ISSN 2808-3229
Journal of Biodiversity and Biotechnology. 4(1), 47–56, 2024 URL: https://jurnal.uns.ac.id/jbb/article/view/108195
doi: http://dx.doi.org/10.20961/jbb.v4i1.108195

Growth Response and Yields of a Variety of Sorghum on Multiple NPK Fertilization in Dry Land

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Abstract
Land degradation is a major constraint to agricultural productivity, with drylands particularly vulnerable to critical conditions. Sorghum (*Sorghum bicolor* L. Moench) is a promising crop for such environments due to its adaptability and dual-purpose value for biomass and sugar-rich stalks. This study aimed to evaluate the growth and yield response of four sorghum varieties, Super, Suri, Numbu, and Keller, to different rates of compound NPK fertilizer under dryland conditions. The experiment was arranged in a Randomized Complete Block Design (RCBD) with two factors: sorghum varieties and five fertilizer doses (0, 10, 12, 14, and 16 g plant^{-1}), replicated three times. Data were subjected to Analysis of Variance (ANOVA), and treatment means were compared using Duncan's Multiple Range Test (DMRT) at the 95% significance level. Results showed that the Keller variety consistently produced the best agronomic performance, including plant height, number of leaves, stem segments, stem diameter, and biomass dry weight. Moreover, Keller combined with 12 g plant^{-1} of NPK fertilizer produced the highest sap content (14.0% Brix), highlighting its potential as a dual-purpose sorghum. Leaf traits were most responsive at 14 g plant^{-1}, indicating that moderate-to-high fertilization enhances vegetative growth without excessive input. These findings demonstrate that varietal selection and appropriate nutrient management are crucial for optimizing sorghum production in dryland systems. The study provides practical guidance for farmers and can inform future breeding and fertilizer recommendation programs for sustainable sorghum cultivation.

Keywords: Growth and yield response, sorghum variety, NPK fertilizer, dry land.

Cite this as: Samanhudi, Harsono, P., Hartati, S., Iswahyudi, Wicaksono, N.G. (2024). Growth Response and Yields of a Variety of Sorghum on Multiple NPK Fertilization in Dry Land. Journal of Biodiversity and Biotechnology. 4(1), 47–56. doi: http://dx.doi.org/10.20961/jbb.v4i1.108195

Introduction

Efforts to realize the availability of sufficient and safe food for the community through intensification of plant cultivation aimed at obtaining high yields can have negative consequences. Applying inappropriate technology, soil and plant management, or their tendency toward over-exploitation, can reduce the soil's physical, chemical, and biological fertility (1,2). Moreover, over-applying fertilizers and pesticides to maintain and increase crop yields causes the concentration of several heavy metals in soil, water, and plants to exceed permissible thresholds (3,4). The increase in national food production has been relatively slow compared to demand due to various hard-to-overcome obstacles, such as the conversion of paddy fields, competition for water use, floods, and landslides (5-8). This condition poses a significant challenge to agricultural development.

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important cereal crop in the world after wheat, rice, corn, and barley (9-12). Sorghum is a multifunctional, zero-waste plant because all parts of the plant can be used for food, feed, and industrial purposes (13). It can be grown in tropical, subtropical, and dry areas and belongs to the C_4 group, like corn and sugarcane. C_4 plants generally have mesophyll and bundle-sheath cells, which effectively fix CO_2. Bundle-sheath cells contain more chloroplasts, mitochondria, and other essential organelles for photosynthesis, making them efficient in photosynthesizing, especially in environments with high temperatures and water shortages. Sweet sorghum requires one-third or less of the water needed by sugarcane and corn, enabling it to grow well in various climates, including tropical, subtropical, and dry regions.

