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Weed Dynamics and Yield of Groundnut (*Arachis hypogaea* L.) as Influenced by Variety and Plant Population

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Abstract
Field trials were conducted during the 2023 rainy season at Bayero University Kano (BUK) and Minjibir to evaluate the effects of groundnut variety and plant population on weed dynamics, crop growth, and yield. The experiment followed a 5 × 3 factorial arrangement, comprising five groundnut varieties of four improved (SAMNUT-21, SAMNUT-23, SAMNUT-24, SAMNUT-27) and one local (Maibargo) and three plant populations (15,000,000, 22,500,000, and 30,000,000 plants ha^{-1}). Treatments were laid out in a randomized complete block design (RCBD) with three replications. Soil analysis revealed contrasting characteristics between locations: BUK had predominantly loamy sand (86% sand) with relatively higher calcium content (Ca^{2+} = 5.8 cmol kg^{-1}), while Minjibir's soil, a sandy loam with higher clay content (8.8%), contained greater levels of micronutrients such as iron (Fe = 212.59 ppm). Significant ($p < 0.05$) varietal effects on weed morphology were observed at Minjibir, where SAMNUT-24 and Maibargo suppressed broadleaf weeds, and SAMNUT-23 and SAMNUT-24 reduced sedge density. Plant population had a highly significant effect ($p < 0.001$) on broadleaf and grass weed suppression at both sites, with the highest density (30,000,000 plants ha^{-1}, corresponding to 30 cm spacing) showing the greatest suppression. Growth traits varied among varieties, with SAMNUT-21 exhibiting the tallest plants (8.1 cm) and Maibargo producing the highest dry matter (68.7 g). SAMNUT-23 recorded the highest pod and kernel yields at both BUK (1013.7 and 599.7 kg ha^{-1}) and Minjibir (639.6 and 363.9 kg ha^{-1}). Although higher plant densities enhanced weed suppression, they reduced yield due to intra-species competition. The optimal pod and kernel yield at BUK (570.4 and 334.2 kg ha^{-1}) was achieved at the lowest density (15,000,000 plants ha^{-1}).

Keywords: Plant Population Density, Varietal Performance, Crop Yield, Weed Suppression, Groundnut.

Introduction
Groundnut (*Arachis hypogaea* L.) is a vital grain legume and oilseed crop cultivated extensively across tropical and subtropical regions due to its adaptability to diverse climatic conditions, moderate resistance to diseases, and multifaceted benefits. The crop is a rich source of oil (43-55%), protein (25-28%), and essential minerals such as sodium, zinc, calcium, and iron, as well as vitamins E, K, and B-complex (Abady et al., 2019), making it a valuable food and feed resource for both humans and livestock (Bakal et al., 2020; Yilmaz et al., 2022). Groundnut also plays a critical ecological role by enhancing soil fertility through biological nitrogen fixation, making it a preferred component in crop rotations (Stewart et al., 2020; Ladha et al., 2023). In 2020, global production reached 53.7 million tonnes, with Asia and Africa contributing over 90% of the output, highlighting its importance in the agricultural economies of developing regions (FAO, 2022).

Despite its nutritional and economic significance, groundnut productivity remains constrained by weed infestation, which competes with the crop for essential resources like light, water, and nutrients, leading to substantial yield losses. Weed dynamics in groundnut cultivation are significantly influenced by factors such as plant population density and

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varietal characteristics. Higher plant densities can reduce weed pressure by limiting space and resources available for weed establishment, while certain varieties exhibit superior competitive traits through rapid canopy closure and allelopathic effects (Abdulrahman et al., 2024; Ibrahim et al., 2021; Rahman et al., 2024). However, the specific interactions between variety selection, plant population, and weed suppression remain underexplored, especially across different agroecological zones. This knowledge gap underscores the need for comprehensive research to optimize agronomic practices that enhance groundnut performance while minimizing reliance on chemical herbicides. Addressing this issue is particularly vital in the context of sustainable agriculture, where resource use efficiency and environmental health are prioritized. Prior studies have shown that integrated weed management strategies combining optimal sowing density and variety selection can improve crop yield and reduce weed biomass (Dolie & Nongmaithem, 2020; Musa, 2023), but there is limited empirical evidence on their combined effects in groundnut systems.

