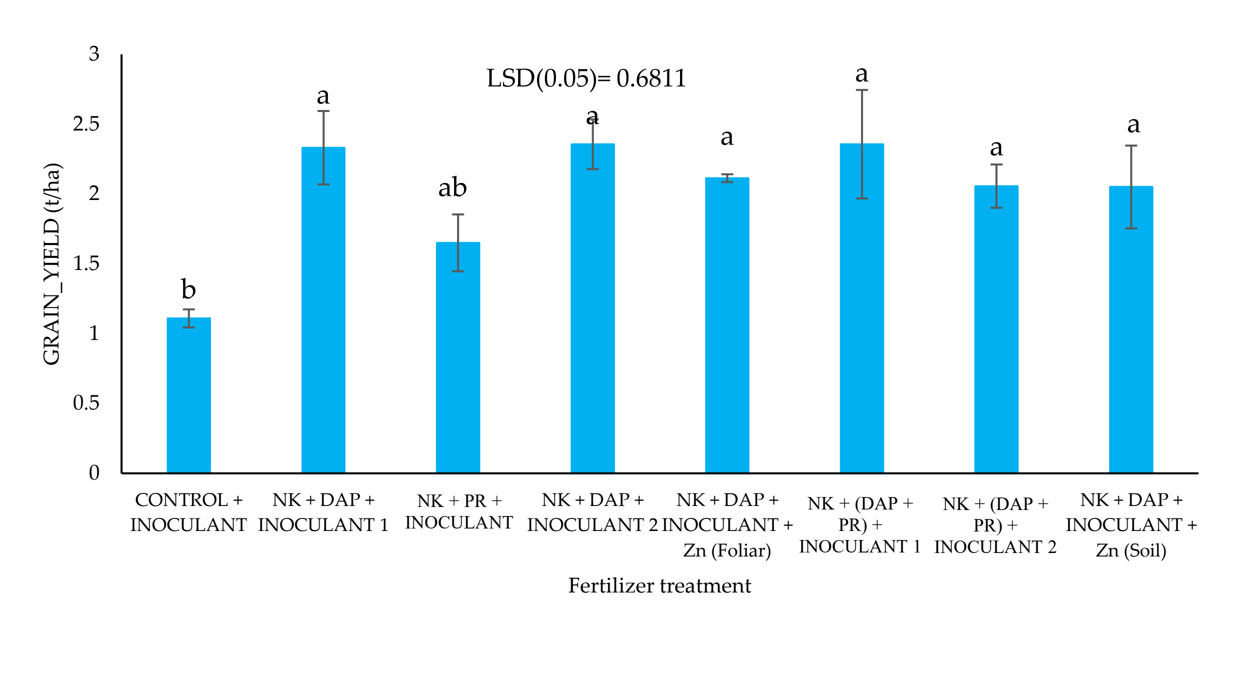

Figure 1. Soybean grain yield by fertilizer treatment.

Conclusion and Recommendations

As a non-traditional and non-staple commercial crop, soybean cultivation gives substantial opportunity for smallholders but also comes with numerous obstacles. The results reveal that, in addition to inoculants, there is a need for fertilizer nutrients to increase yield. Yet, this research did not unveil differences in soybean yield due to different P fertilizer products.

FERARI

FERTILIZER RESEARCH & RESPONSIBLE IMPLEMENTATION

FERARI is an international public-private partnership that builds science-based approaches to site-specific fertilization for widespread adoption by farmers in Ghana for improved food and nutrition security. This calls for a transformation of the fertilizer and food systems that must be driven by evidence-based agro-technical perspectives embedded in multi-stakeholder processes.

To support this transformation, the following institutions have partnered to implement the Fertilizer Research and Responsible Implementation (FERARI) program:

- International Fertilizer Development Centre (IFDC)
- Mohammed VI Polytechnic University (UM6P)
- OCP Group
- Wageningen University and Research (WUR)
- University of Liège (ULiège)
- University of Ghana (UG)
- University for Development Studies (UDS)
- Kwame Nkrumah University of Science and Technology in Kumasi (KNUST)
- University of Cape Coast (UCC)
- University of Energy and Natural Resources (UENR)
- Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) College of Agriculture Education
- Council for Scientific and Industrial Research in Kumasi (CSIR-SRI) and in Tamale (CSIR-SARI) and its subsidiary (CSIR-SARI-Wa)

FERARI operates in conjunction with the Planting for Food and Jobs program of the Government of Ghana (GoG) to embed development efforts into national policy priorities to reach impact at scale. It trains five Ph.D. and two post-doctoral candidates and dozens of master's-level students in building the evidence base for its interventions.

FERARI conducts hundreds of fertilizer response trials on maize, rice, and soybean, on-station and with farmers, and demonstrates them to farmer groups in the northern and middle belt of Ghana. It conducts surveys among farmers and actors in the value chain to understand the drivers for use of fertilizers and other inputs and the marketing of the produce to enhance farm productivity and income. It helps the GoG to establish a Fertilizer Platform Ghana, and is developing its soil mapping expertise toward an information platform.

The content of this report is the sole responsibility of the authors of the involved institutions portrayed on the front page.

IFDC

Developing Agriculture from the Ground Up