Yield Response of Sorghum to Micronutrient-Fortified Fertilizer in the Savanna Agroecological Zone of Nigeria

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Abstract
Sorghum is an important staple food crop in many sub-Saharan African countries, with Nigeria being a leading producer. However, its productivity is being hampered by soil fertility constraints and inappropriate fertilizer use in the producing states in the savanna agroecological zone of Nigeria. Matching nutrient supply with crop nutrient requirements through site-specific and crop-specific fertilizers could optimize crop yield while reducing nutrient losses to the environment. Thus, a two-season field study was conducted to assess the yield response of sorghum to two Sorghum Specialty Fertilizer Formulations [SFF1 (NPK11:22:21+5%S+0.7%Zn+0.5%B) and SFF2 (NPK14:31:0+9%S+1%Zn+1%B)] produced from soil test recommendations. Both formulations were compared against the widely used NPK 20:10:10 (Control) in a randomized complete block design across three savanna agro-ecologies. Data were collected on stover yield and grain yield using standard procedures and subjected to analysis of variance using the General Linear Model Procedure in SAS. Across two seasons of study, both specialty fertilizers significantly ($p < 0.05$) increased stover yield by 32% (SFF1) and 18% (SSF2) relative to NPK 20:10:10. Similarly, grain yield was consistently higher in SFF1 and SFF2 by 16% and 12% than NPK 20:10:10, even in low soil moisture conditions, with agronomic efficiency being in the order of SFF1 > SFF2 > NPK 20:10:10. Our results show both specialty fertilizers, with low amounts of nitrogen and an adequate supply of potassium (in SFF1) and micronutrients via soil test recommendation, could help farmers increase sorghum productivity while minimizing nitrogen losses under varying agro-ecological zones.

Keywords: Soil fertility; Blanket fertilizer application; Sorghum; Specialty fertilizers, Agronomic efficiency

1. Introduction

Although the food security of many developing countries depends on the resilience of major crops to climatic variability [1], crop production is highly dependent on nutrient inputs in various forms to maintain soil fertility and increase crop yields [2, 3]. Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important staple food crops in the world. It is grown in drought-prone regions in semi-arid zones due to its short duration, fast-growing nature, and high productivity, and it has wide adaptability to varied agro-climatic conditions [4]. Nigeria is one of the leading producers of sorghum, with more than 6 million tonnes of sorghum produced on more than 6 million hectares, at an average production rate of more than 1000 kg per hectare in the year 2018 [5]. One of the major drivers of the sorghum market in Nigeria is increased demand by industries for beverages, cereal, and confectionery products. According to [5], industrial demand for sorghum in Nigeria has grown from 2% in 2009 to about 20% of the total sorghum produced in 2018.

Although there has been a steady increase in sorghum yields and total production, it is not commensurable with the potentials ingrained in the varieties developed by breeders. For example, SAMSORG 47 and 49 released by IAR/ABU were reported to have yield potentials of 4.8 and 2.8 t ha $^{-1}$ respectively [6], which is greater than the estimated yield reported by [5]. These yield gaps are attributed to numerous production factors such as low soil fertility status and inappropriate fertilizer use being some of the most limiting. [7] reported that the current fertilizers in use are blankly applied without appropriate formulation to meet the crop and soil needs, and such practices have been found to be uneconomic and inimical to the environment. Further, [8] averred that improved varieties require more nutrients than traditional varieties which necessitate the revision of fertilizer recommendations used for crops. There is therefore an urgent need to use appropriate sorghum fertilizers formulated from soil testing recommendations instead of the current practice of blanket fertilization that may not be suitable for all soil types and crop varieties. It is against this backdrop that this study was conducted to evaluate the performance of two sorghum specialty fertilizer formulations on the yield of sorghum.

2. Materials and Methods

2.1 Study location and experimental setup

Field trials were conducted during the 2020/2021 (Season 1) and 2021/2022 (Season 2) cropping seasons in three sorghum-producing agro-ecologies (Sudan, Northern Guinea, and Southern Guinea Savanna agro-ecologies) across five states (Kaduna, Kano, Katsina, Kebbi and Nasarawa states) in Nigeria (Figure 1). Land preparation, including clearing and seedbed preparation, was done using standard practices across all the locations, and each sown to two (2) most acceptable and suitable sorghum varieties using the recommended spacing for sorghum on a 4.5 m × 4 m plots sizes in two farms per area. Three (3) fertilizer formulations: NPK 20-10-10 (Control), NPK 11:22:21+5%S+0.7%Zn+0.5%B (Sorghum Specialty Fertilizer Formulation 1, SSF1), and NPK 14:31:0+9%S+1%Zn+1%B (Sorghum Specialty Fertilizer Formulation 2, SSF2) were applied as treatments in a randomized complete block design with three replicates (agro-ecological zones). Fertilizers were split-applied at planting and the balance side-dressed at 5-6 weeks after sowing.