The study is anchored in ecological weed management and resource competition theory, which posit that crops and weeds compete for finite growth resources. Modifying crop architecture through variety selection and adjusting plant population can confer competitive advantages to the crop, suppressing weed growth and enhancing yield (Abdulrahman et al., 2024; Ibrahim et al., 2021). Ecological principles suggest that cultural practices, such as high-density planting and selecting vigorous varieties, can shift the competitive balance in favor of the crop and reduce the need for herbicides.
Therefore, the main objective of this study is to evaluate the effects of variety and plant population on weed dynamics, growth, and yield of groundnut. Specifically, it seeks to:

i. determine how different groundnut varieties affect weed suppression and crop performance;
ii. assess the influence of varying plant population densities on weed competition and productivity; and
iii. identify the optimal combinations of variety and plant population for enhanced yield and sustainable weed control.

Materials and Methods
Field trials were carried out during the 2023 rainy season at the Teaching and Research Farm of the Faculty of Agriculture, Bayero University Kano (Latitude 11°58′ N and Longitude 8°41′ E) and IAR Research Farm, Minjibir, Kano (Latitude 12°17′ N and Longitude 8°55′ E), to evaluate the effects of groundnut variety and plant population on weed dynamics, crop growth, and yield. The experiment followed a 5 × 3 factorial arrangement, comprising five groundnut varieties of four improved (SAMNUT-21, SAMNUT-23, SAMNUT-24, SAMNUT-27) and one local (Maibargo) and three plant populations (15,000,000, 22,500,000, and 30,000,000 plants ha^{-1}). Treatments were laid out in a randomized complete block design (RCBD) with three replications. The treatments were factorially combined and laid out in a randomized complete block design (RCBD), replicated three times. Each plot had a total of six ridges of 4.8 m long and a width of 4.5 m, making a gross plot size of 21.6 m², while the net plot size comprised four inner rows (14.4 m²). An alley of 0.5 m and 1.0 m was left to separate plots within and between replicates. Seeds were sown directly into the field at two seeds per hole at a depth of 2-3 cm by the dibbling method on a ridge of 75 cm, and the varied intra-row spacing was as per treatment required. Weeds were controlled manually hoeing at 3 and 6 weeks after sowing (WAS). Harvest was carried out when the crop attained physiological maturity. Plants within the net plots were harvested manually using a hoe; the pods were detached from the haulm and allowed to dry for several days under the sun. Data was collected on pod, kernel, and haulm yield. The data obtained was subjected to a two-way analysis of variance (ANOVA) via GenStat statistical software. Means were compared using the Student Newman's Keuls Test (SNK) at the 5% level of probability.

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Results

Table 1: Physical and Chemical properties of soil of the Experimental sites during the 2023 wet season.

Soil Properties	BUK	Munjibir
Physical (g kg^{-1})		
Sand	860.0	844.0
Silt	86.0	68.0
Clay	54.0	88.0
Texture	Loamy sand	Sandy loam
Chemical composition		
pH in water (1:2.5)	6.6	6.0
Organic compound (g kg^{-1})	4.3	3.2
Total nitrogen (g kg^{-1})	1.4	1.2
Available phosphorus (mg kg^{-1})	5.9	5.6
Exchangeable Bases		
Ca++	5.8	2.1
Mg++	2.7	0.3
K++	0.1	0.1
Na++	0.1	0.4
CEC (cmol kg^{-1})	9.0	7.0
EC (ds m^{-1})	0.03	0.02
EA (cmol kg^{-1})	0.3	0.1
Micronutrients (ppm)		
Cu	4.65	3.92
Zn	209.47	186.2
Fe	170.00	212.59
Mn	90.21	66.68

Source: Department of Soil Science, Bayero University Kano.