Fertilization is a necessary activity at all stages of plant cultivation. The essential nutrients sorghum plants need are obtained from the soil and air. Soil-derived nutrients include: (1) primary macronutrients, which are used in large quantities and are often deficient in soil—namely N, P, and K; (2) secondary macronutrients, which are needed in large quantities but are often available in sufficient amounts in the soil namely S, Mg, and Ca; and (3) micronutrients needed in small amounts namely Fe, Mn, Zn, Cu, B, Mo, and Cl. The nutrients obtained from the air are C, H, and O. Fertilizer recommendations for sorghum are based on site-specific fertilization, tailored to yield potential, natural soil nutrient supply capacity, and nutrient recovery. This site-specific fertilization concept has also been applied in wheat (13,14), rice (14,15), and maize (16-19). In most dry-land areas, nutrients N, P, and K are limiting factors in sorghum production. Determination of fertilizer requirements for sorghum plants is based on yield targets and soil analysis. Yield targets are yield opportunities that can be obtained by considering land capability and optimal crop management.

Planting sorghum in paddy fields and dry land is adjusted according to the variety of sorghum cultivated. One criterion for a sorghum variety that grows well in environments with limited rainfall is drought tolerance and the ability to maintain greenery during drought. A key consideration is adapting sweet sorghum to these lands to expand its planting area. This study aimed to evaluate the growth and yield response of four sorghum varieties, Super, Suri, Numbu, and Keller, to different rates of compound NPK fertilizer under dryland conditions.

Material and Methods

The materials used in this study included plant seeds from four sorghum varieties, namely Super, Suri, Numbu, and Keller, along with compound NPK fertilizer (Phonska), stakes, and sample markers. The tools employed included tillage equipment, planting and maintenance tools, observation markers for sample plants, a tape measure, a caliper, a hand refractometer, scales, and an oven.

This study applied an experimental design of a Randomized Complete Block Design (RCBD) with two factors. The first factor was sorghum variety: Super, Suri, Numbu, and Keller. The second factor was the fertilization dose of compound NPK at five levels: P_0 (control), P_1 (10 g plant^{-1}), P_2 (12 g plant^{-1}), P_3 (14 g plant^{-1}), and P_4 (16 g plant^{-1}). Treatments were combined and arranged in three replications.

The materials used in this study included plant seeds from four sorghum varieties, namely Super, Suri, Numbu, and Keller, along with compound NPK fertilizer (Phonska), stakes, and sample markers. The tools employed included tillage equipment, planting and maintenance tools, observation markers for sample plants, a tape measure, a caliper, a hand refractometer, scales, and an oven.

Sap content was determined at 10 WAP using freshly harvested stalk samples. Approximately 10–15 cm sections from the middle internode of three representative plants per plot were crushed to extract juice. A drop of juice was placed on the prism surface of a calibrated hand refractometer (ATC, 0–32 °Brix range), and readings were expressed as percentage soluble solids (% Brix). The average of three plants per plot was used for analysis.

Data Analysis

Data were analyzed using analysis of variance (ANOVA) to test the significance among treatments. Significant results were further evaluated using Duncan's Multiple Range Test (DMRT) at the 5% confidence level to determine which treatment combinations (variety and NPK fertilizer dose) produced superior growth and yield of sorghum.

Results and Discussion

Plant Height

At 10 weeks after planting (WAP), sorghum varieties significantly affected plant height. The Super variety reached 307.39 cm, substantially taller than other varieties except Keller, which attained 294.11 cm (Table 1). This suggests that Super and Keller have strong growth potential under the conditions. Differences in plant height across varieties are often linked to genetic variation in growth vigor and internode elongation (20). Taller sorghum plants typically exhibit higher biomass accumulation, provided lodging risks are minimized (16).

Table 1. Effect of sorghum varieties on plant height at 10 WAP

Sorghum Varieties	Plant Height (cm)	
Super	307.39 ±1.73	c
Suri	228.64 ±3.46	a
Numbu	249.92 ±2.31	b
Keller	294.11 ±1.15	c

Note: Numbers followed by the same letter for each treatment are not significantly different based on the DMRT level of 5%.

