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Research Article

Agroclimatic and Management Interactions Shaping Genetic and Agronomic Performance of Potato (*Solanum tuberosum L.*) under Sudan Savanna Field Conditions

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ABSTRACT

Potato (*Solanum tuberosum* L.) cultivation is extending into the Sudan Savanna of Nigeria; however, productivity is limited by inadequate knowledge of optimal planting time, seed type, and plant density. A two-year field study (2017/18 and 2018/19) was conducted at Bayero University, Kano, and Aliko Dangote University of Science and Technology, Wudil, to evaluate the effects of planting date, propagation method, and plant density on growth and yield attributes of potato. The experiment employed a fractional factorial design with five planting periods (late October to early December), two seed types (whole and cut tubers), and three plant densities (33,333, 43,333, and 66,666 plants ha^{-1}). Results indicated that planting date and location significantly influenced all measured traits ($p < 0.001$). Late October planting resulted in the earliest emergence (14.6 days), fastest maturity (83.8 days), tallest plants (42.2 cm), and highest leaf and branch numbers, while each delay in planting progressively reduced vegetative growth and yield. High plant density (66,666 plants ha^{-1}) produced more branches and greater tuber yield (16.2 t ha^{-1}) than medium or low densities. The propagation method had no significant effect on any trait measured. Environmental variation also played a key role, as cooler temperatures and higher soil phosphorus at Wudil enhanced plant growth and tuber productivity compared with Kano. Overall, the best performance across morphological and yield parameters was achieved with late October planting at high plant density using cut seed tubers. These findings provide a framework for improving productivity and sustainability of potato production in Sudan Savanna.

Keywords: Growth traits; Planting date; Plant density; Potato; Propagation method; Sudan Savanna; Sustainable production

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INTRODUCTION

Potato (*Solanum tuberosum* L.), a member of the Solanaceae family, is cultivated worldwide for its edible tubers and serves as a major source of food, income, and employment in both developed and developing countries (Kabir et al., 2004; FAO, 2018). Global potato production in 2022 covered about 18.1 million hectares, yielding 326.2 million tons, with China and India accounting for nearly one-third of the total output (FAOSTAT, 2023). In Nigeria, production has expanded from 599,000 tons in 2000 to about 1.2 million tons in 2022, yet the national average yield (3.8 t ha^{-1}) remains far below the global mean of 55 t ha^{-1}, making Nigeria the 38th largest producer worldwide (FAOSTAT, 2023).

Despite the establishment of the National Potato Research Centre in Kuru Jos in 1976, yield improvement has been slow, largely due to the dominance of smallholder farmers who rely on low-input systems and outdated agronomic practices (Aniedu, 2015). Major production constraints include limited access to high-quality seed tubers (Okonkwo and Amadi, 1995), suboptimal planting dates and densities (Saad et al., 2022), and fluctuating market prices during periods of glut (Plaisier et al., 2019).

Planting date and plant density are critical factors determining the efficiency of climatic resource use and, consequently, potato growth and yield (Hoffmann and Kluge-Severin, 2010; Jaggard et al., 2007). Since tuberization declines above 17°C (White and Sanderson, 1983), aligning agronomic practices with seasonal temperature patterns is essential for sustaining productivity in warm, dryland ecologies such as the Sudan Savanna.

This study, therefore, investigates the agroclimatic, genotypic, and management interactions influencing potato performance under field conditions in the Sudan Savanna, with emphasis on optimizing planting window, propagation method, and plant density for improved growth and yield outcomes.

MATERIALS AND METHODS

Experiment was conducted in 2017/2018 and 2018/2019 dry seasons at Teaching and Research Farms of the Faculty of Agriculture, Bayero University, Kano ($11^0$58N; 8^0 25E), and that of Aliko Dangote University of Science and Technology, Wudil (11^0 25`N; 90 E) in Kano State of Nigeria. Both locations were in the Sudan Savanna agroecological zone with an average annual temperature of 26^0C and an average annual rainfall range of between 884-1200 mm per annum.

Soil samples were collected from both experimental fields at 0-30 cm depths before planting. The samples were randomly collected across several points within the field and then bulked to get composite samples. The samples collected were then analyzed to determine their physical and chemical properties (Table 1). Weather data was also collected from weather stations installed in both research locations.

The experimental treatments consisted of five (5) planting periods (late October, early November, mid-November, late November, and early December), two methods of propagation (using whole seed and cut seed), and three planting densities (66,666, 43,333, and 33,333 plants per square meter). The treatments were combined and laid out in an incomplete-block design; in a fractional factorial using the Design of Experiment (DOE) design platform of JMP Pro 14 (SAS, 2018) and adopting the custom D-optimality criterion, which ensures that a full combination of the treatment combinations appears in each of the three replications. The plot size was 3 x 4 meters, consisting of four ridges. A distance of 1m was maintained between plots and a 1 m distance between blocks. The planting materials were sourced from the National Root Crop Research Institute (NRCRI) substation in Jos. Well-sprouted tuber seed of potato variety Marabel were sown at a depth of 10cm across all treatments. NPK 15:15:15 was applied at the rate of 240kg/ha following recommendations by Ugonna et al. 2013. Earthing up was done uniformly by hilling the soil around the plant at 4 weeks after planting, as suggested by Tesfaye (2013). All plots were irrigated uniformly at four-day intervals.

