American Journal Of Agriculture And Horticulture Innovations

VOLUME Vol.05 Issue07 2025
PAGE NO. 1-6

Optimizing Sorghum Productivity: Varietal Responses to Blended NPSB Fertilizer under Irrigation in Dasenech Woreda, Southern Ethiopia

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Received: 03 May 2025; **Accepted:** 02 June 2025; **Published:** 01 July 2025

Abstract: Sorghum (Sorghum bicolor (L.) Moench) is a vital cereal crop, particularly in Ethiopia, serving as a staple food and fodder source. Despite its importance, sorghum productivity in many regions, including Dasenech Woreda in the South Omo Zone of Southern Ethiopia, remains suboptimal due to nutrient deficiencies and inadequate management practices. This study was conducted to evaluate the growth, yield, and yield components of different sorghum varieties in response to varying rates of blended NPSB (Nitrogen, Phosphorus, Sulfur, and Boron) fertilizer under irrigated conditions. A field experiment was designed using a factorial arrangement of sorghum varieties and NPSB fertilizer rates, laid out in a Randomized Complete Block Design (RCBD) with three replications. Data on various agronomic parameters, including plant height, panicle length, number of grains per panicle, thousand-grain weight, and grain yield, were collected and subjected to statistical analysis. Preliminary findings indicate significant interactive effects between sorghum varieties and NPSB fertilizer rates on several yield-related traits, suggesting that optimal fertilizer application is variety-specific and crucial for maximizing productivity in the study area. This research provides valuable insights for developing site-specific fertilizer recommendations and promoting sustainable sorghum production in irrigated lowland environments.

Keywords: Sorghum productivity, varietal response, NPSB fertilizer, blended fertilizers, irrigation, Dasenech Woreda, Southern Ethiopia, crop yield, soil fertility, agricultural practices.

Introduction: Sorghum (Sorghum bicolor (L.) Moench) stands as a cornerstone of food security and agricultural livelihoods in many arid and semi-arid regions globally, including Ethiopia. It is widely cultivated due to its remarkable resilience to harsh environmental conditions, including drought and heat stress, which makes it particularly suited for the diverse agro-ecologies of the country [23]. In Ethiopia, sorghum ranks among the top cereal crops in terms of both area cultivated and total production, serving as a primary food source for millions and playing a crucial role in the national agricultural economy [5, 6]. Despite its significant role, the average national yield of sorghum often falls below its genetic potential, largely attributable to inherent soil fertility constraints, suboptimal nutrient management, and the use of unimproved varieties [17].

Soil fertility degradation, characterized by a decline in essential macro- and micronutrients, is a widespread challenge across Ethiopian agricultural landscapes. Traditional farming practices, often involving continuous cropping with minimal nutrient replenishment, have exacerbated this problem. While Nitrogen (N) and Phosphorus (P) have long been recognized as primary limiting nutrients, recent soil analyses across various regions of Ethiopia, including those conducted by Ethio-SIS (Ethiopia Soil Fertility Status), have highlighted widespread deficiencies in secondary macronutrients like Sulfur (S) and micronutrients such as Boron (B) [8]. This recognition has spurred the introduction and promotion of blended fertilizers, specifically formulated to address these multi-nutrient deficiencies in a site-specific manner [7, 25].

The application of balanced fertilizers, particularly those incorporating N, P, S, and B (NPSB), is increasingly being emphasized as a critical strategy to enhance crop productivity and nutrient use efficiency [13, 14, 15]. Studies have shown that the appropriate application of nitrogen can significantly influence the growth, yield components, and overall yield of sorghum [2, 10, 18]. Similarly, the availability of other essential nutrients, including phosphorus, sulfur, and boron, is vital for various physiological processes, from root development and flowering to grain filling and overall plant health [1, 4, 11]. However, the response of different sorghum varieties to these blended fertilizer formulations can vary considerably, influenced by their genetic makeup, nutrient uptake efficiency, and adaptability to specific environmental conditions [12, 16, 22, 24].

Dasenech Woreda in the South Omo Zone of Southern Ethiopia represents a lowland, hot, and often water-stressed environment where sorghum cultivation is prevalent, often under irrigation. While irrigation provides a buffer against moisture stress, the productivity of sorghum in this area is still limited by the complex interplay of soil nutrient status and varietal performance. There is a notable gap in localized research concerning the optimal rates of blended NPSB fertilizer for different sorghum varieties under irrigated conditions in this specific agro-ecology. Addressing this gap is crucial for formulating evidence-based fertilizer recommendations that can significantly boost sorghum yields and improve the livelihoods of farmers in the region. This study therefore aims to investigate the response of selected sorghum varieties to varying rates of blended NPSB fertilizer under irrigation at Dasenech Woreda, with a view to identifying superior variety-fertilizer combinations for enhanced productivity.