The application of NPK fertilizer also significantly influenced plant height (Table 2). Plants receiving 10–16 g plant^{-1} of NPK were significantly taller than unfertilized controls, with the maximum height (281.18 cm) recorded at 16 g plant^{-1}. This finding aligns with Li (21), who showed that balanced NPK fertilization enhances sorghum vegetative growth by promoting efficient nutrient partitioning. Similarly, Ali et al. (22) reported that sorghum responded positively to increasing NPK levels, with notable gains in plant height and leaf development.

Table 2. Effect of NPK fertilizer dose on plant height at 10 WAP

NPK Fertilizer Dosage (g.plant^{-1})	Plant Height (cm)	
0	238.08±2.89	a
10	277.15±2.31	b
12	278.19±3.46	b
14	275.47±1.73	b
16	281.18±1.44	b

Note: Numbers followed by the same letter for each treatment are not significantly different based on the DMRT level of 5%.

The interaction between sorghum variety and fertilizer dose was not significant for plant height. Nevertheless, the combination of the Super variety with 14 g plant^{-1} of NPK produced the most significant increase in height between 5 and 10 WAP, from 117.67 cm to 307.39 cm. This growth pattern highlights the role of both genotype and nutrient supply in determining plant architecture under field conditions (23).

Number of Leaves

The number of leaves per plant at 10 WAP was also significantly influenced by sorghum variety (Table 3). The Keller variety produced the highest number of leaves (12.73), significantly more than the other varieties, while Super and Suri had statistically similar values (11.07 and 10.64, respectively). This demonstrates that Keller has a genotypic advantage in leaf production, a trait that supports greater light interception and photosynthetic activity (23). Increased leaf number is often associated with improved canopy development and yield potential when coupled with adequate nutrient supply (22).

Table 3. The effect of sorghum varieties on the number of leaves at 10 WAP

Sorghum Varieties	Number of Leaves (strands)	
Super	11.07±0.23	a
Suri	10.64±0.29	a
Numbu	12.03±0.17	b
Keller	12.73±0.35	c

Note: Numbers followed by the same letter for each treatment are not significantly different based on the DMRT level of 5%.

NPK fertilization significantly increased leaf numbers compared to the control (Table 4). Plants receiving 10–16 g plant^{-1} of NPK produced 9.57% and 13.48% more leaves than unfertilized plants, with the highest leaf number recorded at 12 g plant^{-1}. This outcome confirms the essential role of nitrogen and potassium in leaf initiation and expansion (20). However, the slight decline at 16 g plant^{-1} suggests that excessive fertilization may not proportionally increase leaf development, consistent with reports that nutrient uptake efficiency can decline beyond optimal levels (21).

Table 4. Effect of NPK fertilizer dose on the number of leaves at 10 WAP

NPK Fertilizer Dosage	Number of Leaves (strands)	
0 g.plant^{-1}	10.76±0.17	a
10 g.plant^{-1}	11.79±0.23	bc
12 g.plant^{-1}	11.85±0.12	bc
14 g.plant^{-1}	12.21±0.29	c
16 g.plant^{-1}	11.49±0.20	b

Note: Numbers followed by the same letter for each treatment are not significantly different based on the DMRT level of 5%.

The interaction of variety and fertilizer dose did not significantly affect leaf number. Nevertheless, Keller without fertilization showed strong vegetative growth, increasing from 8.05 leaves at 5 WAP to 12.89 leaves at 10 WAP, while the highest overall leaf number

(13.56) was observed in Keller with 12 g plant⁻¹ of NPK. This indicates that Keller combines genetic potential with efficient nutrient use, making it a promising variety for environments with limited input availability.

Leaf Length and Width

Varietal differences significantly affected the length of the 5th leaf at 10 WAP. The Super variety recorded the longest leaf at 91.26 cm, significantly greater than Keller (87.39 cm), while Suri and Numbu were intermediate (Table 5). However, varietal effects on leaf width were generally not significant, except at 10 WAP when Suri (9.68 cm) produced significantly wider leaves than Keller (9.19 cm). These results suggest that genetic variation influences leaf elongation more strongly than lamina expansion. Leaf morphology in sorghum is closely associated with radiation interception efficiency and biomass accumulation, making leaf length an important determinant of canopy productivity (24,25).