2.2 Soil sampling and analysis

Pre-planting soil samples were collected from each site using an auger at 0 – 30 cm depth for the determination of the baseline status of some soil physical and chemical properties. The soils were sampled by randomly selecting points in the field from which soil cores were taken. About 8–10 points were considered at each site and soil cores were taken and bulked to make composite samples. The bulked soil samples were air-dried and sieved through 2 mm mesh for laboratory analysis. Soil chemical constituents determined

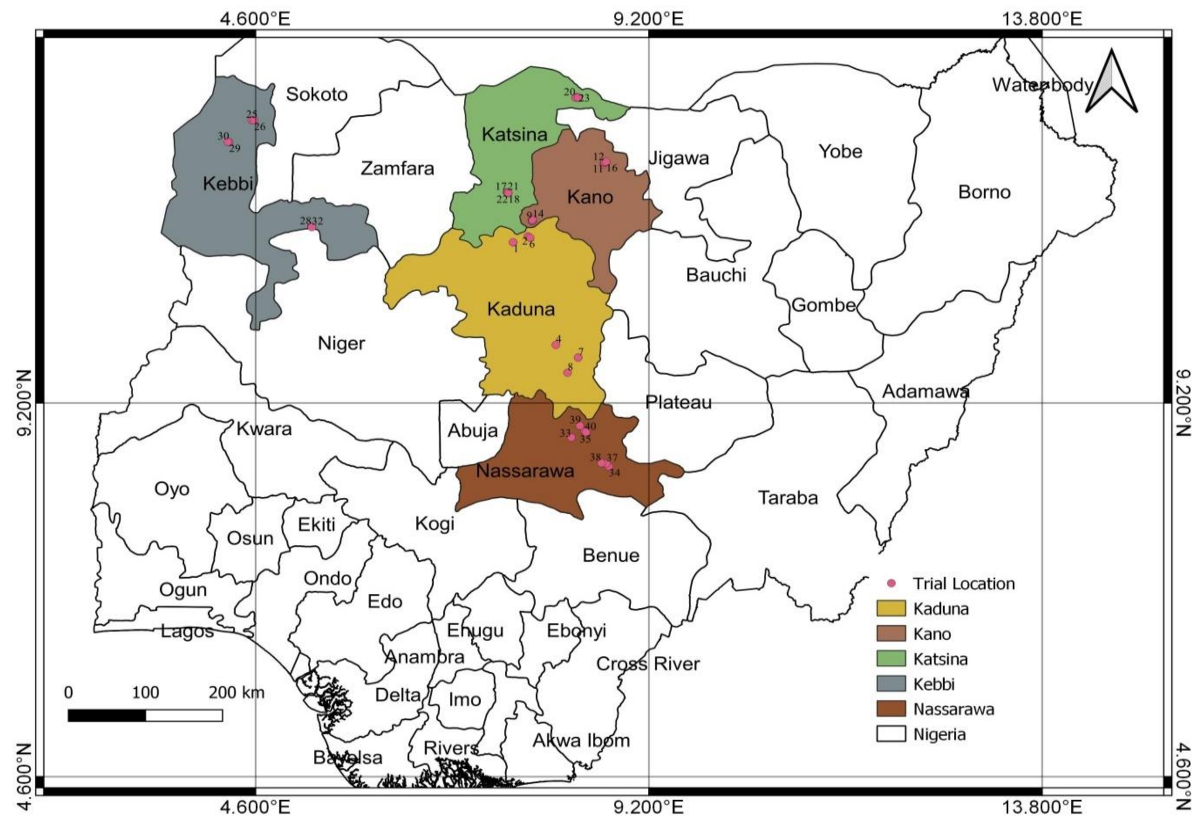

Figure 1: Map of Nigeria showing the states where trials were conducted

were pH, organic carbon, total nitrogen, available phosphorus, electrical conductivity, exchangeable bases (Ca, Mg, K and Na), extractable Fe, Mn, Cu, and Zn. Standard procedures outlined by [9] were used in determining all the mentioned soil properties.