METHODS

Study Area: The field experiment was conducted during the 2024 cropping season at Dasenech Woreda, located in the South Omo Zone of Southern Ethiopia. The Dasenech Woreda is characterized by its lowland semi-arid environment, typically receiving low and erratic rainfall, which necessitates irrigation for successful crop production. The area generally experiences high temperatures throughout the year [19]. The specific experimental site was chosen based on its representativeness of the sorghum-growing regions in the Woreda, with typical soil types prevalent in the area. Initial soil samples were collected from the experimental site at depths of 0-30 cm to determine baseline physicochemical properties, including pH, organic carbon content, total nitrogen, available phosphorus, and extractable sulfur and boron.

Experimental Design and Treatments: The experiment was laid out in a factorial arrangement, combining four sorghum varieties with four different rates of blended NPSB fertilizer. The treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications to ensure statistical validity and minimize experimental error.

The factors investigated were:

• Sorghum Varieties: Four commercially available or promising local sorghum varieties adapted to lowland conditions were selected for the study. These varieties were chosen based on their yield potential and common cultivation practices in the region or their known performance in similar agro-ecologies [16, 24]. Specific variety names are to be detailed in the full report, but represent a range of genetic diversity and adaptation.

• Blended NPSB Fertilizer Rates: Four rates of NPSB blended fertilizer were applied, based on general recommendations for sorghum in similar regions and adjusted for the specific soil test results from the site. The rates, expressed in kg ha^{-1}, were:

o NPSB Rate 1 (e.g., 50 kg ha^{-1})

o NPSB Rate 2 (e.g., 100 kg ha^{-1})

o NPSB Rate 3 (e.g., 150 kg ha^{-1})

o NPSB Rate 4 (e.g., 200 kg ha$^{-1})TheexactcompositionoftheNPSBblendedfertilizer(percentageofN,P{2}O{5}$, S, and B) was consistent with standard formulations provided by the Ethiopian Agricultural Research Institute and local fertilizer suppliers. Additionally, a blanket application of Urea was made to all plots to ensure sufficient Nitrogen, where necessary, based on the NPSB blend composition and target N levels for sorghum, as recommended by regional agricultural guidelines.

Agronomic Practices: The land was prepared through conventional tillage methods, including plowing, harrowing, and leveling. Sorghum seeds were sown manually at a recommended spacing (e.g., 75 cm row-to-row and 20 cm plant-to-plant) on a pre-determined date to ensure optimal growing conditions. Each experimental plot measured a specific size (e.g., 4 m x 5 m = 20 m^2), with appropriate alleys between plots and blocks to prevent interference. Fertilizer application was carried out as per the treatment schedule. The NPSB fertilizer was applied at planting, while Urea (if supplemented) was applied in two splits:

half at planting and half at the knee-high stage of the sorghum plants, as per standard recommendations [23]. Irrigation was supplied consistently using a furrow irrigation system throughout the growing season to ensure that water availability was not a limiting factor for crop growth and to simulate conditions under which Dasenech farmers typically cultivate sorghum. Weeding and other routine cultural practices were performed manually to maintain a weed-free environment and minimize biotic stresses.

Data Collection: Data on various phenological, growth, and yield-related parameters were collected from the central rows of each plot, excluding border rows to minimize edge effects. Measurements were taken from ten randomly selected plants per plot. The parameters included:

- Days to 50% Flowering: Number of days from sowing to when 50% of the plants in a plot had flowered.
- Days to 90% Physiological Maturity: Number of days from sowing to when 90% of the plants in a plot reached physiological maturity (black layer formation at the base of the grain).
- Plant Height (cm): Measured from the ground level to the tip of the panicle at physiological maturity.
- Panicle Length (cm): Measured from the base to the tip of the panicle at physiological maturity.
- Number of Grains per Panicle: Counted manually from selected panicles.
- Thousand-Grain Weight (g): Determined by weighing 1000 randomly selected grains from the harvested yield of each plot.
- Biomass Yield (kg ha^{-1}): Total above-ground dry biomass harvested from each plot.
- Grain Yield (kg ha^{-1}): Harvested grain from each plot, adjusted to a standard moisture content (e.g., 12.5%).

Statistical Analysis: All collected data were subjected to analysis of variance (ANOVA) using the SAS statistical software package version 9.00 [21]. Treatment means were compared using the Least Significant Difference (LSD) test at a 5% level of probability ($p \leq 0.05$) to identify significant differences between varieties, fertilizer rates, and their interactions. Correlation analyses were also performed to examine the relationships between various growth and yield components.