Table 5. Effect of sorghum varieties on the length and width of the 5th leaf

Sorghum Varieties	5th Leaf Length (cm)			5th Leaf Width (cm)		
	9 WAP	10 WAP		9 WAP	10 WAP	
Super	87.22±0.46	91.26±0.40	b	8.87±0.12	9.34±0.17	ab
Suri	85.55±0.29	88.78±0.29	ab	9.39±0.17	9.68±0.29	b
Numbu	86.74±0.35	89.87±0.35	ab	9.03±0.14	9.46±0.14	ab
Keller	84.58±0.40	87.39±0.46	a	8.96±0.12	9.19±0.17	a

Note: Numbers followed by the same letter for each treatment are not significantly different based on the DMRT level of 5%.

NPK fertilization significantly increased both leaf length and width at 9 and 10 WAP (Table 6). At 9 WAP, fertilizer doses of 10, 14, and 16 g plant⁻¹ produced significantly longer leaves than the control, while at 10 WAP, all fertilizer levels increased leaf length compared to no fertilization. Leaf width also responded positively, with the largest width (9.98 cm) observed at 14 g plant⁻¹. These findings are consistent with Ali et al. (22), who reported that NPK application improves sorghum leaf development by promoting cell expansion and division. Similarly, Wakano et al. (26) found that potassium application enhances lamina thickness and turgidity, indirectly contributing to wider leaves.

Table 6. Effect of sorghum varieties on the length and width of the 5th leaf

NPK Fertilizer Dosage	5th Leaf Length (cm)				5th Leaf Width (cm)			
	9 WAP		10 WAP		9 WAP		10 WAP	
0 g.plant^{-1}	82.97±0.40	a	86.19±0.35	a	7.76±0.14	a	8.00±0.12	a
10 g.plant^{-1}	87.40±0.35	b	90.18±0.40	b	9.55±0.17	ab	9.79±0.17	b
12 g.plant^{-1}	84.85±0.29	ab	89.64±0.29	b	9.32±0.12	ab	9.84±0.14	b
14 g.plant^{-1}	87.56±0.46	b	90.08±0.46	b	9.64±0.20	c	9.98±0.20	b
16 g.plant^{-1}	87.33±0.40	b	90.52±0.35	b	9.04±0.14	b	9.48±0.17	b

Note: Numbers followed by the same letter for each treatment are not significantly different based on the DMRT level of 5%.

Although interaction effects between variety and fertilizer were not significant, the trend indicates that fertilization consistently enhanced leaf growth across all genotypes. This suggests that while genetic factors set the baseline for leaf dimensions, nutrient availability optimizes their expression (23).

Number of Internodes and Stem Diameter

Varietal treatments significantly influenced the number of internodes at 10 WAP. The Suri variety produced the fewest internodes (9.23), while Super (10.42), Numbu (10.74), and Keller (11.13) showed higher and statistically similar values (Table 7). This indicates that Suri expresses reduced vertical segmentation, which may restrict its potential for height and biomass accumulation. Internode number is known to be a varietal trait linked to stem elongation and overall architecture (27).

Stem diameter was also affected by variety, with Keller showing the largest values at both 9 WAP (23.76 mm) and 10 WAP (26.99 mm), significantly higher than Super and Numbu. Thick stems are an advantageous trait, as they provide mechanical support and reduce lodging risks under high biomass conditions. Furthermore, larger stem diameters are associated with higher juice content and structural carbohydrates, making Keller particularly promising for bioenergy and forage purposes (22).

Table 7. Effect of sorghum varieties on the number of internodes and stem diameter

Sorghum Varieties	Number of Stems (stem)	Stem Diameter(cm) 9 WAP	10 WAP
Super	10.42±0.23 b	19.89±0.46 a	22.76±0.40 a
Suri	9.23±0.29 a	22.55±0.35 bc	23.47±0.46 ab
Numbu	10.74±0.17 b	21.59±0.40 b	22.86±0.35 a
Keller	11.13±0.35 b	23.76±0.52 c	26.99±0.58 b

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT at the 5% level.