Table 2 illustrates how different groundnut varieties and plant populations influenced weed morphology at BUK and Minjibir during the 2023 rainy season. The results reveal significant varietal effects on weed morphology only at Minjibir and population dynamics at both locations, emphasizing the importance of genotype selection and plant density in weed suppression strategies. At BUK, the varietal influence on weed types was statistically non-significant ($p > 0.05$), suggesting that all tested varieties had relatively similar weed-suppressive capacities. However, at Minjibir, significant ($p < 0.05$) varietal effects were observed on broadleaf weeds and sedges. SAMNUT-24 and Maibargo were associated with reduced broadleaf weed incidence, while SAMNUT-23 and SAMNUT-24 had lower sedge populations. These results suggest that certain groundnut genotypes may naturally exhibit better weed suppression, possibly due to differences in canopy architecture or allelopathic properties. This finding aligns with studies highlighting the role of crop genotype in suppressing weed growth. Daramola et al., (2023) and Kabir et al. (2025) separately reported that certain groundnut varieties exhibited improved weed suppression due to faster canopy closure. Similarly, Shittu et al., (2023) and Bansal et al. (2024) emphasized the effectiveness of genotype selection in integrated weed management systems.

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Plant density had a highly significant ($p < 0.01$) effect on broadleaf and grass weed suppression at both sites, with the 30,000,000 plants/ha population achieving the greatest reduction in weed incidence. This supports the idea that higher plant density reduces available space, light, and nutrients for weed establishment. This outcome is consistent with findings from Burgess and Cardoso (2023), who observed enhanced weed suppression under dense plantings due to increased canopy coverage. Yohannes et al. (2022) also reported that optimal plant spacing limits light penetration and resource competition, thereby suppressing weed growth. The interaction between groundnut variety and plant population density had a significant effect on weed morphology, specifically on broadleaf and grass weed incidence at Minjibir, as presented in Table 3. The results show that SAMNUT-24 and SAMNUT-27, when planted at a high density of 30,000,000 plants per hectare, achieved the greatest weed suppression. This finding underscores the role of plant density in amplifying the weed-suppressive traits of specific varieties, likely due to faster canopy closure and greater ground cover, which reduce light availability for weed germination and growth. This interaction effect supports the principle that genotype performance in weed suppression is not fixed, but context-dependent, particularly on spatial planting arrangements. Recent studies have confirmed that higher planting densities in groundnut can significantly reduce weed biomass and improve resource-use efficiency, especially when paired with competitive varieties such as SAMNUT-23 and SAMNUT-24 (Kabir et al., 2025). Similarly, Negewo et al. (2024) demonstrated that integrated crop management practices, including optimal spacing and variety selection, substantially reduce weed infestation and maximize yield in Ethiopian agro-ecologies. These results highlight the importance of integrated varietal and spatial planning as a sustainable weed management approach as described by Gebeyehu (2020). It reduces the need for synthetic herbicides, lowers input costs, and improves both environmental outcomes and yield potential particularly in smallholder and low-input farming systems.

Table 2: Influenced of groundnut variety and plant population on Weed morphology at BUK and Minjibir during 2023 rainy season.

	BUK			Minjibir		
Treatment	Broad leaf	Grasses	Sedges	Broad leaf	Grasses	Sedges
Variety (V)						
SAMNUT- 21	44.3(6.6)	13.5(3.5)	5.1(2.3)	56.2ab(2.9a)	16.7(3.9)	9.1a(3.0)
SAMNUT -24	32.6(5.6)	16.6(4.0)	7.0(2.6)	41.8c(2.7b)	10.8(3.3)	3.6b(2.0)
SAMNUT -23	39.8(6.2)	9.8(3.2)	4.8(2.3)	46.1ac(2.7ab)	8.1(2.8)	2.5b(1.7)
SAMNUT -27	38.8(6.1)	13.2(3.6)	4.1(2.0)	56.7a(2.9a)	8.0(2.7)	4.3b(2.0)
Maibargo	32.7 (5.6)	9.4(3.1)	2.8(1.7)	41.0c(2.7b)	13.5(3.5)	6.3ab (2.5)
Fprob	0.099 (0.079)	0.216(0.263)	0.378(0.433)	0.003(0.004)	0.052(0.090)	0.007(0.063)
SE±	3.39 (0.27)	2.38(0.30)	1.43(0.32)	3.36(0.04)	2.29(0.35)	1.23(0.32)
Plant population (P)						
15,000,000	23.2c(4.8)	7.7b(2.8a)	4.5(2.2)	42.0b(2.7)	6.6b(2.6b)	4.1(2.0)
22,500,000	35.2b(5.9)	14.7a(3.8a)	4.8(2.1)	50.3a(2.8a)	12.6a(3.4a)	5.3(2.3)
30,000,000	54.6a(7.4)	15.2a(2.8)	5.0(2.2)	52.8a(2.8a)	15.0a(3.7a)	6.1(2.4)
Fprob	0.001(0.001)	0.013(0.006)	0.944(0.952)	0.016(0.016)	0.007(0.016)	0.345(0.485)
SE±	2.63(0.21)	2.38(0.23)	1.11(0.25)	2.60(0.03)	1.77(0.27)	0.95(0.25)
Interaction						
V x P	0.416(0.285)	0.343(0.273)	0.727(0.725)	0.002(0.002)	0.027(0.039)	0.448(0.805)