Data Analysis

The data collected was subjected to analysis of variance (ANOVA) using the Fit model platform of JMP Pro 14 statistical package (SAS, 2018). Significant treatment means were ranked using the Tukey HSD test.

RESULTS

The soil at Wudil was classified as sandy clay, while that of BUK was clayey sand. Soil reaction differed slightly between sites, with Wudil being slightly acidic (pH 6.41) and BUK nearly neutral (pH 7.35) (Table 1). Both soils contained relatively high levels of total nitrogen, but available phosphorus was medium at Wudil (11.14 mg kg-1) and very low at BUK (2.39 mg kg^{-1}), following Esu's (1991) classification. These soil differences likely contributed to the observed variation in potato performance, with the higher phosphorus content at Wudil favoring better crop growth and tuber yield compared with BUK. Additionally, temperature dynamics varied across the growing period. A significant drop in minimum and maximum temperatures occurred from early December to mid-February in both locations, followed by a steady rise from late February to late March (Figures 1 & 2). These seasonal fluctuations can strongly influence crop development: cooler temperatures during early growth stages were associated with delayed emergence and reduced vegetative vigor in later plantings, while the warmer conditions in late October–November might promote faster establishment and higher yields.

Table 1. **Physical and chemical properties of soils of the experimental sites at 0-30cm depths during 2017/2018 and 2018/2019 dry seasons**

Soil properties	Wudil	BUK
Physical (%)		
Sand	59.81	64.20
Silt	21.35	19.43
Clay	18.84	16.37
Classification	Sandy clay	Clayey sand
Chemical		
pH (1:1)	6.41	7.35
O C (%)	0.61	0.55
N (%)	0.09	0.07
P (mg/kg)	11.14	2.39
Mn (mg/kg)	11.74	3.72
Zinc (mg/kg)	1.86	7.48
Fe (mg/kg)	180.41	128.29
Exchangeable base (cmol (+)kg^{-1})		
Ca	1.39	1.14
Mg	0.34	0.51
K	0.08	0.07
Na	0.015	0.013
ECEC (effective cation exchange capacity)	1.82	1.73

Analyzed at the Central Laboratory Centre for Dryland Agriculture, Bayero University, Kano.

