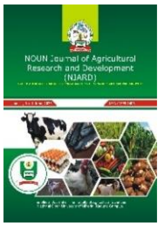
NOUN Jour. of Agric. Res. & Dev. Vol. 1, No.1, Page 30 - 36

p-ISSN: 1595-1405

NOUN Journal of Agricultural Research and Development (NJARD)

The Official Journal of the Faculty of Agricultural Sciences, National Open University of Nigeria, Kaduna Campus

Journal homepage: https://journal.agric.nou.edu.ng



Original Article

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Optimization of Tillage Practices for Enhanced Sorghum Productivity in Semi-Arid Nigeria

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Editor: *Dr. Sunday N. Obasi*
National Open University of Nigeria

Received: *April 10, 2025*
Accepted: *May 15, 2025*
Published online: *June 4, 2025*
Peer-review: Externally peer-reviewed

Conflict of Interest: *The authors have no conflicts of interest to declare*

Financial Disclosure: *The authors declared that this study has received no financial support*

ABSTRACT

Sorghum (Sorghum bicolor (L.) Moench) is a critical cereal for food security in semi-arid regions, yet yields in Nigeria remain suboptimal due to inadequate agronomic practices. This study evaluated four tillage treatments: wide level disc (T1), disc harrow (T2), chisel harrow (T3) and zero tillage (T4) on sorghum growth and yield over two cultivation seasons from 2022 to 2023 in Gombe State, Nigeria. A 4-ha field, divided into four subplots with uniform agronomic practices, was used to measure plant height, tillering, and yield at 2, 4, 6, and 8 weeks after planting (WAP). Early vegetative growth was enhanced by T2 and T3, with taller plants at 6 WAP, though differences largely disappeared by 8 WAP. In season 2, T3 and T2 increased yields by 43.6% and 33.4% over T1, respectively, while T4 showed more modest gains. These results highlight the importance of context-specific tillage strategies. For example, deeper chisel harrowing may be best suited to heavier soils, whereas shallower disc harrowing can optimize moisture retention, root penetration, and nutrient availability in drier, lighter-textured fields. Based on our findings, chisel and disc harrowing are recommended for enhancing sorghum productivity under semi-arid conditions.

Keywords: *Crop yield, Semi-Arid Agriculture, Sorghum bicolor, Sustainable Agriculture, Tillage*

1.0 INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench), a cereal native to Africa, ranks as the fifth most important globally, following wheat, maize, rice, and barley (Rather *et al.*, 2023). It serves as a staple food and livestock feed in Asia and Africa, with its stalks utilized for fodder, construction, and biofuel production due to their high sugar and starch content. The grain is nutritionally rich, containing 70–80% carbohydrates, 11–13% protein, and 2–5% fat, and is also used in ethanol production for renewable energy (Lim & Lim, 2013). Sorghum thrives in arid and semi-arid regions, performing well in low-nutrient soils with annual rainfall between 400–800 mm (FAOSTAT, 2017). In Nigeria, sorghum production was estimated at seven million metric tons in 2022, making it one of the top producers globally. However, yields in Nigeria (approximately 1,192 kg ha^{-1}) lag behind global averages, indicating significant potential for improvement (Sasu, 2024, September 30). Given Africa's rapid population growth and the increasing demand for resilient crops, sorghum's rapid growth, high tillering, and drought tolerance position it as essential for food security and livestock sustainability (Hossain *et al.*, 2022).

The importance of agricultural mechanization in enhancing crop yields and maintaining soil health amid climate variability has been emphasized (Amare & Endalew, 2016; Peng *et al*., 2022; Liu & Li, 2023). In sub-Saharan Africa, despite sorghum's significance, its productivity remains suboptimal due to inadequate soil management and tillage practices (Tonitto & Ricker-Gilbert, 2016; Masaka *et al*., 2020; Ciampitti *et al*., 2020; Mabasa *et al*., 2025). While mechanization advancements have benefited major crops like maize and rice, optimizing tillage for sorghum, especially in semi-arid environments, has received limited attention (Singh *et al*., 2020; Kumar *et al*., 2023). Despite the critical role of tillage in crop establishment and resource use, empirical data on its specific impact on sorghum productivity in semi-arid Gombe State remain scare. Studies suggest that reduced soil disturbance can enhance early vegetative growth by improving root penetration and moisture retention (Salahin *et al*., 2021; Yu *et al*., 2024); however, the long-term impacts on plant height, tillering, and grain yield are not fully understood.