Means with common letter(s) in the same column are not significantly different at 5% probability level according to Students-Neuman Keuls (SNK
Value in parenthesis=transformed mean√+0.5.

Table 3: Interaction between groundnut variety and plant population on broad leaf and grasses at Minjibir during 2023 rainy season

Treatment		**Plant population (P)**	
	15,000,000	22,000,000	30,000,000
Variety (V)		**Broad leaf**	
SAMNUT-21	29.0c(2.5d)	51.0abc(2.8a-d)	52.3abc(2.8a-d)
SAMNUT-24	47.0abc(2.8a-d)	55.3abc(2.9a-d)	66.3a(3.0ab)
SAMNUT-23	36.3bc(2.6bcd)	50.6abc(2.6a-d)	35.6bc(2.6cd)
SAMNUT-27	64.3ab(3.0ab)	57.0abc(2.9abc)	68.3a(3.0a)
Maibargo	33.3c(2.6cd)	37.6bc(2.6a-d)	41.6abc(2.7a-d)
SE±		5.82	

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		Grasses	
SAMNUT-21	5.3b(2.3ab)	12.3ab(3.5ab)	15.0ab(3.8ab)
SAMNUT-24	12.3ab(3.5ab)	22.3ab(1.6b)	25.6a(5.1a)
SAMNUT-23	5.0b(2.3ab)	7.3ab(2.7ab)	12.0ab(3.3ab)
SAMNUT-27	7.3ab(2.8ab)	19.3ab(4.3ab)	14.6ab(3.6ab)
Maibargo	3.3b(2.0)	2.0b(1.6b)	8.0ab(2.9ab)
SE±		3.96	

Means with common letter(s) across row and column are not significantly different at 5% probability level according to Students-Neuman Keuls (SNK).

Table 4 reveal how different groundnut varieties and planting densities affect plant growth characteristics at two locations (BUK and Minjibir). Result indicate that plant height, crop growth rate (CGR) and LAI were not significantly influenced by varieties while at Minjibir, varietal effects were statistically significant for plant height and CGR. The SAMNUT-21 and SAMNUT-23 produced the tallest plants (8.1 cm and 8.0 cm, respectively), which is significantly higher than SAMNUT-24 (3.6 cm). SAMNUT-24 and SAMNUT-27 recorded the highest LAI (1.3), indicating a denser canopy, which can contribute to better weed suppression by reducing light penetration to the soil surface as previously reported by Yohannes et al. (2022). Increasing plant population to 30,000,000 plants/ha tended to enhance plant height (9.0 cm at BUK, 7.0 cm at Minjibir) and LAI (1.2 at Minjibir), although differences were not statistically significant ($p > 0.05$). The higher LAI at greater plant populations supports findings that increased density enhances canopy closure and limits weed emergence through shading which corroborates the findings of Burgess and Cardoso (2023) and Waclawowics et al. (2023). There were no significant ($p > 0.05$) interactions between variety and plant population at either location, indicating that the effect of each factor is largely independent in this case. However, trends suggest that varieties like SAMNUT-24 and SAMNUT-27 perform better in high-density conditions due to superior leaf area expansion, which could enhance both photosynthetic efficiency and weed suppression.