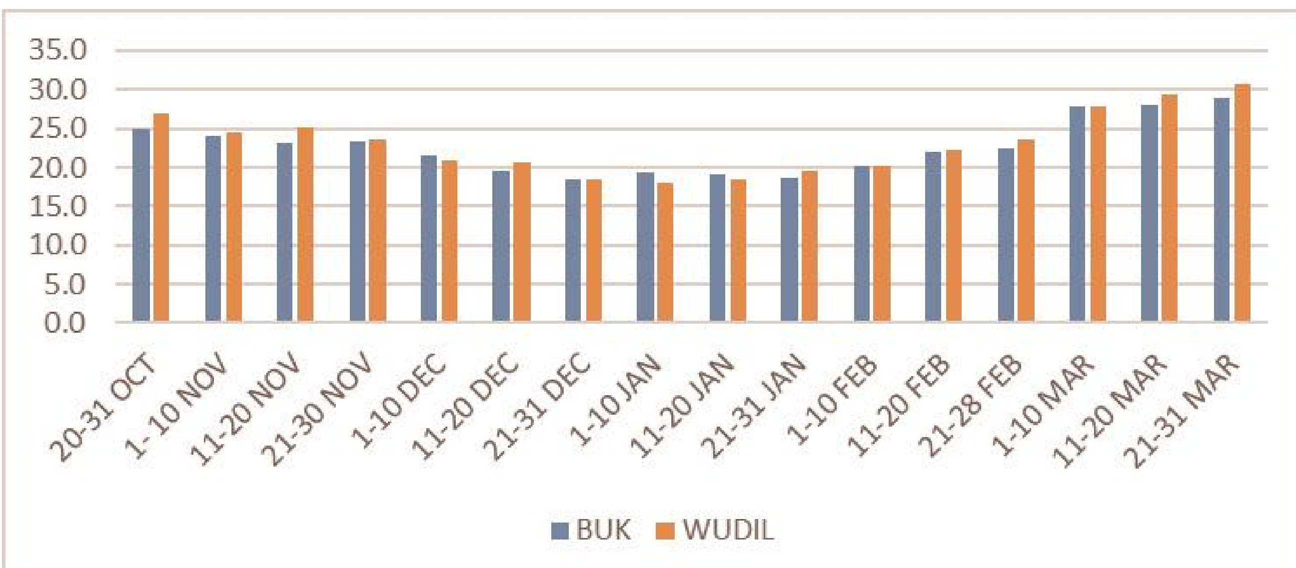

Figure 1. Periodic minimum temperature (Tmin) at Buk and Wudil for 2017/2018

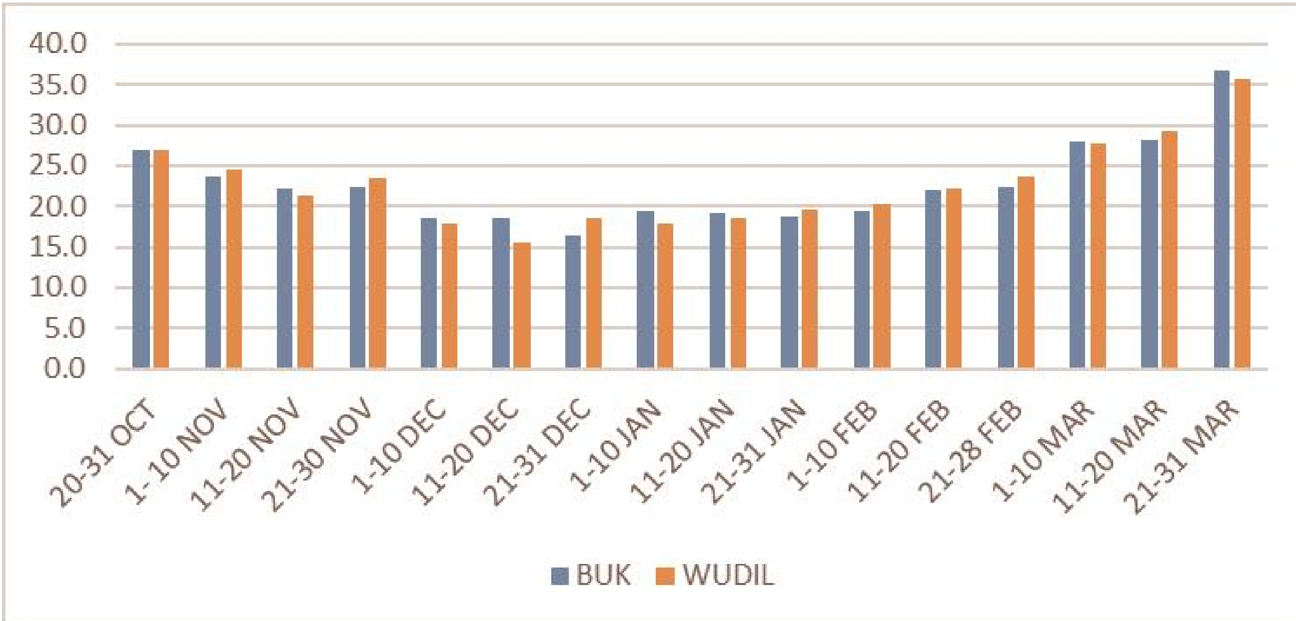

Figure 2. **Periodic maximum temperature (Tmax) at BUK and Wudil for 2018/2019**

Growth and Developmental Responses of Potato to Agroclimatic and Management Factors

Plant growth and development were significantly influenced by location, planting period, and planting density (Table 2). Days to emergence (DE) differed notably ($p < 0.0001$) across seasons and locations. Tubers planted during the 2018/2019 season emerged earlier (14.6 days) than those in 2017/2018 (16.1 days). Similarly, plants established at Bayero University, Kano (BUK) sprouted faster (15.0 days) than those at Wudil (15.7 days). Among planting dates, late October recorded the shortest emergence period (14.6 days), whereas early December plantings delayed emergence to 15.2 days. Propagation method and planting density had no significant effects on emergence, and no interaction among these factors was observed.

Days to 95% maturity were also significantly affected by location and planting period ($p < 0.0001$). Plants at BUK attained maturity earlier (86.4 days) than those at Wudil (87.3 days). Late October planting reached maturity at 83.8 days, while early December extended the crop cycle to 89.9 days. Although season, propagation method, and density did not show independent effects, important interaction effects were observed for season × location ($p = 0.006$), season × planting period ($p = 0.001$), and location × planting period ($p = 0.004$). These interactions indicated that potatoes planted at BUK matured faster than those at Wudil, regardless of the season.

Vegetative growth parameters, including plant height (PH) and number of leaves per plant (NL), were significantly influenced by location, planting period, and planting density ($p < 0.001$). Plants grown at BUK were taller (37.4 cm) and had more leaves (47.4 leaves plant^{-1}) than those at Wudil (34.1 cm and 39.3 leaves plant^{-1}, respectively). The late October planting produced the tallest plants (42.2 cm) and the highest leaf number (54.5 leaves plant^{-1}), while early December sowing resulted in the shortest plants (29.3 cm) and the Dfewest leaves (32.7 leaves plant^{-1}).