2.3 Harvesting

Harvesting was carried out when the plants had attained physiological maturity. This was done by marking out a net plot of 4 m × 3 m with a plant population of 64 stands per plot. Yield parameters such as grain and stover weight were taken by oven-drying grain and stover samples at 65°C until constant weight was obtained before recording grain and stover yields on dry weight basis. In addition, harvest index (HI) was estimated for all fertilizer types as the ratio of grain yield to the total shoot dry matter yield.

2.4 Data analysis

All data collated were subjected to analysis of variance (F test) using GLM procedure in SAS software. Where the F value was significant at either 0.05% or 0.01%, DMRT was used to separate the means.

3. Results

3.1 Soil properties of the experimental sites

The baseline properties of the soils of the experimental sites are presented in Table 1. The results are typical characteristics of common soils found in the Nigeria's Savannahs, where most soils are derived from Pre-Cambrian crystalline basement complex. The organic matter and total nitrogen contents are low; less than 13 g kg^{-1} for organic carbon and 1 g kg^{-1} for total nitrogen respectively, across the three agro-ecologies. The soils are slightly acidic (average pH of 6.4).

3.2 Grain and stover yield as influenced by fertilizer types

Table 1. Baseline properties of experimental soil in each agro-ecological zone

Properties	Units	Sudan Savanna	Northern Guinea Savanna	Southern Guinea Savanna
pH (H_2O)	–	6.3	6.6	6.4
Org. carbon	g kg^{-1}	2.68	3.86	5.27
Total nitrogen	g kg^{-1}	0.20	0.355	0.475
Avail. phosphorus	mg kg^{-1}	18.3	29.9	12.3
Electrical conductivity	dS m^{-1}	0.03	0.04	0.12
Calcium	cmol kg^{-1}	2.70	3.89	4.30
Magnesium	cmol kg^{-1}	0.74	1.07	1.17
Potassium	cmol kg^{-1}	0.10	0.18	0.14
Sodium	cmol kg^{-1}	0.09	0.17	0.13
Iron	mg kg^{-1}	137.04	158.07	64.61
Manganese	mg kg^{-1}	7.50	11.10	15.79
Copper	mg kg^{-1}	6.82	7.25	6.94
Zinc	mg kg^{-1}	4.53	4.62	5.06

There were substantial ($p < 0.05$) variations in the performances of the fertilizers on sorghum grain and stover yield across two cropping seasons (Figure 2). On average, grain yield was highest in SFF1 and was significantly ($p < 0.05$) higher than the control (NPK 20:10:10) by 16% (Figure 2a). Although SFF1 was statistically at par with SFF2, it was higher in grain yield by 4%. In comparison, SFF2 was also higher than the control by 12%. On the other hand, the average stover yield of sorghum was higher by 32% and 18% in SFF1 and SFF2 relative to the control, respectively (Figure 2b).