In Nigeria, inconsistent agronomic practices and varying tillage methods hinder sorghum yields. Environmental factors, including seasonal fluctuations in rainfall and soil fertility, further complicate the relationship between tillage and crop performance (Ahmad Yahaya *et al*., 2022). Although conservation tillage has been linked to improved early growth, its sustainability and scalability for sorghum require comprehensive field validation in semi-arid regions like Gombe State (Mwamahonje *et al*., 2024).

This study aims to evaluate the effects of four tillage treatments: wide-level disc, disc harrow, chisel harrow, and zero tillage, on sorghum growth and yield over two consecutive cultivation seasons in a semi-arid Nigerian environment. Conducted on a 4-hectare field subdivided into four subplots, the research assesses key growth parameters such as plant height, tillering, and yield at multiple stages. Using a robust experimental design and advanced statistical analyses, the study seeks to elucidate the interactions between tillage practices, soil conditions, and crop performance. Ultimately, the objective is to refine tillage strategies that optimize sorghum productivity. The findings hold significant implications for sustainable agriculture, as improved tillage management could enhance yield, maintain soil health, and contribute to food security in resource-limited, semi-arid regions of Nigeria.

2. MATERIALS AND METHODS

2.1 Study Location

The experiment was conducted in Gadam community, Kwami Local Government Area, Gombe State, Nigeria (Figure 1). The area is characterized by a semi-arid climate with an annual rainfall of 600–900 mm concentrated during the wet season (May–October) (National Bureau of Statistics, 2019; Gombe State Agricultural Development Programme, 2020; Nigerian Meteorological Agency, 2023). Soils in the region are predominantly sandy loam - typically composed of about 60 - 70% sand, 20 - 30% silt, and 10 - 15% clay - which confer good drainage and aeration but relatively low water-holding capacity. Surface horizons (0 - 20 cm) generally exhibit pH values in the slightly acidic to neutral range (6.2 - 7.0), organic carbon contents of 0.8 - 1.5%, and moderate cation exchange capacities (5 - 10 cmol(+)/kg). Bulk densities average 1.4 g/cm³, reflecting a loose structure that supports rapid root penetration. Although inherently moderate in native fertility, these soils respond well to residual moisture and minimal tillage, making them suitable for rain-fed cultivation of drought-tolerant staples such as sorghum, millet, maize, Bambara nut, and cowpea (Mayomi *et al*., 2018; Gombe State Ministry of Agriculture, 2021; Tugga *et al*., 2023).

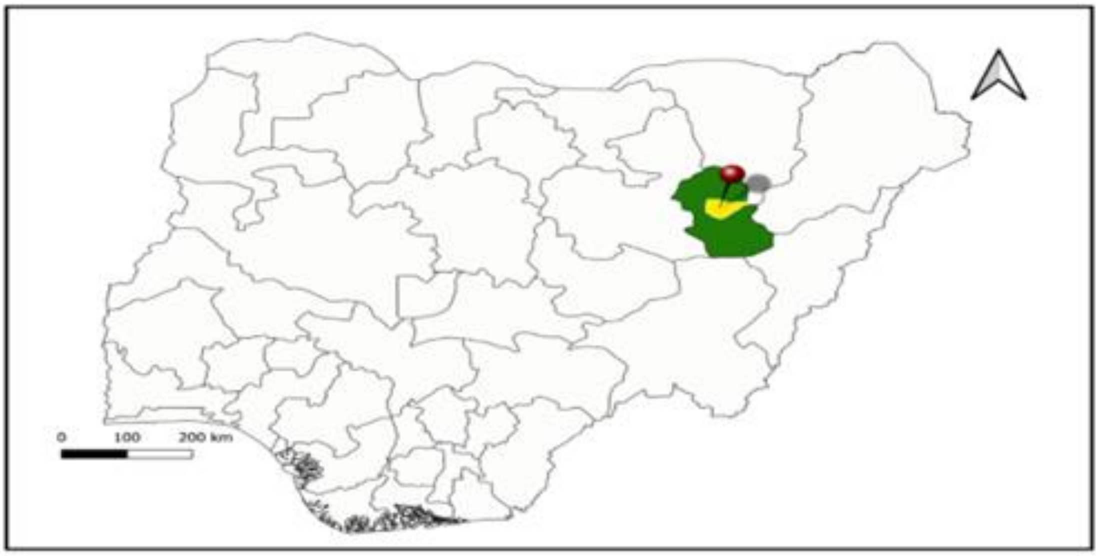

Fig 1. Gadam in Kwami Local Government Area of Gombe State, Nigeria.