Plant density also had a marked effect on vegetative traits. The widest spacing (33,333 plants ha^{-1}) produced the tallest plants (37.7 cm) and highest leaf number (46.5 leaves plant^{-1}), while the highest density (66,666 plants ha^{-1}) resulted in shorter plants (34.0 cm) and fewer leaves (41.4 leaves plant^{-1}). Neither season nor propagation method significantly influenced plant height or leaf number ($p > 0.05$).

Table 2. Effects of season, location, planting period, propagation method, and planting density on some agronomic, and yield characters of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

Treatment	DE	PH	NLVS	NBR	Days to 95% Maturity	Yield (kg/ha)
Season (S)						
2017/2018	16.06[b]	35.711	43.78	4.68[a]	86.81	7.60[b]
2018/2019	14.59[a]	35.83	42.88	3.89[b]	86.88	20.86[a]
Probability level	0.0001	0.717	0.173	0.001	0.5025	0.001
SE±	0.1117	0.232	0.462	0.093	0.673	0.288
Location (L)						
Wudil	15.70[b]	34.129[b]	39.25[b]	4.01[a]	87.30[a]	15.18[a]
BUK	14.96[a]	37.412[a]	47.41[a]	4.56[b]	86.39[b]	13.28[b]
Probability level	0.0001	0.0001	0.001	0.001	0.0001	0.001
SE±	0.0017	0.232	0.462	0.093	0.067	0.288
Planting period (PP)						
Late October	14.62[a]	42.186[a]	54.46[a]	5.22[a]	83.79[e]	21.25[a]
Early November	15.753[c]	39.454[b]	46.33[b]	4.96a	84.79[d]	18.35[b]
Mid November	15.37[bc]	34.850[c]	44.28[c]	3.99[b]	83.50[c]	13.48[c]
Late November	15.71[c]	33.100[c]	38.92[d]	4.02[b]	89.25[b]	10.82[d]
Early December`	15.21[a]	29.264[d]	32.69[e]	3.24[c]	89.91[a]	7.25e
Probability level	0.0001	0.001	0.001	0.001	0.0001	0.001
SE±	0.176	0.875	0.730	0.148	0.106	0.455
Propagation method (PM)						
Whole seed	15.43	36.1	43.67	4.37	86.79	14.56
Cut seed	15.23	35.5	42.99	4.20	86.90	13.90
Probability level	0.2100	0.07	0.303	0.227	0.285	0.108
SE±	0.117	0.23	0.462	0.093	0.082	0.288
Planting density (PD)						
66,666	15.09	34.0[c]	41.36[c]	4.70[a]	86.84	16.17[a]
43,333	15.53	35.6[b]	42.15[b]	4.16[b]	86.80	13.93[b]
33,333	15.38	37.7[a]	46.49[a]	4.00[b]	86.90	12.59[c]
Probability level	0.0898	0.001	0.001	0.001	0.6932	0.001
SE±	0.137	0.28	0.5659	0.114	0.082	0.353
Interaction						
S X L	0.745	0.001	0.001	0.001	0.006	0.001
S X PP	0.236	0.001	0.001	0.001	0.001	0.001
S X PM	0.673	0.326	0.876	0.625	0.157	0.919
S X PD	0.434	0.717	0.889	0.601	0.602	0.101
L X PP	0.675	0.238	0.202	0.220	0.004	0.009
L X PM	0.675	0.070	0.378	0.625	0.284	0.994
L X PD	0.756	0.785	0.828	0.047	0.693	0.873
P X PM	0.744	0.786	0.958	0.229	0.062	0.281
P X PD	0.859	0.003	0.042	0.484	0.674	0.456
M X PD	0.500	0.737	0.562	0.762	0.693	0.901

DE = Days to emergence; PH = Plant height; NLVS = Number of leaves; NBR = Number of branches. Levels not connected by the same letter are significantly different using Tukey HSD

Potato growth was strongly influenced by planting density, planting period, season, and location. Tubers planted at the widest spacing (33,333 plants/ha) produced the tallest plants during both early and critical growth stages. Significant interactions were observed for plant height and leaf number, including season × location, season × planting period, and planting period × planting density (Figures 3–5). Considering the season alone, taller plants were observed in 2017/2018, though across locations, BUK consistently produced taller plants with more leaves than Wudil (Figure 6).

Leaf production followed a similar pattern. Regardless of season, the highest leaf numbers were recorded in late October and early November plantings, while December sowings produced the lowest counts. For example, in 2017/2018, plants established in late October and early November carried significantly more leaves than later plantings (Figure 8). Location effects were also clear: BUK plants produced more leaves than those at Wudil ($p<0.001$). Planting density had a strong influence ($p<0.001$), with wider spacing (40 cm; 33,333 plants/ha) producing the highest leaf counts due to reduced competition for light, nutrients, and water. Significant interactions further showed that leaf numbers decreased steadily from October to December across both seasons and densities (Figures 6–8). Branching was also significantly affected by season, location, planting period, and plant density ($p<0.001$). More branches were recorded in 2017/2018 compared with 2018/2019, and Wudil plants bore more branches than those at BUK. Early planting in late October produced the highest branching, suggesting that relatively warmer temperatures at this stage favored branch development. The propagation method had no significant effect on branching ($p=0.227$). Plant density, however, was critical: the highest density (66,666 plants/ha, equivalent to 20 cm spacing) produced the most branches per plant. Interactions among factors (season × location, season × planting period, and location × planting density) further highlighted these differences (Figures 9–11). For instance, in Wudil, branching was similar across densities, whereas at BUK, more branches were observed at the widest spacing.