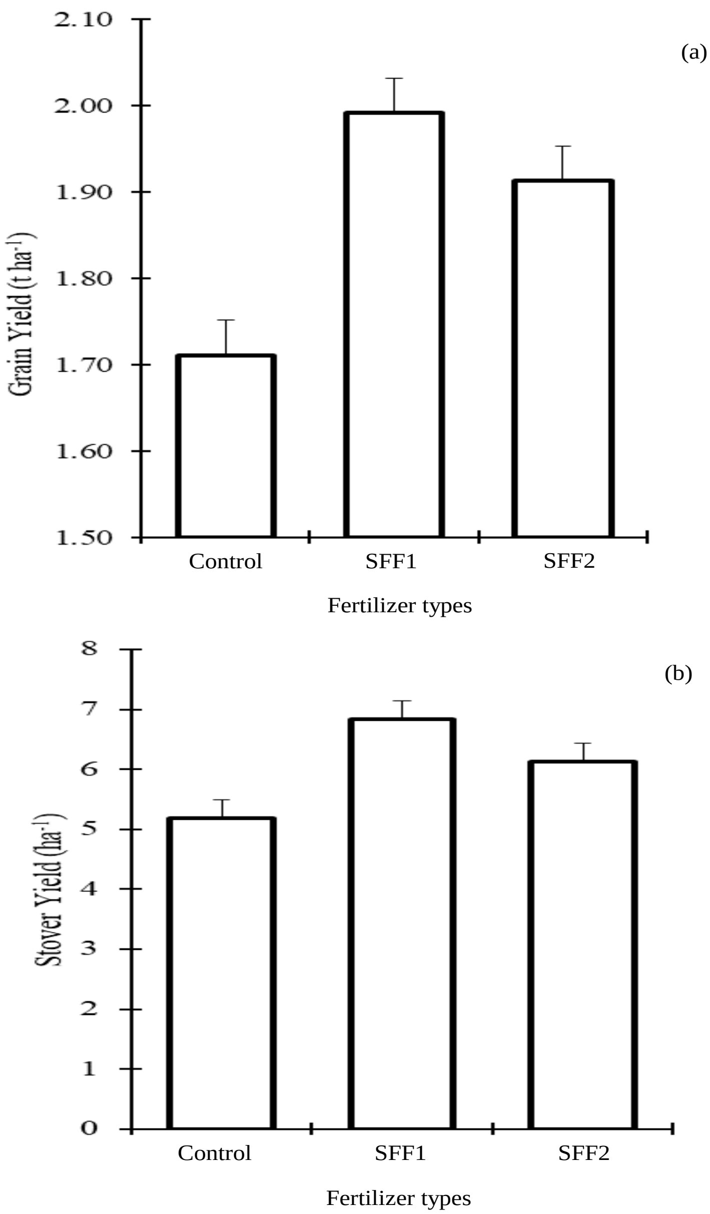

Figure 2. Average (a) grain and (b) stover yield of sorghum as influenced by fertilizer types

3.3 Yield response of sorghum to seasonal variations

Regardless of the nutrient applied and the varieties tested, the results of the combined analysis of the two cropping seasons showed that the yield response of sorghum was better in Season 1 relative to Season 2 (Figure 3). Both the grain and stover yield were significantly ($p < 0.05$) higher during Season 1 by 19% and 31% compared with Season 2, respectively.

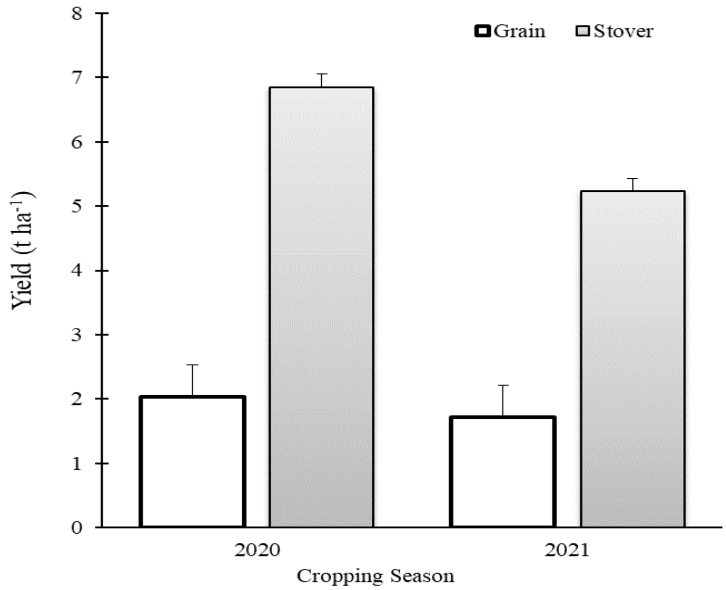

Figure 3. Average Grain and Stover yield across the cropping seasons

3.4 Harvest index and agronomic efficiency

The result of the analysis showed that the harvest index (HI) of sorghum was significantly ($p < 0.05$) higher in SFF2 than SFF1. Comparatively. There was no significant difference between SFF1 and the control in HI (Figure 4). It is also worthy to note that HI was generally lower than 40% regardless of the fertilizer types. This suggests that there were other influences such as environmental or climatic, that affected sorghum productivity. Environmental factors are important determinants of HI and include seasonal pattern of water supply and extreme temperatures during crop reproductive development. Relative to the control (NPK 20:10:10), the agronomic efficiency for stover yield was higher by 35% and 15% for SFF1 and SFF2, respectively (Figure 5). Corresponding values for agronomic efficiency for grain yield differed significantly ($p < 0.05$) between the specialty fertilizers and were higher by 18% and 15% in SFF1 and SFF2 than the control.

