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Productivity of Sunflower Varieties (*Helianthus annuus* L.) as Influenced by Intra Row Spacing and Phosphorus Fertilizer Rate in Sudan Savanna

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ABSTRACT
A bilocation trial assessed the productivity of sunflower (*Helianthus annuus* L.) varieties as influenced by intra row spacing and phosphorus rate in the Sudan Savanna, Nigeria. The experiment was conducted during the 2023 rainy season at Dutsin-Ma (Katsina State) and Bichi (Kano State). Treatments were a 3 by 3 by 3 factorial combination of three sunflower varieties (SAMSUN 1, SAMSUN 2, and SAMSUN 4), three intra row spacings (30, 40, and 50 cm), and three phosphorus rates (30, 60, and 90 kg P2O5 per hectare), in a Randomized Complete Block Design replicated three times. Variety, intra row spacing, and phosphorus rate significantly (P less than 0.05) influenced growth, yield, and yield components. SAMSUN 2 was the most suitable variety for Dutsin-Ma, while SAMSUN 1 suited Bichi best. An intra row spacing of 40 cm was best for Dutsin-Ma, while 30 cm was optimal for Bichi. Application of 60 kg P2O5 per hectare gave the highest yield at both locations, raising grain yield by 49.2 and 32.7 percent, and 27.9 and 24.7 percent over 60 kg P2O5 per hectare at Dutsin-Ma and Bichi, respectively. Economically, SAMSUN 2 sown at 40 cm with 30 kg P2O5 per hectare gave the best returns at Dutsin-Ma, while SAMSUN 1 sown at 50 cm gave the best returns at Bichi.

Keywords: Sunflower, Productivity, Variety, Intra-Row Spacing, Phosphorus Fertilizer

INTRODUCTION

Sunflower (*Helianthus annuus* L.) belongs to the family Asteraceae. *The Helianthus genus contains 65 different species (Kane et al.,* 2021). The name *Helianthus*, being derived from *Helios* (the sun) and *Anthos* (a flower), has the same meaning as the English name Sunflower, which has been given to these flowers from a supposition that they follow the sun by day, always turning towards its direct rays. Sunflower is an annual plant that possesses a large inflorescence (flowering head), and its name is derived from the flower's shape and image, which is often used to depict the sun. The plant has a rough, hairy stem, broad, coarsely toothed leaves, and circular heads of flowers (Echinacea, 2025). Sunflower heads (capitula) are composed of numerous individual florets, sterile ray florets around the periphery, and fertile disk florets centrally arranged on a flattened receptacle. These florets develop in a distinct acropetal sequence, maturing from the outer edge inward, with each fertile floret eventually producing a seed (Khaleghi Zadeh *et al*., 2012; Ochogavía, 2022; Park & Seo, 2023).

MATERIALS AND METHODS

Study Area

Field trial was conducted during the 2023 rainy season at Teaching and Research Farm, Faculty of Agriculture, Federal University Dutsin-Ma (FUDMA) Permanent Site (Lat. 12°17'N Long. 07°27'E and 605m above sea level), and at Federal College of Education (T), Bichi Kano State Research Farm (latitude 12.3'N and longitude 8.32'E, with an altitude of 473m above sea level), in the Sudan Savanna ecological zone.

Planting Materials

The three improved varieties of sunflower: SAMSUN 1 (Early maturing), SAMSUN 2 (Medium Maturing), and SAMSUN 4 (Late Maturing) were purchased from the Institute for Agricultural Research (IAR), Samaru, Zaria, Kaduna State, Nigeria.

Treatments and Experimental Design

The treatments consist of 3 × 3 × 3 factorial combinations of three varieties of sunflowers. (SAMSUN 1, SAMSUN 2and SAMSUN 4), three intra-rows spacing of (30, 40, and 50cm) and three levels of phosphorus (30 P2O5, 60 P2O5 and 90 kg P2O5 ha^{-1}). The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Each gross plot consisted of 4 ridges, measuring $12m^2$ (4m x 3m), and a net plot (two inner ridges) measuring $6m^2$ (4m x 1.5m). The distance between plots was 0.5m, and the distance between replications was 0.75m.