Table 4: Influence of variety and plant population on plant height, crop growth rate and leaf area index of groundnut at BUK and Minjibir during 2023 rainy season

	BUK			Minjibir		
Treatment	Plant height (cm)	CGR (g/wk)	LAI	Plant height (cm)	CGR (g/wk)	LAI
Variety (V)						
SAMNUT -21	9.7	9.7	0.6	8.1a	8.1a	0.9
SAMNUT -24	5.4	5.4	0.9	3.6b	3.6b	1.3
SAMNUT -23	6.6	6.6	0.8	8.0a	8.0a	1.1
SAMNUT -27	7.4	7.4	0.7	7.0ab	7.0ab	1.3
Maibargo	7.7	7.7	0.9	5.7ab	5.7ab	1.1
Fprob	0.435	0.435	0.858	0.030	0.030	0.420
SE±	1.590	1.590	0.1743	1.067	1.067	0.1525
Plant population (P)						
15,000,000	7.1	7.1	0.8	7.1	7.1	1.0
22,500,000	6.1	6.1	0.8	5.3	5.3	1.3
30,000,000	9.0	9.0	0.7	7.0	7.0	1.2
Fprob	0.254	0.254	0.797	0.239	0.239	0.240
SE±	1.232	1.232	0.1350	0.826	0.826	0.1182
Interaction						
V x P	0.844	0.844	0.837	0.658	0.658	0.405

Means with common letter(s) in the same column are not significantly different at 5% probability level according to Students-Neuman Keuls (SNK).

Table 5 demonstrates how different groundnut varieties and plant populations influenced key physiological traits PAR interception, photosynthetic rate, and dry matter accumulation at two distinct locations of BUK and Minjibir during 2023

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rainy season. The results revealed that the varietal differences were not statistically significant (p > 0.05) at either location for the measured parameters. At Minjibir, plant population had a significant effect on dry matter production where the lowest plant population (15,000,000 plants ha^{-1}) produced significantly (p < 0.05) more biomass (61.4 g) than 22,500,000 (49.6 g) and 30,000,000 plants ha^{-1} (50.0 g). This suggests that increased intra-specific competition at higher densities can suppress biomass accumulation per plant. These results are in agreement with findings that optimal spacing enhances resource-use efficiency and reduces stress, ultimately boosting productivity (Haile *et al*., 2022; Abukari *et al.*, 2024). At BUK, there is no significant density-related differences observed, implying that the influence of spacing may be location-dependent due to soil or climatic variations. There were no significant interactions between variety and plant population for any measured traits at both locations. This suggests that variety and spacing independently affected physiological responses.

Table 5: Influence of variety and plant population on photosynthetic active radiation (PAR), photosynthesis rate and dry matter production of groundnut at BUK and Minjibir during 2023 rainy season

Treatment	BUK			Minjibir		
	PAR	Photsnths	Dry matter production (g)	PAR	Photsnths	Dry matter production (g)
Variety (V)						
SAMNUT -21	20.8	1.2	63.9	30.9	0.1	49.8
SAMNUT -24	40.8	0.7	60.6	36.1	0.1	48.2
SAMNUT -23	28.5	0.5	63.9	32.7	0.1	59.6
SAMNUT -27	28.6	0.2	62.7	38.4	0.1	57.4
Maibargo	29.4	0.5	68.7	40.6	0.1	53.4
Fprob	0.276	0.608	0.856	0.547	0.966	0.099
SE±	6.16	0.435	5.21	4.49	0.0678	3.28
Plant population (P)						
15,000,000	29.5	1.0	61.6	31.9	0.09	61.4a
22,500,000	29.3	0.6	59.8	38.2	0.1	49.6b
30,000,000	30.2	0.3	70.5	37.3	0.1	50.0b
Fprob	0.990	0.336	0.152	0.392	0.512	0.003
SE±	4.77	0.337	4.04	3.48	0.0525	2.54
Interaction						
V x P	0.775	0.352	0.979	0.313	0.439	0.184

Means with common letter in the same column are not significantly different at 5% probability level according to Students-Neuman Keuls (SNK).