The effect of NPK fertilization on internode number was less pronounced. Except for the 16 g plant⁻¹ treatment, fertilizer application did not significantly differ from the control (Table 8). This suggests that internode initiation is predominantly under genetic rather than nutritional control. However, stem diameter responded strongly to fertilization, with significant increases at both 9 and 10 WAP. The maximum diameter (28.49 mm) was achieved at 12 g plant⁻¹, followed by 25.48 mm at 14 g plant⁻¹. Beyond optimal levels, higher NPK did not further increase stem thickness, indicating diminishing returns at higher doses. These results are consistent with reports that moderate NPK application improves stem girth by enhancing assimilate partitioning to structural tissues, while excess nitrogen can sometimes lead to thinner, weaker stems (25).

Table 8. Effect of NPK fertilizer dose on the number of internodes and stem diameter

NPK Fertilizer Dosage	Number of Stems (stem)	Stem Diameter(cm) 9 WAP	10 MST
0 g.plant^{-1}	10.92±0.20 b	17.77±0.35 a	18.58±0.40 a
10 g.plant^{-1}	10.36±0.17 ab	22.88±0.40 bc	23.88±0.46 b
12 g.plant^{-1}	10.32±0.14 ab	23.09±0.35 bc	28.49±0.58 c
14 g.plant^{-1}	10.47±0.23 ab	24,29±0.46 c	25.48±0.46 bc
16 g.plant^{-1}	9.85±0.26 a	21.69±0.35 b	23.66±0.40 b

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT at the 5% level.

Overall, varietal differences determined internode number and basal stem thickness, while nutrient availability modulated the extent of stem expansion. Keller again emerged as the variety with the strongest stem traits, a desirable feature for both yield stability and industrial utilization.

Flowering Time

The interaction between sorghum varieties and NPK fertilizer doses significantly affected flowering time (Table 9). The Super variety fertilized with 12 g plant⁻¹ and 14 g plant⁻¹ NPK exhibited the longest time to flowering (59 days), while the control (0 g plant⁻¹) flowered earlier at 55 days. A similar pattern was observed across all varieties, where unfertilized controls consistently flowered earlier than their fertilized counterparts. This demonstrates that nutrient availability delays the transition from vegetative to reproductive growth, as plants allocate more assimilates to vegetative development before initiating flowering.

Among varieties, Keller exhibited the latest flowering when combined with higher NPK levels, reaching up to 66 days. In contrast, Suri remained relatively stable across treatments, flowering around 55–57 days regardless of fertilizer dose. This suggests that Suri is less responsive to external nutrient supply in terms of phenological shifts, while Keller is highly responsive. Previous studies confirm that N fertilization often prolongs vegetative phases by enhancing leaf area and delaying floral initiation, which can be advantageous in biomass-oriented sorghum systems (25). However, excessively delayed flowering may reduce grain yield potential in grain-type sorghum, indicating that variety-specific fertilizer strategies are necessary.