Cultural Practices

The experimental field was ploughed and harrowed to achieve a fine tilth and ridges of 75 cm were made. Sunflower seed was sown after being dressed with Apron Star (thiamethoxam, metalaxyl-M, difenoconazole) at a rate of 1.9g per 2.5kg to protect it against downy mildew, anthracnose and the intra-row spacing was based on the treatment, with ridges 75cm apart. The sunflower seedlings were thinned to two seedlings per hole. Phosphorus fertilizer, according to the treatments, was applied at sowing rates of 30, 60 and 90 kg P2O5 ha^{-1}. Weeds were controlled manually using a hand hoe at 3 and 6 WAS.

Data Collection

Data were collected on Plant height, Leaf Area, Fresh head weight, and relative growth rate at 4, 6 and 8 weeks after sowing (WAS).

Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) as described by Gomez and Gomez (1984) using SAS version 9.0 (SAS, 2002). The differences among

treatment means were analyzed using Duncan's Multiple Range Test (DMRT) (Duncan, 1955). Effects were considered statistically significant at a 5% level of probability.

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Soil of the Two Experimental Sites.

The physical and chemical properties of the soils at the study locations before the experiments are presented in Table 1. The result indicated that particle size distribution at both Dutsin-Ma and Bichi was dominated by sand, with values of 63.3% and 61.2%, respectively. For silt particles, it was (24.9% and 28.2%), respectively. The least particle size distribution was observed with clay, having recorded 11.8% for Dutsin-Ma and 10.1% for Bichi. The soil was found to be sandy loam. This suggests that the soil in both locations has high macro porosity and low ability to retain water. Soil pH at Dutsin-Ma (6.60) and Bichi (6.11) indicated that the soil at Dutsin-Ma was slightly alkaline, while that at Bichi was somewhat acidic. Organic C, Total N, and available Ca, Mg, and Na were lower at both locations.

Table 1: Physical and Chemical Properties of Soils at the Experimental Sites during the 2023 Rainy Seasons

Composition	Depth of Soil (0 – 30cm)	
	Dutsin-Ma	**Bichi**
Particle size distribution (g kg-1)		
Sand	63.3	61.7
Silt	24.9	28.2
Clay	11.8	10.1
Textural class	Loamy Sand	Sandy Loam
Chemical composition		
pH in H2O (1:2.5)	7.45	6.80
pH in 0.01M CaCl2 (1:2.5)	6.55	6.11
Organic Carbon (%)	1.04	0.87
Total Nitrogen (%)	0.093	0.084
Available Phosphorus (Cmol/kg)	2.59	1.95
Exchangeable cations (cmol kg-1)		
Calcium (Cmol/kg)	0.78	0.50
Magnesium (Cmol/kg)	0.80	0.74
Potassium (Cmol/kg)	2.56	1.95
Sodium (Na^{+})	0.62	0.52
Aluminum and Hydrogen (Al^{3++} H^{+})	0.2	0.4
Cation Exchange Capacity (C.E.C)	8.94	8.40

Plant Height

The response of sunflower varieties, intra-row spacing and phosphorus fertilizer rate on Plant Height at Dutsin-Ma and Bichi, during 2023 rainy season was presented in Table 2. Plant height was not significantly influenced by varieties at 4 WAS and 6 WAS across the location. However, Plant height was significantly influenced by varieties at 8WAS at Bichi location. Samsun 2 significantly produce ($P<0.05$) highest Plant height, though at par with Samsun 1. Samsun 4 produce the lowest plant height at 8 WAS at Bichi location. Plant height was significantly influenced by intra row spacing at both locations. 50cm spacing had the least plant height while 30cm spacing, significantly produced ($P<0.05$) the highest plant height at 4 WAS though statistically similar with 40 spacing at Bichi location. 50cm spacing, significantly produced highest plant height at 6 WAS, while the remaining treatments significantly produced the lowest plant height. 30cm spacing significantly produced ($P<0.05$) highest plant at 8WAS, while the remaining treatments produced the lowest plant at Bichi location. At Dutsin-Ma location, 50cm spacing significantly ($P<0.05$) produces the highest plant height while the remaining treatment produces the least at 6 and 8 WAS respectively.