2.2 Experimental Design

The field for this study comprised a 4-ha area, which was divided into four 1-ha blocks. Each block was further subdivided into four 0.25-ha subplots, yielding 16 total plots. The trial ran over two consecutive seasons (June - September 2022 and June - September 2023) to assess the effects of tillage on sorghum growth and yield. A randomized complete block design (RCBD) was employed: within each block, the four tillage treatments - wide-level disc (T1), disc harrow (T2), chisel harrow (T3), and zero tillage (T4) - were randomly assigned to one subplot apiece. All agronomic operations (crop residue management, fertilizer application, weeding, etc.) were applied uniformly to every subplot to isolate the tillage effect. This layout ensured that each treatment was replicated four times across the blocks, providing robust, block-accounted comparisons.

2.3 Data Collection

At each sampling date (2, 4, 6, and 8 weeks after planting, plus at harvest), ten plants per subplot were randomly selected using a random-number grid to ensure unbiased coverage. For each selected plant, plant height (cm) was measured from the soil surface to the tip of the main panicle, and tillering was recorded as the count of all tillers ≥ 5 cm in length. At physiological maturity, grain yield was determined by harvesting all plants within a centrally located 2 m × 2 m quadrat in each subplot; panicles were threshed, oven-dried to 12% moisture, and weighed, with yield expressed as kg ha^{-1}.

2.4 Data Analysis

All statistical analyses were conducted using IBM SPSS Statistics Version 27. Prior to analysis of variance, residuals for each response variable were tested for normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test); both assumptions were met ($p > 0.05$). One-way ANOVA was then applied to assess the effects of tillage treatments on plant height, tiller number, and grain yield. Where ANOVA indicated significant treatment effects, pairwise mean comparisons were performed using LSD at $\alpha = 0.05$.

3. RESULTS AND DISCUSSIONS

3.1 Effect of Tillage on Plant Height

Tillage practices significantly influenced plant height across all growth stages in both seasons, with distinct temporal trends observed. In the first season as shown in Table 1, plant height increased progressively across treatments, with chisel harrowing (T3) consistently yielding taller plants from 2 to 8 weeks after planting (WAP). Notably, at 6 WAP, plants under disc harrow (T2) and chisel harrow (T3) reached 66.05 cm and 67.85 cm, respectively, compared to 51.15 cm under zero tillage (T4). By 8 WAP, however, these differences diminished, suggesting that the initial advantages conferred by tillage may be moderated by later-stage soil and environmental factors.

Table 1: Effect of tillage on plant height in first season

Treatment	2^{nd} WAP	4^{TH} WAP	6^{TH} WAP	8^{TH} WAP
T1 (wide level disc)	15.89^{a}	32.94^{a}	53.22^{a}	87.10^{a}
T2 (Disc harrow)	19.01^{a}	34.87^{a}	66.05^{a}	90.45^{a}
T3 (Chisel harrow)	20.51^{a}	41.02^{a}	67.85^{ab}	89.11^{a}
T4 (Zero tillage)	16.11^{a}	33.10^{a}	51.15^{ab}	85.92^{a}
LSD	6.48	8.38	10.35	10.64

Table 2: Effect of tillage on plant height in second season

Treatment	2^{nd} WAP	4^{TH} WAP	6^{TH} WAP	8^{TH} WAP
T1 (Wide level disc)	16.92^{a}	29.85^{a}	56.89^{a}	91.05^{a}
T2 (Disc harrow)	16.15^{a}	32.11^{a}	67.98^{b}	98.01^{a}
T3 (Chisel harrow)	20.50^{a}	35.00^{a}	65.96^{b}	91.82^{a}
T4 (Zero tillage)	16.50^{a}	26.95^{a}	59.00^{a}	93.00^{a}
LSD	9.58	9.57	8.75	49.87

In the second season as shown in Table 2, similar trends emerged, albeit with greater variability. At 6 WAP, T2 and T3 again produced significantly taller plants (67.98 cm and 65.96 cm, respectively) relative to wide level disc (T1) and zero tillage (T4). Interestingly, at 8 WAP, the advantage of chisel harrowing (T3) diminished, while disc harrowing (T2) maintained the highest plant height at 98.01 cm. This compensatory growth, or "catch-up" effect, occurs when the initial root and shoot benefits from chisel tillage are eventually matched and surpassed by disc-tilled plants as their root systems mature and soil conditions equilibrate (Lu *et al*., 2025). Zero tillage (T4) eventually exhibited comparable plant height to tilled treatments, indicating that factors such as nutrient availability, moisture retention, and root system adaptability may eventually override early tillage benefits.