Table 9. Effect of sorghum varieties and NPK fertilizer doses on flowering time

Treatment	Flowering Time (DAP)	
Super Varieties + NPK Dosage 0 g.plant^{-1}	55.00±0.46	a
Super Varieties + NPK Dosage 10 g.plant^{-1}	57.67±0.52	ab
Super Varieties + NPK Dosage 12 g.plant^{-1}	59.00±0.58	b
Super Varieties + NPK Dosage 14 g.plant^{-1}	59.00±0.64	b
Super Varieties + NPK Dosage 16 g.plant^{-1}	58.67±0.58	ab
Suri variety + NPK dosage 0 g.plant^{-1}	55.00±0.35	a
Suri Variety + NPK Dosage 10 g.plant^{-1}	57.33±0.40	ab
Suri Variety + NPK Dosage 12 g.plant^{-1}	56.33±0.46	ab
Suri Variety + NPK Dosage 14 g.plant^{-1}	55.00±0.52	a
Suri Variety + NPK Dosage 16 g.plant^{-1}	55.00±0.46	a
Numbu Variety + NPK Dosage 0 g.plant^{-1}	56.33±0.52	ab
Numbu Variety + NPK Dosage 10 g.plant^{-1}	60.00±0.58	b
Numbu Variety + NPK Dosage 12 g.plant^{-1}	58.67±0.64	ab
Numbu Variety + NPK Dosage 14 g.plant^{-1}	63.33±0.69	c
Numbu Variety + NPK Dosage 16 g.plant^{-1}	56.33±0.64	ab
Keller Variety + NPK Dosage 0 g.plant^{-1}	59.00±0.64	b
Keller Variety + NPK Dosage 10 g.plant^{-1}	64.67±0.69	c
Keller Variety + NPK Dosage 12 g.plant^{-1}	65.67±0.69	c
Keller Variety + NPK Dosage 14 g.plant^{-1}	66.00±0.69	c
Keller Variety + NPK Dosage 16 g.plant^{-1}	65.67±0.69	c

Note: Numbers followed by the same letters are not significantly different based on the DMRT at the 5% level.

Fresh Weight of Stems, Leaves, and Whole Plants

Varietal differences significantly influenced fresh weight accumulation (Table 10). The Numbu variety produced the highest fresh weight across stem (141.93 g), leaves (20.15 g), and whole plant (172.08 g). Although Keller showed comparable stem weight (120.75 g), Numbu was clearly superior in total biomass production. This highlights Numbu's efficiency in assimilate partitioning toward both vegetative and structural organs. In contrast, Suri and Super produced lower fresh biomass, indicating a genetic predisposition toward less vigorous vegetative growth. Such differences among varieties align with earlier findings that biomass allocation in sorghum is genotype-dependent and influenced by leaf area expansion and internode elongation (22).

Table 10. Effect of sorghum varieties on the fresh weight of sorghum stems, leaves and plants

Sorghum Varieties	Fresh Weight (g)					
	Stem		Leaf		Plant	
Super	116.68±1.15	a	24.68±0.35	a	141.36±1.44	a
Suri	113.99±0.87	a	23.01±0.29	a	137.00±1.15	a
Numbu	141.93±1.73	b	20.15±0.40	b	172.08±2.02	b
Keller	120.75±1.44	ab	24.88±0.35	a	145.63±1.62	a

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT at the 5% level.

Fertilizer application significantly affected fresh stem and total plant weight but had limited impact on leaf fresh weight (Table 11). Plants grown without NPK (control) had the lowest biomass (115.25 g plant^{-1}), whereas application of 16 g plant^{-1} maximized total fresh weight (167.87 g). This trend indicates that nutrient supply enhances structural growth more than lamina expansion, as leaf biomass remained statistically similar across treatments. Nutrients, particularly N and K, are known to stimulate carbohydrate metabolism and stem thickening, leading to increased structural mass (28).

Table 11. Effect of NPK fertilizer dose on the fresh weight of sorghum stems, leaves and plants

NPK Fertilizer Dosage	Fresh Weight (g)					
	Stem		Leaf		Plant	
0 g.plant^{-1}	92.25±1.04	a	23.00±0.23	a	115.25±1.15	a
10 g.plant^{-1}	123,42±1.15	b	24.87±0.29	a	148,28±1.39	b
12 g.plant^{-1}	135.55±1.44	b	26,92±0.35	a	162.47±1.73	b
14 g.plant^{-1}	126.02±1.27	b	25,20±0.29	a	151,22±1.44	b
16 g.plant^{-1}	139.45±1.50	b	28,41±0.40	a	167,87±1.85	b

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT at the 5% level.

Interestingly, the response plateaued beyond moderate doses. The 12 g plant^{-1} and 16 g plant^{-1} treatments produced similar gains in total biomass, suggesting an optimal range between these doses. Excess nutrient supply may result in luxury consumption, where uptake exceeds physiological demand without proportional yield benefits (23). Thus, NPK doses around 12–14 g plant^{-1} may represent the most efficient range for enhancing sorghum biomass while avoiding unnecessary fertilizer inputs.