The influence of groundnut varieties and plant population densities on yield and yield components such as pod and kernel production at two locations (BUK and Minjibir) is presented in Table 6. The results show significant varietal effects on all measured traits, while plant population was significant in only few parameters. At both BUK and Minjibir, SAMNUT-23 significantly (p < 0.001) outperformed all other varieties in pod number (24.8 and 16.2 pods stand^{-1}), pod weight (16.0 g and 10.4 g), kernel number (28.5 and 18.0 kernels stand^{-1}), kernel yield per stand (8.9 g and 5.0 g), and overall pod and kernel yield (1013.7 and 639.6 kg ha^{-1}; 599.7 and 363.9 kg ha^{-1}, respectively). These results highlight its superior reproductive potential and yield performance under the conditions tested. Other varieties like SAMNUT-24 and SAMNUT-27 recorded intermediate yield levels, while Maibargo and SAMNUT-21 were generally lower yielding, although Maibargo had relatively better performance in kernel and pod yield than SAMNUT-21 at BUK. The strong varietal influence, consistent across both locations, suggests a dominant genetic effect on yield traits, as also reported in previous genotype × environment studies (Patil *et al.,* 2020; Yami *et al.*, 2025) At BUK, plant population significantly (p <0.001) affected kernel number per stand, pod yield, and kernel yield. The 15,000,000 plants/ha density recorded the highest pod and kernel yield (570.4 and 334.2 kg ha^{-1}), while 30,000,000 plants ha^{-1} gave the lowest kernel yield (117.9 kg ha^{-1}), suggesting a possible negative effect of excessive density on seed filling or pod set. At Minjibir, there was significant influence yield and yield related characters due to plant population effect.

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Table 6: Influence of variety and plant population on pod number stand^{-1}, pod weight stand^{-1}, kernel number stand^{-1}, kernel yield stand^{-1}, pod yield and kernel yield tha-1 of groundnut at BUK and Minjibir during 2023 rainy season

Treatment	BUK						Minjibir					
	Pod Number stand^{-1}	Pod Weight Stand^{-1} (g)	Kernel number stand^{-1}	Kernel yield stand^{-1} (g)	Pod yield (kg ha^{-1})	Kernel yield (Kg ha^{-1})	Pod Number stand^{-1}	Pod Weight Stand^{-1} (g)	Kernel number stand^{-1}	Kernel yield stand^{-1} (g)	Pod yield (kg ha^{-1})	Kernel yield (Kgha^{-1})
Variety (V)												
SAMNUT -21	7.1b	3.7b	9.7b	2.1b	168.6d	94.05c	7.2b	4.2b	11.1ab	2.2b	130.0c	69.3c
SAMNUT -24	10.1b	5.2b	13.4b	3.2b	271.8b	167.2b	8.8b	4.1b	11.4b	2.4b	177.1b	109.6b
SAMNUT -23	24.8a	16.0a	28.5a	8.9a	1013.7a	599.7a	16.2a	10.4a	18.0a	5.0a	639.6a	363.9a
SAMNUT -27	8.1b	5.6b	10.3b	2.7b	237.9c	120.4c	6.8b	4.7b	9.7ab	2.5b	262.3b	144.6b
Maibargo	5.5b	3.6b	7.8b	2.1b	386.7b	291.4b	5.3b	3.5b	6.7b	1.5b	306.1b	219.9b
Fprob	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.002	0.011	0.002	0.001	0.001
SE±	2.31	1.430	2.214	0.818	60.00	22.20	1.980	1.175	2.179	0.575	47.00	41.40
Plant population (P)												
15,000,000	11.7	6.7	17.4a	3.9	570.4a	334.2a	8.1	5.0	10.9	2.9	303.0	138.0
22,500,000	10.2	6.5	13.0ab	3.7	316.9b	221.5b	9.5	6.0	12.6	2.9	286.5	185.0
30,000,000	11.9	7.2	11.4b	3.8	270.0b	117.9c	9.0	5.1	10.4	2.7	229.5	124.5
Fprob	0.822	0.905	0.049	0.978	0.001	0.001	0.820	0.688	0.611	0.846	0.621	0.560
SE±	1.79	1.107	1.715	0.634	46.50	17.25	1.534	0.910	1.688	0.445	54.60	32.10
Interaction												
V x P	1.00	0.968	0.325	0.989	0.114	0.101	0.899	0.958	0.737	0.897	0.930	0.897

Means with common letter in the same column are not significantly different at 5% probability level according to Students-Neuman Keuls (SNK).