Early-season height gains under disc (T2) and chisel harrowing (T3) reflect the benefits of reduced soil strength and improved physical properties, as manual tillage was shown by Ogundare *et al*. (2015) to enhance root penetration and boost sorghum yield compared to no-till. However, by 8 WAP, plants under zero tillage "caught up," a pattern reminiscent of compensatory root growth described by Unger and Kasper (1994), who noted that roots avoid compacted zones and exploit less impeded soil layers, thereby mitigating early tillage advantages. Moreover, Pittelkow *et al*. (2015) found that no-till systems in dry climates often match conventional tillage yields, suggesting that moisture conservation under zero tillage can offset initial establishment delays. These studies indicate that while intensive tillage accelerates early shoot and root development, later-season soil–plant interactions, including moisture retention and compensatory rooting, can equalize height differences across tillage systems.

3.2 Effect of Tillage on Plant Tillering

Across both seasons, tillage treatments produced modest but statistically non-significant differences in sorghum tiller number ($p > 0.05$), with chisel harrowing (T3) and zero tillage (T4) generally promoting higher tiller numbers compared to other treatments (Tables 3 and 4). Table 3 showed the first season where zero tillage (T4) recorded the highest average tiller count (1.75 tillers at 2 WAP), followed by chisel harrowing (T3) at 1.25 tillers, while disc harrowing (T2) produced the fewest (0.75 tillers). By 4 WAP, both T3 and T4 reached an average of 2.00 tillers, a trend that persisted through 8 WAP, suggesting that minimal soil disturbance may enhance early tiller development, possibly through improved soil moisture retention and reduced root disruption.

Table 3: Effect of tillage on plant tillers in first season

Treatment	2nd WAP	4TH WAP	6TH WAP	8TH WAP
T1 (Wide-level disc)	1.00[a]	1.50[a]	1.50[a]	1.50[a]
T2 (Disc harrow)	0.75[a]	1.50[a]	1.50[a]	1.50[a]
T3 (Chisel harrow)	1.25[a]	2.00[a]	2.00[a]	2.00[a]
T4 (Zero tillage)	1.75[a]	2.00[a]	2.00[a]	2.00[a]
LSD	1.51	1.51	1.26	1.35

Table 4: Effect of tillage on plant tillers in second season

Treatment	2nd WAP	4TH WAP	6TH WAP	8TH WAP
T1 (Wide-level disc)	0.75[a]	1.50[a]	1.50[a]	1.50[a]
T2 (Disc harrow)	1.50[a]	1.75[a]	1.75[a]	1.75[a]
T3 (Chisel harrow)	2.00[a]	2.00[a]	2.25[a]	2.25[a]
T4 (Zero tillage)	1.00[a]	1.25[a]	1.50[a]	1.75[a]
LSD	1.38	0.95	1.06	1.08

Table 5: Effect of Different Tillage Treatments on Sorghum Yield (kg/ha) and Increase Percentage Over Wide Level Disc in First Season

Treatment	Mean Yield	Increase of yield over check (%)
T1 (Wide-level disc)	555.36[a]	-
T2 (Disc harrow)	603.57[a]	8.68
T3 (Chisel harrow)	696.43[a]	25.40
T4 (Zero tillage)	577.98[a]	4.07
LSD	102.08	

In the second season (Table 4), a similar pattern emerged: at 8 WAP, chisel harrowing (T3) averaged 2.25 tillers and zero tillage (T4) 1.75, with wide-level disc (T1) and disc harrowing (T2) producing fewer tillers. Again, none of these differences reached statistical significance ($p > 0.05$), likely due to high variability from seasonal rainfall, soil fertility, and microclimate factors. These observations align with previous reports on tillage's influence on sorghum growth (Mishra *et al*., 2019; Mrubata *et al*., 2024). Overall, while chisel harrowing and zero tillage tended to promote early tillering, the lack of statistically significant separation underscores the need for further study into how soil-plant interactions and environmental variability govern productive tiller formation and final yield.

3.3 Effect of Tillage on Yield

In the first season, sorghum yield varied among the tillage treatments, with mean yields of 555.36, 603.57, 696.43, and 577.98 kg/ha for treatments T1, T2, T3, and T4 respectively (Table 5). Although T3 recorded the highest yield, an increase of 25.40% over the wide level disc check (T1), all treatments were statistically similar given the LSD of 102.08 kg/ha. This suggests that while there is a numerical trend favouring more intensive tillage methods (particularly T3), variability within the data prevented a statistically significant differentiation among treatments in the first season.