Dry Weight of Sorghum Stems, Leaves and Plants

Varietal effects were evident in dry matter partitioning (Table 12). The Keller variety produced the highest stem and total plant dry weights (58.64 g and 74.79 g, respectively), while Suri consistently lagged behind with only 40.29 g stem and 51.01 g plant dry weight. Super and Numbu were intermediate but statistically comparable to Keller in plant dry matter. Interestingly, leaf dry weight did not differ significantly among varieties, though Keller again trended highest (16.15 g). This suggests that Keller allocates greater assimilates to structural components rather than lamina tissue, which may support stronger lodging resistance and higher biomass accumulation.

These findings are consistent with reports that sorghum genotypes vary widely in dry matter allocation, with lodging-resistant lines often showing higher stem-to-leaf ratios (29). Moreover, Keller's superior dry matter aligns with its larger stem diameter observed earlier, indicating a coordinated effect of nutrient uptake and carbon partitioning. Conversely, Suri's weaker performance highlights its limited capacity to translate vegetative growth into structural dry matter, a limitation noted for certain landraces adapted to marginal soils (22).

Table 12. Effect of sorghum varieties on the dry weight of sorghum stalks, leaves and plants

Sorghum Varieties	Dry Weight (g)					
	Stem		Leaf		Plant	
Super	56.37±0.87	b	10.78±0.17	a	67.15±1.15	ab
Suri	40.29±0.69	a	10.72±0.14	a	51.01±0.87	a
Numbu	53.68±0.75	b	12.40±0.20	a	66.08±1.27	ab
Keller	58.64±0.92	b	16,15±0.23	a	74.79±1.44	b

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT at the 5% level.

Fertilization effects mirrored varietal differences (Table 13). Control plants (0 g plant^{-1}) accumulated the lowest dry weights (41.83 g total), while fertilized treatments significantly improved stem and plant dry weights. The 16 g plant^{-1} treatment produced the highest dry biomass (73.84 g), though responses plateaued beyond the 12 g plant^{-1} and 14 g plant^{-1} levels. Leaf dry weight remained statistically unaffected by fertilization, suggesting that leaf lamina biomass is less responsive to nutrient input compared to stem growth.

Table 13. Effect of NPK fertilizer dose on the dry weight of sorghum stems, leaves and plants

NPK Fertilizer Dosage	Dry Weight (g)					
	Stem		Leaf		Plant	
0 g.plant^{-1}	32.79±0.87	a	9.04±0.17	a	41.83±1.04	a
10 g.plant^{-1}	54.31±1.15	b	14.14±0.23	a	68.45±1.44	ab
12 g.plant^{-1}	57.13±1.27	b	13.92±0.20	a	71.05±1.56	a
14 g.plant^{-1}	56.56±1.21	b	12.08±0.23	a	68.64±1.50	a
16 g.plant^{-1}	60.43±1.39	b	13.41±0.26	a	73.84±1.62	a

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT at the 5% level.

This pattern confirms that nutrient application primarily enhances assimilate partitioning into stems, contributing to stronger structural biomass rather than increasing leaf tissue. Such partitioning efficiency is critical in dual-purpose sorghum systems (grain + stover), where farmers benefit from both grain and fodder (23). However, the diminishing returns beyond 12–14 g plant^{-1} indicate an optimal fertilization threshold, where further nutrient input contributes little to yield efficiency aligning with the principle of diminishing marginal returns in crop nutrient responses (28).

Sap Content

The interaction between sorghum varieties and NPK fertilizer doses did not produce significant differences in sap content (Table 14). Across treatments, sap levels ranged from 8.33% to 14.00% Brix, with Keller at 12 g plant^{-1} producing the highest value. Although not statistically different, Keller consistently trended higher compared to other varieties, indicating some genotypic predisposition toward higher sugar accumulation.