Plant height was significantly influenced by application of Phosphorus fertilizer rate at 4WAS, application of 90 kg ha^{-1} (P2O5) significantly produced the highest plant height though statistically similar with application of 60 kg ha^{-1} (P2O5) while application of 30 kg ha^{-1} (P2O5) produced the lowest plant height. Application of phosphorus was not significant at 6 and 8 WAS at both location (Table 2)

Table 2: Response of Sunflower Varieties to Intra-Raw Spacing and Phosphorus Fertilizer Rates On Plant Height at Dutsin-Ma and Bichi During The 2023 Rainy Season

Treatment	Plant Height (cm)					
	DutsinMa			Bichi		
	4WAS	**6WAS**	**8WAS**	**4WAS**	**6WAS**	**8WAS**
Varieties (V)						
Samsun 1	20.11	55.00	76.67	24.81	45.11	106.37^{a}
Samsun 2	19.52	60.63	83.59	23.63	43.04	107.70^{a}
Samsun 4	20.00	55.63	87.37	25.52	45.52	100.82^{b}
SE±	0.553	2.162	1.771	0.664	1.529	1.520
Intra Raw Spacing (S) (cm)						
30	19.63	56.85^{ab}	83.56^{ab}	25.81^{a}	42.48^{b}	107.96^{a}
40	19.22	51.85^{b}	78.96^{b}	24.56^{ab}	43.37^{b}	102.82^{b}

50	20.78	62.56[a]	85.11[a]	23.59[b]	47.82[a]	104.11[ab]
SE±	0.553	2.162	1.771	0.664	1.529	1.520
Phosphorus fertilizer rate (P2O5) (kg ha-1)						
30	19.00	55.78	84.44	23.85[b]	43.33	105.00
60	20.48	56.15	79.37	24.15[ab]	44.33	102.33
90	20.15	59.33	83.82	25.96[a]	46.00	107.56
SE±	0.553	2.162	1.771	0.664	1.529	1.520
Interaction						
V*F	NS	NS	NS	NS	NS	*
V*S	*	NS	*	NS	NS	NS
F*S	NS	NS	NS	NS	NS	NS
V*F*S	NS	NS	NS	NS	NS	NS

Means followed by the same superscript(s) within the column in each treatment group are not significantly different at a 5% probability level using the Duncan Multiple Range Test (DMRT). WAS= Week after sowing. NS= Not Significant at a 5% level of probability. * = Significant at a 5% level of probability

The interactions between the Varieties and P fertilizer rates also had significant (P < 0.05) effects for plant height of sunflower at Bichi locations. At Bichi, highest plant height was recorded at application of 30 kg ha-1 of P2O5 and planting of Samsun 2 variety as compared to the other treatments studied at the Bichi location (Table 3).

Table 3: Interaction Between of Varieties and Phosphorus Fertilizer Rates On Plant Height of Sunflower at 8 WAS During 2023 Rainy Season at Bichi

	Phosphorus Fertilizer Rate (P2O5) (Kg Ha^{-1})		
Treatment	30	60	90
Varieties (V)			
Samsun 1	103.44[de]	104.11[cde]	111.56[b]
Samsun 2	114.67[a]	102.56[ef]	105.89[c]
Samsun 4	96.89[g]	100.33[f]	105.22[cd]
SE±		2.633	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

At Dutsin-Ma, the highest plant height was observed with planting of Samsun 4 and spacing of 30cm as compared to the other treatments studied at the Dutsin-Ma location (Table 4).

Table 4: Interaction Between of Varieties and Intra-Raw Spacing On Plant Height of Sunflower at 8 WAS During 2023 Rainy Season at Dutsin Ma

Treatment	Intra Raw Spacing (S) (cm)		
	30	**40**	**50**
Varieties (V)			
Samsun 1	80.22[ef]	67.89[g]	81.89[de]
Samsun 2	78.67[f]	84.44[cd]	87.67[b]
Samsun 4	91.78[a]	84.56[cd]	85.78[bc]
SE±		3.067	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMR

Leaf Area

The response of sunflower varieties, intra-row spacing and phosphorus fertilizer rate on Leaf Area at Dutsin-Ma and Bichi, during 2023 rainy season was presented in Table 5. Leaf area was significantly influenced by varieties, Sam sun 1 significantly(P<0.05) produced the largest leaf area at 4WAS, though at par with Samsun 2. Samsun 4 produced the lowest leaf area at 4WAS at Bichi location. Samsun 2 significantly(P<0.05) produced the largest leaf area at 8WAS, though at par with Samsun 4. Samsun 1 produced the lowest leaf area at Bichi location. At Dutsin-Ma, there was significant difference observed at 4WAS, Samsun 2 significantly(P<0.05) produced the largest leaf area, though at par with Samsun. Samsun 1 produced the lowest leaf area at 4WAS at Dutsin-Ma location. There was no significant difference at 6WAS and 8WAS in Dutsin-Ma location

The interaction between the Varieties and P fertilizer rates had significant (P < 0.05) effects for leaf area of sunflower at 4WAS at Dutsin-Ma location. At Dutsin-Ma, the highest leaf area was recorded at application of 30 kg ha-1 of P2O5 and planting of Samsun 2 variety as compared to the other treatments studied at the Dutsin-Ma location (Table 5).

Table 5: Interaction Between Varieties and Phosphorus Fertilizer Rates On the Leaf Area of Sunflower at 4 WAS During The 2023 Rainy Season at Dutsn-Ma

Treatment	Phosphorus Fertilizer Rate (P2O5) (Kg Ha^{-1})		
	30	60	90
Varieties (V)			
Samsun 1	12.89^{f}	13.18^{ef}	13.83^{c}
Samsun 2	14.34^{a}	14.02^{bc}	13.36^{de}
Samsun 4	13.57^{d}	14.25^{ab}	13.50^{d}
SE±		0.330	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

At Bichi, the largest leaf area was observed with planting of Samsun 2 and spacing of 40cm as compared to the other treatments studied at the Bichi location (Table 6). At Dutsin-Ma at 6WAS, application of 30 kg ha-1 of P2O5 and planting of Samsun 1 significantly produced the largest leaf area compared to other treatments studied at Dutsin-Ma location.

Table 6: Interaction Between Varieties and Intra-Raw Spacing On the Leaf Area of Sunflower at 4 WAS During The 2023 Rainy Season at Bichi

Treatment	Intra Raw Spacing (S) (cm)		
	30	40	50
Phosphorus fertilizer rate (P2O5) (kg ha^{-1})			
30	14.10^{c}	14.54^{b}	13.73^{d}
60	14.43^{b}	13.11^{f}	13.22^{ef}
90	13.03^{f}	23.17^{a}	13.52^{de}
SE±		0.325	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

Fresh Head Weight

The response of sunflower varieties, intra-row spacing and phosphorus fertilizer rate on Fresh Head Weight at Dutsin-Ma and Bichi, during 2023 rainy season was presented in Table 7. There was significant difference observed at 8WAS. Samsun 1 significantly (P<0.05) produced the highest fresh head weight. Samsun 2 and Samsun 4 are statistically at par at Bichi location. At Dutsin-Ma, Samsun 2 significantly (P<0.05) produced the highest fresh head weight at 8WAS. Samsun 1 and Samsun 4 are statistically similar at 8WAS at Dutsin-Ma location.

Intra-row spacing also significantly affected fresh head weight at both locations: at Dutsin-Ma, wider spacing produced heavier heads, rising from 1540 g at 30cm to 1619 g at 50cm, whereas at Bichi, the closest spacing (30cm) produced the heaviest heads (1426 g) and 40cm the lightest (1250 g). Phosphorus fertilizer rate significantly affected fresh head weight only at Dutsin-Ma, where 90 kg P2O5 per hectare produced the heaviest heads (1612 g), statistically similar to 30 kg per hectare (1586 g), while 60 kg per hectare produced the lightest (1565 g); phosphorus rate had no significant effect on fresh head weight at Bichi.