In the second season (Table 6), yield differences were more pronounced. Wide-level disc (T1) produced 559.52 kg ha^{-1}, while disc harrow (T2) and chisel harrow (T3) achieved significantly higher yields of 746.43 kg ha^{-1} and 803.57 kg ha^{-1}—33.41% and 43.62% above wide-level disc (T1), respectively. Zero tillage (T4) yielded 622.62 kg ha^{-1}, a modest 11.28% increase. With an LSD of 68.02 kg ha^{-1}, the clear advantage of disc and chisel harrowing underscores their capacity to enhance sorghum productivity, likely through improved soil structure and root development.

Table 6: Effect of Different Tillage Treatments on Sorghum Yield (kg/ha) and Increase Percentage Over Wide Level Disc in Second Season

Treatment	Mean Yield	Increase of yield over check (%)
T1 (Wide-level disc)	559.52[a]	-
T2 (Disc harrow)	746.43[b]	33.41
T3 (Chisel harrow)	803.57[b]	43.62
T4 (Zero tillage)	622.62[a]	11.28
LSD	68.02	

These results align with Mishra *et al*. (2019), who found that conventional tillage boosted sorghum grain yield by 14% over reduced tillage and 58% over no-till, although no-till systems suffered higher weed densities. Our T4's modest gains further highlight the trade-off: zero tillage conserves moisture and maintains soil structure but can exacerbate weed pressure and nutrient stratification (Mbasa *et al*., 2025). Laborde *et al*. (2020) note that the full benefits of reduced-tillage emerge only after multiple seasons in low-rainfall climates, while Shaheb *et al*. (2021) caution that repeated deep tillage may re-compact soil if compaction management (e.g., controlled traffic) is not practiced. Taken together, these findings demonstrate that optimizing sorghum productivity requires balancing early root and moisture advantages against mid-season weed, compaction, and nutrient challenges. Integrating tillage with precision water, nutrient, and traffic management is essential for long-term yield stability.

3.4 Implications and Limitations

This two-season study highlights the variability inherent in semi-arid sorghum systems and underscores the importance of multi-year trials. However, its scope was constrained by potential soil heterogeneity within plots, varying pest and disease pressures, and a relatively uniform fertilizer regime that may not reflect on-farm variability. These factors, combined with seasonal rainfall fluctuations and background soil fertility, likely contributed to the observed yield and tillering variability.

For farmers in semi-arid regions with access to mechanization, disc and chisel harrowing should be prioritized to boost early sorghum growth and improve yields. Yet, because height advantages diminish later in the season and tillering differences proved statistically insignificant, tillage should be integrated with site-specific management, including targeted residue management, crop rotation, and adaptive fertilization, to sustain benefits. Future research ought to extend to multi-year, multi-site trials that account for long-term soil structure dynamics, pest/disease cycles, and variable nutrient management to refine sustainable tillage strategies for sorghum.

4. CONCLUSION

This study demonstrates that tillage exerts a significant, yet dynamic, influence on sorghum growth and yield in semi-arid Nigerian conditions. Both disc and chisel harrowing consistently accelerated early vegetative development, producing taller plants and a modest boost in tiller number during the first six weeks, while zero tillage caught up by later stages through compensatory root growth and moisture conservation. Yield advantages under disc (33.4% increase) and chisel (43.6% increase) harrowing in the second season underscore their capacity to enhance productivity when moisture is sufficient, although first-season variability and the statistically non-significant tillering differences highlight the overriding roles of rainfall distribution, soil heterogeneity, and pest pressures.

For practitioners, these findings translate into site-specific recommendations. On heavier or more moisture-retentive soils, adopt disc or chisel harrowing to maximize early root penetration and shoot growth. In contrast, consider zero tillage on lighter, drier fields to conserve moisture. In all cases, tillage should be paired with tailored residue management, precision fertilization, and effective weed control. Controlled traffic and periodic subsoiling should be integrated to prevent compaction build-up under repeated deep tillage.

Looking ahead, future research must pursue multi-year, multi-site trials that capture long-term soil organic matter dynamics, pest and disease cycles, and variable nutrient regimes. Moreover, investigations into the integration of tillage with precision water, nutrient, and traffic management will be critical to achieving sustained yield improvements and resilient sorghum systems in resource-limited semi-arid landscapes.

Acknowledgments

The authors sincerely appreciate the Gadam community in Kwami Local Government Area, Gombe State, for their invaluable support and provision of necessary resources for this study. We are also grateful to the farmers, field technicians, and research assistants whose efforts were instrumental in data collection and fieldwork.

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