Tuber yield was significantly influenced by season, location, planting period, and planting density ($p<0.001$; Table 2). The highest yields were recorded in 2018/2019, likely due to cooler temperatures during the season (Figure 2). Across locations, Wudil outperformed BUK, producing higher tuber yields. Planting period had a strong effect: late October planting gave the maximum yield (21.25 t/ha), while yields declined steadily with later plantings, reaching the lowest level in early December (7.25 t/ha). Plant density also had a marked impact on yield. The highest density (66,666 plants/ha) produced the maximum yield (16.2 t/ha), compared with 13.9 t/ha at 43,333 plants/ha and 12.6 t/ha at 33,333 plants/ha. This trend reflects the benefit of increased land coverage at higher population densities.

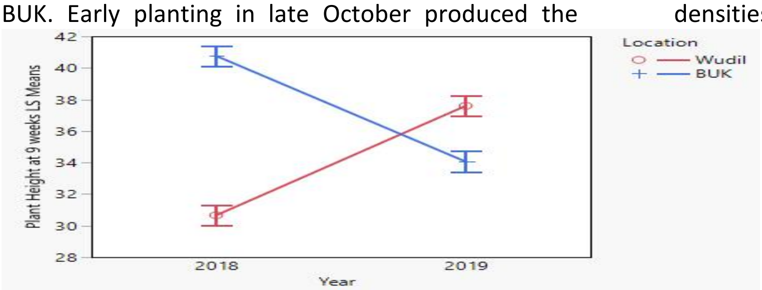

Figure 3. Interaction between season and location on plant height at 9 weeks of potato in 2017/2018 and 2018/2019 dry Seasons at Wudil and BUK

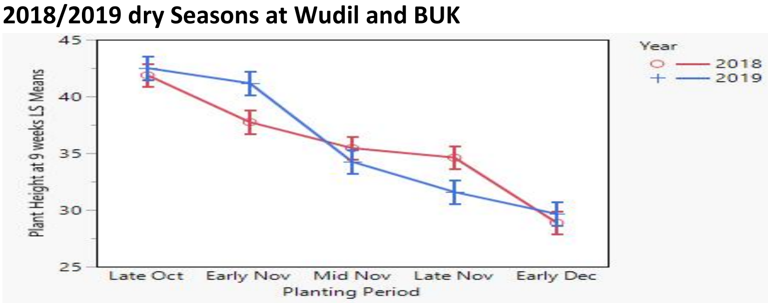

Figure 4. Interaction between season and planting period on plant height at 9 weeks of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

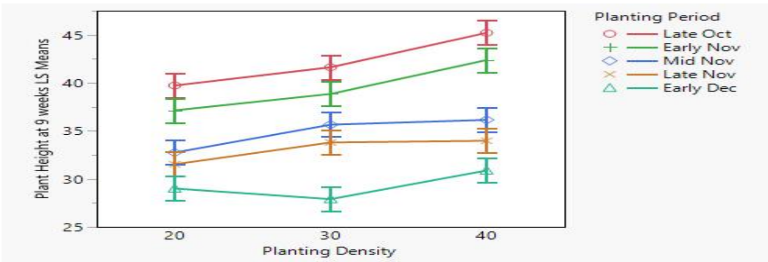

Figure 5. Interaction between planting period and plant density on plant height at 9 weeks of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

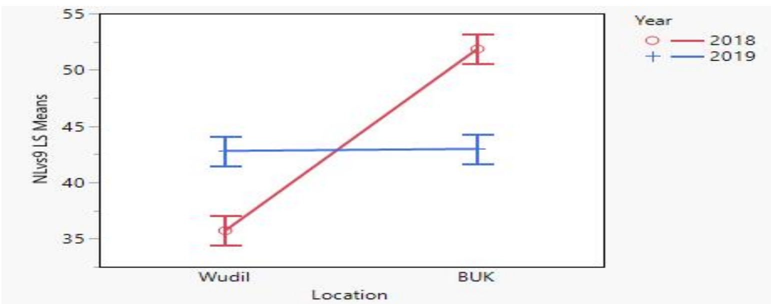

Figure 6. **Interaction between season and location on number of leaves at 9 weeks after planting of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK**