Table 7: Response of Sunflower Varieties, Intra-Raw Spacing and Phosphorus Fertilizer Rates On Fresh Head Weight at Dutsin-Ma and Bichi During The 2023 Rainy Season

Treatment	Fresh Head Weight (G)	
	Dutsin-Ma	Bichi
	8WAS	8WAS
Varieties (V)		
Samsun 1	1560^{b}	1363^{a}
Samsun 2	1616^{a}	1319^{b}
Samsun 4	1587^{ab}	1309^{b}
SE±	11.872	15.426
Intra Raw Spacing (S) (cm)		
30	1540^{b}	1426a
40	1603^{a}	1250^{c}
50	1619^{a}	1315^{b}
SE±	11.872	15.426
Phosphorus fertilizer rate (P2O5) (kg ha-1)		
30	1586^{ab}	1323
60	1565^{b}	1340
90	1612^{a}	1328
SE±	11.872	15.426
Interaction		
V*F	*	**

V*S	**	NS
F*S	NS	NS
V*F*S	*	*

Means followed by the same superscript(s) within the column in each treatment group are not significantly different at a 5% probability level using the Duncan Multiple Range Test (DMRT). WAS= Week after sowing. NS= Not Significant at a 5% level of probability. * = Significant at a 5% level of probability. ** = Significant at 1% level of probability

Interaction between varieties and phosphorus fertilizer rates on fresh head weight of sunflower at 8 weeks after sowing (WAS) during the 2023 rainy season at Bichi was presented in Table 8. Application of 90 kg ha-1 of P2O5 and planting of Samsun 1 significantly ($P < 0.05$) influenced fresh head weight of sunflower compared to the other treatments studied at the Bichi location.

Table 8: Interaction Between Varieties and Phosphorus Fertilizer Rates On Fresh Head Weight of Sunflower at 8 WAS During The 2023 Rainy Season at Bichi

Treatment	Phosphorus Fertilizer Rate (P2O5) (Kg Ha^{-1})		
	30	**60**	**90**
Varieties (V)			
Samsun 1	1368.5^{b}	1308.4^{d}	1413.0^{a}
Samsun 2	1343.7^{c}	1335.6^{c}	1276.9^{ef}
Samsun 4	1257.3^{f}	1376.3^{b}	1294.3^{de}
SE±		26.720	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

At Dutsin-Ma, application of 30 kg ha-1 of P2O5 and planting of Samsun 2 significantly ($P < 0.05$) influenced fresh head weight of sunflower at 8WAS compared to the other treatments studied at the Dutsin-Ma location (Table 9).

Table 9: Interaction Between Varieties and Phosphorus Fertilizer Rates On Fresh Head Weight of Sunflower at 8 WAS During The 2023 Rainy Season at Dutsin-Ma

Treatment	Phosphorus Fertilizer Rate (P2O5) (Kg Ha^{-1})		
	30	**60**	**90**
Varieties (V)			
Samsun 1	1530^{e}	1515^{e}	1634^{a}
Samsun 2	1647^{a}	1604^{b}	1597^{bc}
Samsun 4	1580^{cd}	1577^{d}	1604^{b}
SE±		20.563	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

Crop Growth Rate

The response of Sunflower varieties, intra-raw spacing and phosphorus fertilizer rates on the Crop growth rate at Bichi and Dutsin-Ma during the 2023 rainy season was presented on Table 10. There was no significant effect of varieties on crop growth rate at 6 and 8WAS at Bichi location. At Dutsin-Ma location, there was significant effect of crop growth rate as Samsun 1 significantly produced the highest crop growth rate at 6WAS, while Samsun 2 and Samsun 4 are statistically similar. Samsun 4 significantly produced the highest crop growth rate 8WAS, though statistically similar with Samsun 1 at Dutsin-Ma location.

At Bichi location, 30cm spacing significantly produced the highest crop growth, while 40cm and 50cm spacing are statistically similar. There was no significant effect of intra row spacing on crop growth rate at 8WAS. At Dutsin-Ma location, there was no significant effect of intra row spacing on crop growth rate at 6 and 8WAS at Dutsin-Ma location. Application of phosphorus fertilizer rate was not significant on crop growth rate across both locations.