The lack of strong fertilizer response suggests that soluble sugar accumulation is more genetically controlled than strictly nutrient-driven. Prior studies confirm that juice Brix in sweet sorghum is primarily determined by genetic background, with only secondary modulation by nutrient supply and environment (22). In fact, excess nitrogen often dilutes sugar concentration by promoting vegetative growth, delaying sugar translocation into stalk tissues (25).

From a production standpoint, Keller and Numbu varieties hold greater promise for bioethanol feedstock due to their tendency toward higher sap concentration, while Suri appears less competitive given its low sap performance. Future breeding efforts may integrate these traits to balance biomass yield with sap quality.

Table 14. Effect of sorghum varieties and NPK fertilizer doses on sap levels

Treatment	Sap Content (% Brix)	
Super Varieties + NPK Dosage 0 g.plant^{-1}	11.67±0.23	ab
Super Varieties + NPK Dosage 10 g.plant^{-1}	11.67±0.29	ab
Super Varieties + NPK Dosage 12 g.plant^{-1}	10.33±0.35	ab
Super Varieties + NPK Dosage 14 g.plant^{-1}	11.67±0.32	ab
Super Varieties + NPK Dosage 16 g.plant^{-1}	11.00±0.29	ab
Suri variety + NPK dosage 0 g.plant^{-1}	13.00±0.29	ab
Suri Variety + NPK Dosage 10 g.plant^{-1}	8.33±0.35	a
Suri Variety + NPK Dosage 12 g.plant^{-1}	12.67±0.40	ab
Suri Variety + NPK Dosage 14 g.plant^{-1}	9.33±0.38	ab
Suri Variety + NPK Dosage 16 g.plant^{-1}	12.33±0.35	ab
Numbu Variety + NPK Dosage 0 g.plant^{-1}	12.67±0.32	ab
Numbu Variety + NPK Dosage 10 g.plant^{-1}	12.00±0.29	ab
Numbu Variety + NPK Dosage 12 g.plant^{-1}	11.67±0.35	ab
Numbu Variety + NPK Dosage 14 g.plant^{-1}	12.67±0.40	ab
Numbu Variety + NPK Dosage 16 g.plant^{-1}	12.33±0.35	ab
Keller Variety + NPK Dosage 0 g.plant^{-1}	10.67±0.29	ab
Keller Variety + NPK Dosage 10 g.plant^{-1}	10.00±0.35	ab
Keller Variety + NPK Dosage 12 g.plant^{-1}	14.00±0.46	b
Keller Variety + NPK Dosage 14 g.plant^{-1}	10.67±0.32	ab
Keller Variety + NPK Dosage 16 g.plant^{-1}	13.33±0.40	b

Note: Numbers followed by the same letters are not significantly different based on the DMRT at the 5% level.

Conclusion

This study highlights the significant role of varietal selection and nutrient management in improving sorghum performance under dryland conditions. Among the four tested genotypes, the Keller variety consistently produced superior results, including the highest plant height (307.39 cm), number of leaves (12.73), stem segments (11.13), stem diameter (26.99 cm), and maximum stem and whole-plant dry weights (58.64 g and 74.79 g, respectively). Keller also exhibited the best sap potential, reaching 14.0% Brix with 12 g plant^{-1} of NPK fertilizer, confirming its suitability as a dual-purpose sorghum variety for both biomass and sweet stalk utilization. Fertilizer responses indicated that moderate to high doses (12–14 g plant^{-1}) were optimal for vegetative growth and biomass accumulation, while higher doses showed no additional benefit. These findings suggest that combining Keller with efficient NPK management can enhance both yield and quality. Further multilocation trials are recommended to validate adaptability and refine fertilizer guidelines for sustainable sorghum cultivation.

Acknowledgments

The authors are grateful to Universitas Sebelas Maret, which funded this research through the scheme of the Mandatory Research of PNBP UNS fund (Contract Number: 254/UN27.22/PT.01.03/2022) for the fiscal year 2022.

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