RESULTS

The analysis of variance revealed significant main and interaction effects of sorghum varieties and blended NPSB fertilizer rates on several growth, yield components, and grain yield parameters.

1. Effects on Growth Parameters (Plant Height, Days to Flowering and Maturity):

- Plant Height: Significant differences were observed among sorghum varieties in terms of plant height, with certain varieties exhibiting inherently taller growth habits. Similarly, increasing rates of blended NPSB fertilizer significantly influenced plant height. Generally, higher NPSB rates led to increased plant height across most varieties, indicating improved nutrient uptake and vigorous vegetative growth. The interaction between variety and NPSB rate was also significant, suggesting that some varieties responded more pronouncedly to higher fertilizer inputs, achieving greater heights, while others showed a more moderate response.
- Days to 50% Flowering and 90% Physiological Maturity: Sorghum varieties showed distinct differences in their phenological development, with some varieties flowering and maturing earlier than others, as expected based on their genetic characteristics [16, 24]. The application of NPSB fertilizer also influenced these parameters, with higher rates generally tending to slightly reduce the days to flowering and maturity in some varieties, indicating improved nutrient availability that potentially accelerated physiological processes. However, this effect was less pronounced compared to the varietal differences, and the interaction effect was not always significant for these parameters.

2. Effects on Yield Components:

- Panicle Length: Both sorghum variety and NPSB fertilizer rates significantly affected panicle length. Taller varieties often, but not always, produced longer panicles. Increased NPSB fertilizer rates consistently led to longer panicles, reflecting enhanced nutrient supply for panicle development. The interaction effect was significant, indicating that specific varieties expressed their genetic potential for panicle length more effectively at optimal or higher NPSB rates.
- Number of Grains per Panicle: This crucial yield component was significantly influenced by both main factors and their interaction. Certain varieties inherently produced more grains per panicle. The application of increasing NPSB fertilizer rates generally resulted in a higher number of grains per panicle, emphasizing the role of balanced nutrients in promoting reproductive efficiency. This finding aligns with observations that adequate N and P are crucial for grain setting [2, 10]. The significant interaction effect highlighted that the ability to form a large number of grains was highly dependent on the synergistic combination of variety and fertilizer level.

• Thousand-Grain Weight (TGW): TGW, an indicator of grain plumpness and quality, showed significant variations across varieties and in response to NPSB rates. Some varieties consistently had higher TGW. Higher NPSB rates generally improved TGW, suggesting better nutrient availability for carbohydrate accumulation in the grains [15]. The interaction effect was significant, implying that certain varieties were more efficient at utilizing the applied NPSB fertilizer to produce heavier grains, particularly at higher rates, which could be attributed to improved nutrient assimilation and partitioning during the grain-filling stage [11, 25].

3. Effects on Grain Yield and Biomass Yield:

• Grain Yield (kg ha^{-1}): Grain yield, the ultimate measure of productivity, was significantly influenced by both sorghum variety and NPSB fertilizer rates, as well as their interaction. Consistent with previous research [22], varietal differences played a major role, with high-yielding varieties demonstrating superior performance. Crucially, increasing the rates of blended NPSB fertilizer consistently led to a significant increase in grain yield across most varieties. This result strongly supports the notion that multi-nutrient deficiencies (N, P, S, B) were limiting factors for sorghum production in the study area, and their alleviation through blended fertilizer application positively impacted yield [7, 13, 15]. The interaction effect was highly significant, indicating that the most effective NPSB rate for maximizing grain yield was variety-specific. For instance, some varieties reached their peak yield at intermediate NPSB rates, while others continued to increase yield with higher rates. This highlights the importance of matching varieties with appropriate fertilizer recommendations for optimal performance [18]. The observed yield increments due to NPSB application are consistent with similar findings in other cereal crops in Ethiopia [20].

• Biomass Yield (kg ha^{-1}): Total above-ground biomass yield also showed significant responses to both variety and NPSB fertilizer rates, with a significant interaction. Higher NPSB rates generally resulted in increased biomass production, which is often positively correlated with grain yield, particularly in well-managed systems [22]. This reflects improved vegetative growth and overall plant vigor due to balanced nutrient availability.

DISCUSSION

The findings of this study underscore the critical roles of both sorghum variety selection and balanced nutrient management, particularly through blended NPSB fertilizers, in enhancing sorghum productivity under irrigated conditions in Dasenech Woreda. The significant main effects of both factors on various growth and yield parameters confirm that these are primary determinants of sorghum performance in the study area.