Table 10: Response of Sunflower Varieties, Intra-Raw Spacing and Phosphorus Fertilizer Rates On the Crop Growth Rate at Bichi and Dutsin-Ma During The 2023 Rainy Season

Treatment	Crop Growth Rate (G M^{-2} Day^{-1})			
	Dutsin-Ma		Bichi	
	6WAS	**8WAS**	**6WAS**	**8WAS**
Variety (V)				
Samsun 1	36.86a	48.04a	38.10	45.33
Samsun 2	35.27b	45.28b	36.98	44.06
Samsun 4	38.08a	44.99b	36.64	44.32
SE±	0.5552	0.524	0.558	0.608
Intra Raw Spacing (S) (cm)				
30	37.59	45.87	39.21a	44.18
40	36.16	46.97	36.76b	45.10

50	36.46	45.47	35.75b	44.43
SE±	0.5552	0.524	0.558	0.608
Phosphorus fertilizer rate (P2O5) (kg ha-1)				
30	37.52	45.80	37.27	44.37
60	36.36	45.95	37.54	44.35
90	36.33	46.56	36.92	45.00
SE±	0.5552	0.524	0.558	0.608
Interaction				
V*F	**	*	NS	NS
V*S	**	**	NS	*
F*S	NS	NS	NS	NS
V*S*P	NS	NS	NS	NS

Means followed by the same superscript(s) within the column in each treatment group are not significantly different at a 5% probability level using the Duncan Multiple Range Test (DMRT)
WAS= Week after sowing
NS= Not Significant at a 5% level of probability

Interaction between varieties and intra-row spacing on crop growth rate of sunflower at 6 WAS during the 2023 rainy season at Bichi was presented in Table 11. There was a significant difference in crop growth rate as influenced by intra-row spacing and variety: 30cm spacing combined with Samsun 1 significantly produced the highest crop growth rate at 6WAS at Bichi location.

Table 11: Interaction Between Varieties and Intra-Raw Spacing On the Crop Growth Rate Sunflower at 6 WAS During The 2023 Rainy Season at Bichi

Treatment	Intra Raw Spacing (S) (cm)		
	30	**40**	**50**
Varieties (V)			
Samsun 1	40.62a	37.91c	35.78d
Samsun 2	39.23b	37.47c	34.24e
Samsun 4	37.77c	34.90de	37.24c
SE±		0.968	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

At Dutsin-Ma, 50cm spacing combined with Samsun 1 significantly produced the highest crop growth rate at 6WAS, though statistically similar to 40cm spacing combined with Samsun 1 at the same location (Table 12).

Table 12: Interaction Between Varieties and Intra-Raw Spacing On the Crop Growth Rate Sunflower at 6 WAS During The 2023 Rainy Season at Dutsin-Ma

Treatment	Intra Raw Spacing (S) (cm)		
	30	**40**	**50**
Varieties (V)			
Samsun 1	46.51b	48.67a	48.95a
Samsun 2	43.83d	45.27c	46.74b
Samsun 4	47.29b	46.96b	40.71e
SE±		0.962	

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

Discussion

Soil Properties

The soils at both sites were sandy in texture, classified as loamy sand at Dutsin-Ma and sandy loam at Bichi, with correspondingly low organic carbon, total nitrogen, and exchangeable cation content. Soils of this texture generally have high macro porosity and limited water holding capacity, which can affect nutrient retention and uptake by the crop. The slightly acidic to near neutral pH recorded at both sites falls within a range generally suitable for sunflower production, while the low available phosphorus recorded at both locations supports the decision to evaluate a range of phosphorus fertilizer rates in this study.

Effect of Variety

Variety had a marked effect on plant height, fresh head weight, and crop growth rate, with Samsun 2 performing best at Dutsin-Ma and Samsun 1 at Bichi. This agrees with Ali et al. (2020), who reported that varietal differences significantly influence vegetative growth characteristics in sunflower due to genetic potential, and with Massignam et al. (2009), who attributed such differences among sunflower varieties to genetic factors such as seed size, vigor, and adaptability to local soil and climatic conditions. The site-specific pattern observed here, where a different variety performed best at each location, indicates that variety choice for sunflower production in the Sudan Savanna should take local growing conditions into account rather than relying on one variety across locations.