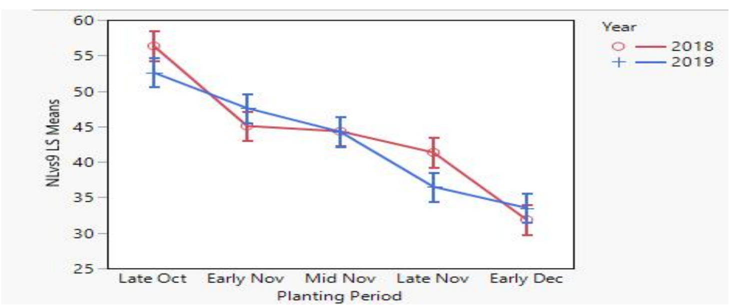

Figure 7. **Interaction between season and planting period on number of leaves at 9 weeks after planting of potato in 2017/2018 and 2018/2019 dry Seasons at Wudil and BUK**

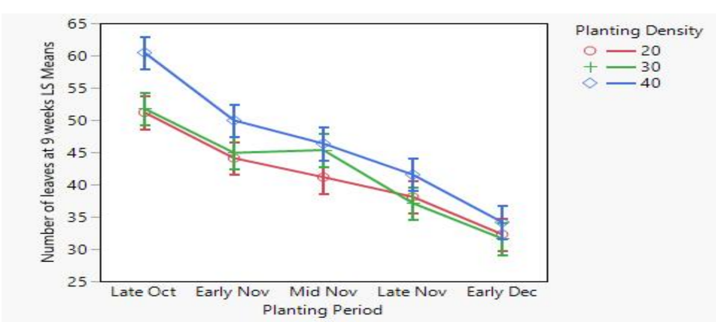

Figure 8. **Interaction between planting density and planting period on number of leaves at 9 weeks after planting of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK**

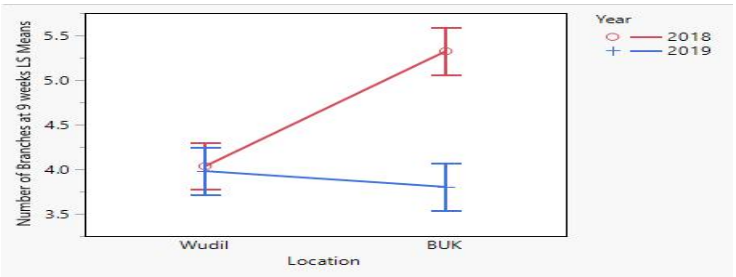

Figure 9. Interaction between season and location on number of branches at 9 weeks after planting of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

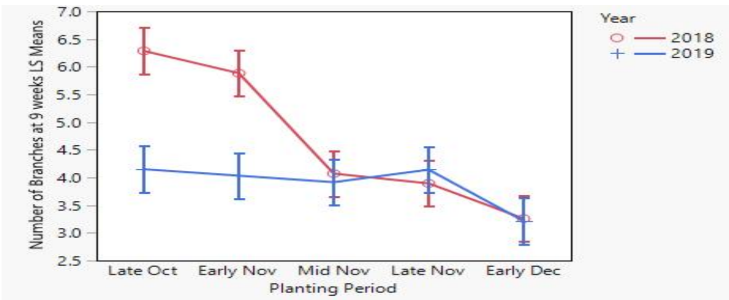

Figure 10. **Interaction between season and planting period on number of branches at 9 weeks after planting of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK**

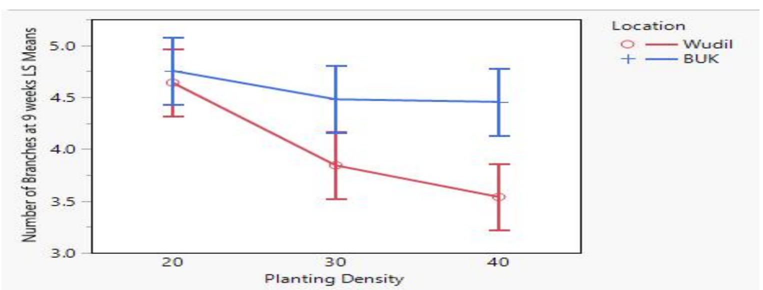

Figure 11. Interaction between location and planting density on number of branches at 9 weeks after planting of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

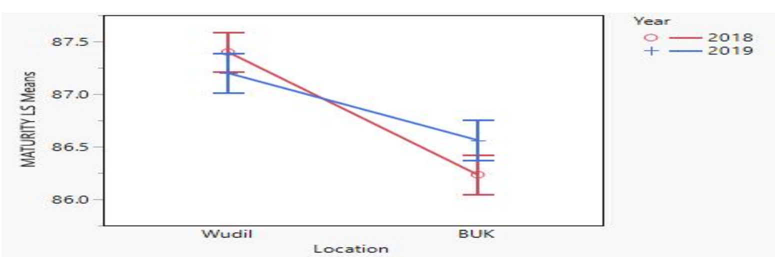

Figure 12. **Interaction between season and location on days to 95% maturity of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK**