Discussion

The results of the physical and chemical properties of the soil at the experimental sites during the 2023 wet season are presented in Table 1. The findings show notable variations between the BUK and Minjibir locations in terms of soil texture, nutrient content, and overall fertility status. The soil at BUK is predominantly sandy (86.0%), with smaller proportions of silt (8.6%) and clay (5.4%), classifying it as loamy sand. Loamy sand soils are typically well-drained but have low water-holding capacity and limited nutrient retention (Brady and Weil, 2019). In contrast, Minjibir soil contains slightly less sand (84.4%), lower silt (6.8%), and higher clay (8.8%), classifying it as sandy loam. The increased clay content at Minjibir suggests slightly improved moisture and nutrient retention compared to BUK (FAO, 2021).

The pH of both soils falls within the slightly acidic range, with BUK at 6.6 and Minjibir at 6.0. Minjibir is more acidic, which may limit the availability of certain nutrients and may benefit from pH adjustments such as liming (Havlin *et al.*, 2016). Organic carbon content is low at both sites (4.3 g kg^{-1} (0.43%) in BUK and 3.2 g kg^{-1} (0.32%) in Minjibir, indicative of typical conditions in tropical soils and suggesting a need for organic amendments to improve fertility (FAO, 2021).

Total nitrogen levels are similarly low: 1.4 g kg^{-1} (0.14%) in BUK and 1.2 g kg^{-1} (0.12%) in Minjibir which could limit plant growth. Available phosphorus is also limited, at 5.9 mg/kg in BUK and 5.6 mg kg^{-1} in Minjibir, which may hinder root development and energy transfer in crops (Havlin *et al.,* 2016). Exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) are significantly higher in BUK (5.8 and 2.7 cmol kg^{-1}, respectively) compared to Munjibir (2.1 and 0.3 cmol kg^{-1}), indicating better base saturation in BUK. Potassium (K^+) remains low in both soils (0.1 cmol kg^{-1}), and sodium (Na^+) is higher in Munjibir (0.4 cmol kg^{-1}) than in BUK (0.1 cmol kg^{-1}). The CEC values are moderate, with BUK at 9.0 cmol kg^{-1} and Minjibir at 7.0 cmol kg^{-1}, suggesting BUK has a greater capacity to retain nutrients (Brady and Weil, 2019). Electrical conductivity (EC) is low in both sites, indicating no salinity issues. The exchangeable acidity (EA) is slightly higher in BUK (0.3 cmol kg^{-1}) than in Minjibir (0.1 cmol kg^{-1}), suggesting a slightly greater presence of acidic cations, although both values remain within acceptable limits for most crops (Havlin *et al.*, 2016).

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Micronutrients content in the order of iron (Fe) is present in high quantities in both soils, with higher levels in Minjibir (212.59 ppm) than in BUK (170.00 ppm), which supports chlorophyll synthesis and respiration. Zinc (Zn) is abundant, especially in BUK (209.47 ppm vs. 186.2 ppm in Minjibir), which is beneficial for plant enzyme activity. Copper (Cu) and manganese (Mn) are also adequate, with higher Mn in BUK (90.21 ppm) compared to Minjibir (66.68 ppm), and higher Cu in BUK (4.65 ppm) compared to Minjibir (3.92 ppm). These micronutrients are essential for various physiological processes in plants (Lilay et al., 2024). Both soils face fertility limitations such as low nitrogen and phosphorus levels, as well as low organic matter. However, BUK soil exhibits better nutrient-holding capacity due to higher CEC, base saturation, and organic carbon levels compared to Minjibir. Soil management strategies including organic amendments, balanced fertilization, and pH correction could enhance productivity in both sites.

Conclusion

Findings from the trials reveals SAMNUT-23 is the most productive, while SAMNUT-24 and -27 offer superior weed suppression in high-density systems. For balanced yield and weed control in low-input systems, SAMNUT-23 at 15,000,000 plants ha^{-1} is ideal. Where weed pressure is high, SAMNUT-24 or -27 at 30, 000,000 plants ha^{-1} is preferred to enhance ecological weed management.

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