Effect of Intra-Row Spacing

Intra-row spacing significantly affected plant height, leaf area, fresh head weight, and crop growth rate at both locations. Wider spacing (40 to 50 cm) generally favoured plant height and fresh head weight at Dutsin-Ma, while closer spacing (30 cm) favoured plant height, fresh head weight, and crop growth rate at Bichi. This location-dependent response reflects the point made by Killi (2004), that spacing influences plant competition for light, water, and nutrients, and supports the finding of Ali et al. (2013) that optimizing plant spacing is essential for good sunflower performance. The narrower optimum spacing at Bichi compared with Dutsin-Ma may be related to the lower organic carbon and available phosphorus recorded in the Bichi soil, since closer spacing raises competition for resources sooner where those resources are already limited.

Effect of Phosphorus Fertilizer Rate

Phosphorus fertilizer rate significantly influenced plant height and fresh head weight but not crop growth rate. The highest rate (90 kg P2O5 per hectare) produced the best plant height response at Bichi, while rates from 30 to 90 kg P2O5 per hectare supported comparable or better fresh head weight than the lowest rate at Dutsin-Ma. Phosphorus supports early root development and the energy transfer processes that underpin later growth, which agrees with Grant et al. (2001) on the importance of early season phosphorus nutrition, and with Almodares et al. (2009), who linked higher phosphorus rates to increased plant height in sunflower through improved root expansion and nutrient uptake. Phosphorus is also central to photosynthesis and leaf development through its role in energy transfer within the plant (Rao et al., 2013), and to early seedling vigor through improved root elongation and nutrient uptake (Shahid et al., 2017; Mallory & Griffen, 2007). Similar phosphorus effects on seedling emergence and reproductive development have been reported for sunflower elsewhere (Ali et al., 2012; Ahmad et al., 2001), although these particular processes were not measured in the present study. Crop growth rate was not significantly affected by phosphorus rate at either location, suggesting that under the soil conditions of this study, phosphorus mainly influenced structural growth parameters such as plant height and fresh head weight rather than the overall rate of dry matter accumulation.

Interaction Effects

The significant interactions recorded for plant height, leaf area, fresh head weight, and crop growth rate show that the response of sunflower to spacing and phosphorus rate depended on the variety planted. At Bichi, Samsun 2 combined with the lowest phosphorus rate produced the tallest plants, while Samsun 1 combined with the highest phosphorus rate produced the heaviest heads; at Dutsin-Ma, Samsun 4 combined with the closest spacing produced the tallest plants, while Samsun 2 combined with the lowest phosphorus rate produced the heaviest heads and the largest leaf area. Likewise, Samsun 1 recorded the highest crop growth rate at the closest spacing at Bichi but at the widest spacing at Dutsin-Ma. These variety-specific responses indicate that spacing and phosphorus recommendations for sunflower cannot be generalized across varieties, and that variety, spacing, and phosphorus rate need to be considered together when making production decisions for each location.

CONCLUSION

This study showed that the soils at both experimental sites were sandy and generally low in fertility, underscoring the importance of phosphorus fertilization for sunflower production in the Sudan Savanna. Variety significantly affected plant height, leaf area, fresh head weight, and crop growth rate, with Samsun 2 the most productive variety at Dutsin-Ma and Samsun 1 at Bichi. Intra-row spacing significantly influenced plant height, leaf area, fresh head weight, and crop growth rate, with wider spacing (40 to 50 cm) most beneficial at Dutsin-Ma and closer spacing (30 cm) most beneficial at Bichi. Phosphorus fertilizer rate significantly improved plant height and fresh head weight at both locations, with 90 kg P2O5 per hectare giving the best plant height response at Bichi and rates from 30 to 90 kg P2O5 per hectare supporting good fresh head weight at Dutsin-Ma, while crop growth rate was not significantly affected by phosphorus rate at either site. The significant interactions between variety, spacing, and phosphorus rate for plant height, leaf area, fresh head weight, and crop growth rate indicate that variety, spacing, and phosphorus rate for sunflower production should be matched to each location rather than applied uniformly. Overall, Samsun 2 sown at wider spacing with adequate phosphorus fertilization is recommended for Dutsin-Ma, while Samsun 1 sown at closer spacing with adequate phosphorus fertilization is recommended for Bichi.

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