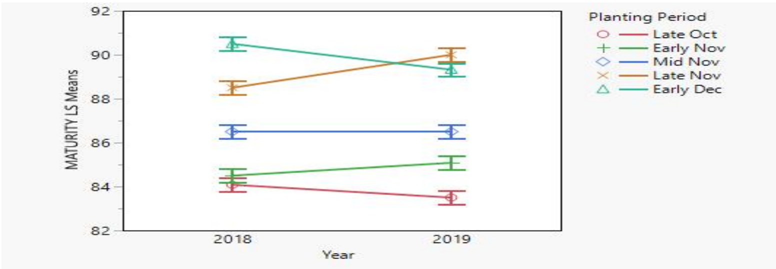

Figure 13. Interaction between season and planting period on days to 95% maturity of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

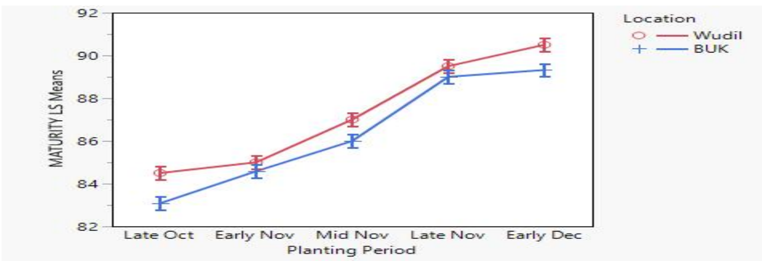

Figure 14. Interaction between location and planing period on days to 95% maturity of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

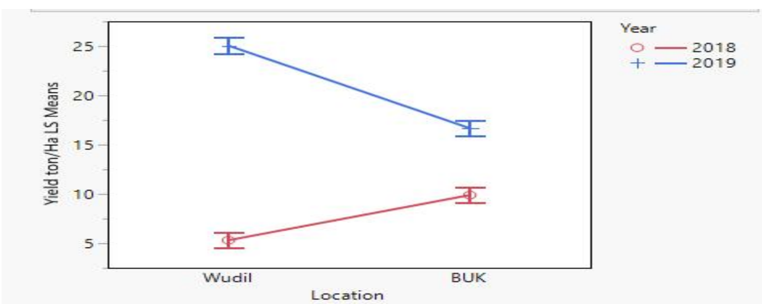

Figure 15. Interaction between season and location on tuber yield of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

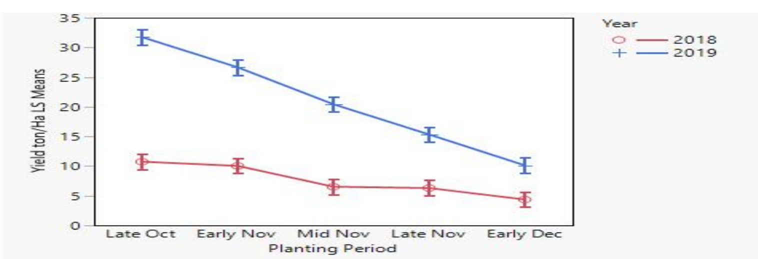

Figure 16. Interaction between season and planting period on tuber yield of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK

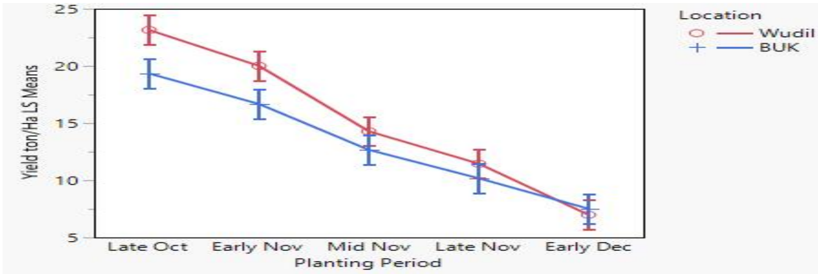

Figure 17. **Interaction between location and planting period on tuber yield of potato in 2017/2018 and 2018/2019 dry seasons at Wudil and BUK**

Significant (p<0.001) season x location and season x planting period interaction on tuber yield was observed in this study (Figure 15). The highest tuber yield was obtained from a field planted in 2018/2019 at Wudil. Tuber yield was observed to decrease from potatoes planted at BUK in the same season. However, tuber yield was statistically similar in Wudil and BUK when potato was planted in the 2017/2018 season. The result also showed that, irrespective of planting period, higher tuber yield was recorded from potatoes planted in 2017/2018 season. It was also observed that potatoes planted in late October produced significantly higher tuber yield irrespective of season (Figure 16). Considering the location alone, potatoes planted at Wudil produced the highest tuber yield irrespective of planting period. Also, irrespective of location, potatoes planted in late October produced the highest tuber yield. In general, tuber yield was decreased with every delay in the planting period, irrespective of location (Figure 17).