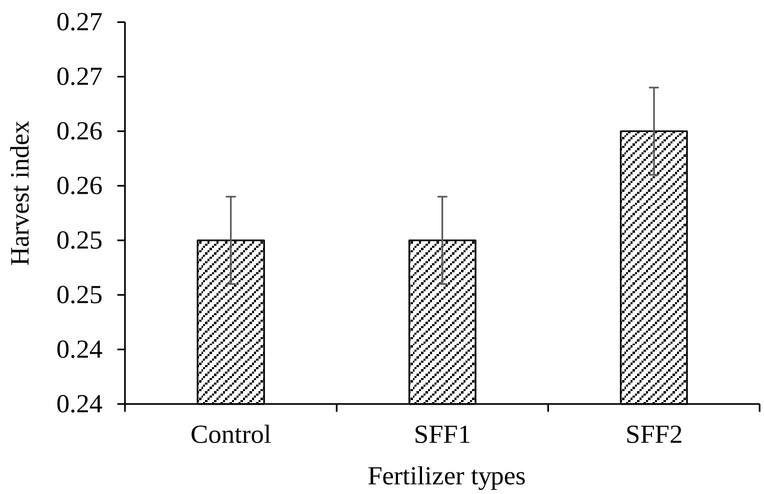

Figure 4. Effects of fertilizer types on harvest index of sorghum

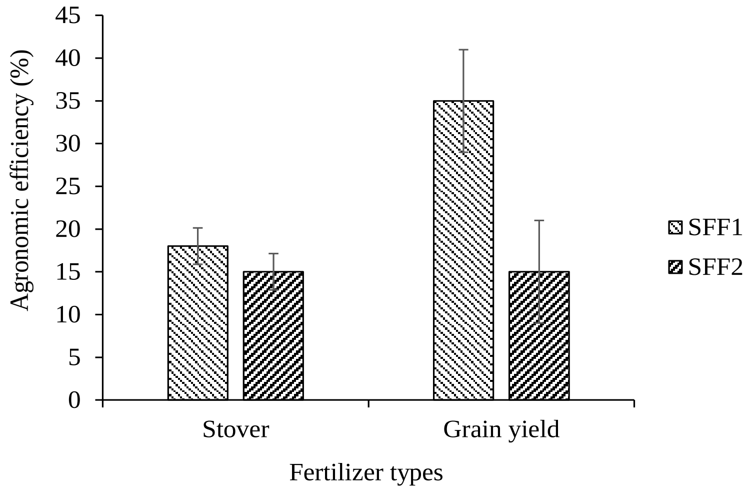

Figure 5. Effects of specialty fertilizers on agronomic efficiency of stover and grain yield of sorghum

4. Discussion

The organic matter content and ECEC of these soils are sure pointers to the fact that the soils will have poor buffering capacities and a likelihood to respond to fertilizer application. Similar results were reported by [10], who explained that these soils lack adsorptive capacity for basic plant nutrients. The difference in grain and stover yield among the fertilizers could be attributed to the secondary and micronutrients contained in SFF1 and SFF2. Although secondary and micronutrients are important for the nutrition, growth, and yield of sorghum, they were deficient in most of the study locations. Our results show that micronutrients are essential for sorghum plants for proper growth, development, and disease resistance. This corroborates the findings of [11], who averred that plants fail to thrive without micronutrients. Several studies [12, 13, 14] have also reported the effect of micronutrients on stover and grain yield of crops. On the other hand, the superiority of SFF1 over SFF2 might not be unconnected with the absence of potassium in SFF2. Even though there is a general belief that Savanna soils are well supplied with potassium and only small amounts are needed in crop production, our results confirm that potassium is important in sorghum production in most of the study locations. The differences in yield response between the cropping seasons may be attributed to the moisture deficit experienced during Season 2 which was crucial for the growth and yield of sorghum. Furthermore, the rain break experienced at the critical stage of the crop development during Season 2 could have seriously impacted on the yield recorded during this Season 2. This corroborates the assertion [15], who reported that seasonal variations and scarcity of water in critical stages of crop life cycle often result to moisture stress which affects crop growth and yield. The increase in harvest index and agronomic efficiency could be attributed to improved soil fertility by the specialty fertilizers for improved growth and yield of sorghum. Similar findings were reported by [16] who attributed low harvest index to decrease in soil fertility.

5. Conclusions

Sorghum yield can be affected by improper nutrient management practices characterized by the omission of micronutrients that are crucial for enhanced crop growth and yield production. Both specialty fertilizers fortified with micronutrients improved the stover yield and grain yield of sorghum relative to the conventional NPK 20:10:10, with improved agronomic efficiency. This shows that both specialty fertilizers, with low amounts of nitrogen and an adequate supply of potassium (in SFF1) and micronutrients, could help farmers increase sorghum productivity while minimizing nitrogen losses under varying agro-ecological zones.

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Conflicts of Interest: The authors declare no conflict of interest.

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