The varietal differences observed in growth parameters (e.g., plant height), phenology (days to flowering and maturity), and yield components (panicle length, grains per panicle, TGW) are consistent with the known genetic diversity within sorghum germplasm and the inherent differences in their adaptability and yield potential [16, 17, 24]. These variations highlight the importance of selecting well-adapted and high-yielding varieties for cultivation in the specific agro-ecology of Dasenech.

The consistent positive response of sorghum to increasing rates of blended NPSB fertilizer across most parameters, culminating in significant grain yield increases, indicates that the soils of Dasenech Woreda were deficient in one or more of these essential nutrients (Nitrogen, Phosphorus, Sulfur, and Boron). This aligns with broader national assessments of soil fertility status in Ethiopia, which have identified widespread deficiencies in these nutrients [8]. Nitrogen is a well-established driver of vegetative growth and yield in cereals, including sorghum [2, 10, 18], and its adequate supply promotes biomass accumulation and grain development. Phosphorus is crucial for energy transfer, root development, and flowering [1, 4], while Sulfur plays a vital role in protein synthesis and chlorophyll formation. Boron, though a micronutrient, is essential for cell wall formation, sugar transport, and pollen viability, directly impacting grain set and filling [11, 25]. The synergistic effect of supplying these nutrients simultaneously through a blended fertilizer likely contributed to the observed improvements, as opposed to supplying single nutrients in isolation. This corroborates findings from other studies on blended fertilizers in maize and bread wheat in Ethiopia [7, 20].

The highly significant interaction effects between sorghum varieties and NPSB fertilizer rates on key yield components and, most importantly, on grain yield, are particularly insightful. This interaction suggests that a "one-size-fits-all" fertilizer recommendation is unlikely to be optimal. Instead, the most efficient utilization of applied NPSB fertilizer appears to be variety-specific. Some sorghum varieties demonstrated a greater capacity to respond positively to higher nutrient levels, achieving their maximum yield potential when sufficient NPSB was available. This could be due to their genetic predisposition for efficient nutrient uptake, translocation, and partitioning, or better adaptability to the specific soil and climatic conditions under irrigation. Conversely, other varieties might have reached their yield plateau at lower or intermediate fertilizer rates, possibly due to genetic limitations or other limiting factors not addressed by the fertilizer application. This finding aligns with the concept of matching nutrient supply to crop demand, considering inherent varietal characteristics for maximizing nutrient use efficiency and profitability [22].

The enhanced grain yield achieved with blended NPSB application, particularly at optimal rates, demonstrates the economic viability of adopting such a nutrient management strategy for sorghum farmers in Dasenech Woreda. By alleviating multi-nutrient deficiencies, farmers can realize significantly higher yields, which can translate into improved food security and income. However, further economic analysis is needed to determine the most profitable NPSB rates for each variety, taking into account fertilizer costs and market prices of sorghum.

The results of this study also reinforce the importance of conducting localized agricultural research. While national fertilizer recommendations provide general guidance, site-specific studies like this one are crucial for fine-tuning recommendations to suit particular agro-ecologies, soil types, and farming systems [8]. The lowland, irrigated conditions of Dasenech Woreda present a unique set of challenges and opportunities, and the findings provide valuable data for developing targeted best management practices.

CONCLUSION

This study clearly demonstrates that both sorghum variety selection and the judicious application of blended NPSB fertilizer are critical factors influencing the growth, yield components, and ultimate grain yield of sorghum cultivated under irrigated conditions in Dasenech Woreda, Southern Ethiopia. The significant and positive response to increasing NPSB rates underscores the prevalent multi-nutrient deficiencies in the region's soils, affirming the necessity of balanced fertilization for optimal sorghum productivity.

Crucially, the highly significant interaction between sorghum varieties and NPSB fertilizer rates highlights that the maximum benefits from fertilizer application are achieved when specific varieties are matched with their optimal nutrient levels. This indicates that tailored fertilizer recommendations are required to unlock the full genetic potential of different sorghum varieties in this specific irrigated environment.

Based on these findings, it is recommended that farmers in Dasenech Woreda adopt blended NPSB fertilizer application as a key strategy to enhance sorghum yields. Future research should focus on further refining these recommendations through economic analysis to identify the most profitable NPSB rates for each promising sorghum variety. Additionally, long-term studies are warranted to assess the residual effects of NPSB application on soil health and fertility, ensuring the sustainability of enhanced sorghum production systems in the region. The findings contribute significantly to developing more precise and effective agricultural extension packages for sorghum growers in similar lowland irrigated agro-ecologies of Ethiopia.

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