DISCUSSION

The growth duration of potato in this study was strongly influenced by prevailing climatic conditions, particularly temperature. Warmer conditions in late October (approximately 27 °C, Figure 1) enhanced emergence, resulting in earlier sprouting compared with later planting dates. This trend aligns with the findings of Van Oort et al. (2012), who highlighted the critical role of temperature in regulating crop phenology, growth, and yield. Recent work further supports this: Naawe et al. (2024) reported that moderate increases in temperature enhanced potato emergence and yield by ~25% under field conditions, highlighting the sensitivity of the crop to early-season temperature regimes (Naawe et al., 2025). The lack of influence from propagation method or planting density on emergence in our study suggests that these factors are secondary compared to climatic drivers. Early planting also led to earlier maturity, while each delay in sowing extended the time to 95% maturity. This agrees with Wang et al. (2014), who showed that delayed planting prolongs the growth cycle. In semi-arid lowland Nigeria, potatoes planted between 1–15 November yielded significantly more than those planted later, reinforcing the importance of timely planting windows in this environment.

In this study, growth traits also varied with season and planting period. Plants established later (November–December) were shorter and produced fewer leaves, likely due to lower temperatures limiting vegetative development. While this agrees with our observations, it contrasts with Van Dam et al. (1996) and Modisane (2007), who found that high temperature and long days favored taller plants and higher biomass accumulation. Interestingly, no significant differences were found between whole and cut seed tubers in this study, whereas Mayakaduwa et al. (2017) reported taller plants from whole seed. More recently, Addisu et al. More recently, Addisu et al. (2023) in Ethiopia observed that cut seed tubers improved multiplication rates under irrigated conditions. The contrast with our findings, where propagation method had no significant effect on yield, may reflect differences in production objectives and environmental context. While Addisu et al. focused on seed multiplication under controlled irrigation, our study was conducted under field conditions typical of the dry Sudan Savanna, where high evaporative demand and heat stress may offset the advantage of cut tubers. This suggests that the benefit of seed cutting is context-dependent, with greater potential under well-managed irrigation systems but limited influence on yield performance under dryland field conditions. Together, these findings suggest that the role of the propagation method depends on the production environment, particularly irrigation and moisture availability. Plant density also played a clear role. Wider spacing (33,333 plants/ha) produced taller plants with more leaves, reflecting reduced competition for light, nutrients, and water. In contrast, denser stands reduced plant height and leaf number due to stronger competition, echoing the findings of Zamil et al. (2010). Similarly, branching was strongly affected by density: higher populations (66,666 plants/ha) promoted more branches per plant, possibly because intense intra-specific competition stimulated secondary stem formation. Dhangrah et al. (2024) observed comparable density effects on potato branching in southern Africa.

Tuber yield integrated these growth responses. Although potatoes are adaptable to both warm and cool climates, excessive heat or humidity can suppress yield (Scott et al., 2000). In this study, yields were higher at Wudil than at BUK, likely reflecting differences in soil fertility, particularly phosphorus availability. The highest yields came from late October planting, consistent with Dash et al. (2018), who reported that extending planting into December significantly reduced yield due to less favorable temperatures. Recent studies confirm the same pattern: potatoes planted early under favorable temperature and soil conditions achieved the greatest tuber yields (Naawe et al., 2024; Omics, 2022). Interestingly, seed type did not affect yield in our conditions. This contrasts with Diop et al. (2019), who found that cut seeds produced a greater proportion of small tubers than whole seeds. However, the agreement with Dayok et al. (2021) suggests that in the Sudan Savanna, temperature and planting date override propagation method as the primary determinants of yield.

Overall, these findings demonstrate that temperature, planting period, and density are the most critical factors for potato production in the Sudan Savanna, while propagation method is less influential under field conditions. Early planting, when temperatures are optimal, provides a clear yield advantage, ensuring stronger vegetative growth, better assimilate partitioning, and higher tuber productivity.

CONCLUSION

The present study demonstrated that potato performance in the Sudan Savanna is strongly influenced by planting period, plant density, and agroclimatic conditions. Early planting in late October consistently enhanced vegetative growth and tuber yield, producing more than twice the yield obtained from early December planting. A plant density of 66,666 plants ha^{-1} proved optimal for maximizing yield without compromising plant vigor, while the choice between cut and whole seed tubers had minimal influence on productivity under field conditions. Based on these findings, it is recommended that potato farmers in the Sudan Savanna adopt early planting (late October) to exploit cooler temperatures favorable for tuberization. A high plant population (66,666 plants ha^{-1}) should be maintained for optimum land use efficiency and yield. The use of cut seed tubers remains an economical alternative to whole seed, provided proper curing and disinfection practices are followed to minimize disease risk.

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Author Contributions

AMS & SAZ conducted the research, collected, analyzed the data, and drafted the manuscript. S U Y supervised the study and revised the draft manuscript. AAA & SAZ designed the research and revised the draft manuscript. All authors proofread the manuscript.

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Competing interests

The authors declare that there were no competing interests.

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