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Planting date and tillage effects on yield and nutrient uptake of two sorghum cultivars grown in sub-humid and semi-arid regions in South Africa

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Introduction: Sorghum is emerging as a viable crop option to increase food production under changing climate due to its resilience to drought and marginal soils. Appropriate planting date, crop cultivars, type of tillage and rotations, under contrasting climatic conditions, could make significant contribution on the effective management of sorghum under changing climatic conditions. A short-term study was carried out to investigate the effects of planting date, crop cultivar, tillage type and rotations on the growth and primary nutrient uptake of sorghum in contrasting climatic regions.

Methods: The study was conducted in Free State - (FS) and KwaZulu Natal (KZN) Provinces of South Africa over two seasons (2020/21 and 2021/22). The two cultivars (Pan8816 and Macia) were sown in December (PD1) and in January (PD2) under conventional tillage (CT) and no-till (NT) and with two rotations (Sorghum-Cowpea-Sorghum and Sorghum-Sorghum-Sorghum) resulting in 2x2x2x2 factorial experiment.

Results and discussion: In KZN, in both the first (2020/21) and second (2021/22) seasons, the effects of all the factors, except cultivar in the second season, were not significant on yield, and uptake of nitrogen (N), phosphorus (P) and potassium (K). In the second season, Pan8816 (4.40 t/ha) produced 3.3 times higher yield than Macia (1.32 t/ha), and took up higher N, K and P. In FS, the early planted sorghum (1.15 t/ha for season one; 3.39 t/ha for season two) had significantly higher yield than late planted sorghum (0.434 and 0.91 t/ha for seasons one and two, respectively). Furthermore, the early-planted crops took up higher N, K and P than when planted late, while Pan8816 took up 1.74 times more P than Macia. Plants grown under CT (2.61 t/ha) produced significantly higher yield than under NT (1.70 t/ha), with plants under CT taking up significantly more K than those grown on NT. These findings suggest that in the drier FS, early planting under conventional tillage, while in the wetter KZN, selecting the appropriate cultivar (PAN8816), are essential for sorghum grain yield, at least in the short-term.

KEYWORDS

conservation agriculture, climate change, food security, small-scale famers, sub-Saharan Africa

1 Introduction

The agriculture sector needs to produce more food from less land and water resources to provide for a growing population with an increasing per capita income in an urbanized world (FAO, 2017) under the difficult conditions of a changing climate (Lal, 2013). Climate change poses direct and indirect threats to food security through its influence on soil properties, water resources, and crop production (Fischer et al., 1996; Gornall et al., 2010; Lal, 2013; Masipa, 2017). These effects include, but are not limited to, loss of SOC, reduced fertility and plant available water, the prevalence of pests and diseases, changes in the hydrological balance, and increased soil erosion (Gornall et al., 2010; Lal, 2013). According to Lal (2013), agriculture is vulnerable to changes in climate, and projections point toward challenging times for farmers and land users, especially those in the developing world, especially sub-Saharan Africa (SSA) (Lal, 2019). It is therefore important to develop agricultural technologies and strategies that minimize the effects of climate change and can enhance and sustain soil productivity levels under adverse climatic conditions. This can be achieved through the selection of the appropriate crops to be grown under systems modified to suit the prevailing conditions in a particular region.

Conservation agriculture (CA) continues to be promoted as a suitable strategy that can ensure improved and sustainable production levels without compromising the environment and exacerbating land degradation (Aziz et al., 2013; Busari et al., 2015). In essence, CA entails the integrated management of available natural resources and other inputs to maximize efficiency (Choudhary et al., 2016) through minimal soil disturbance, permanent soil cover, and crop rotations (Hobbs et al., 2008). For maximum benefits to be realized, all the three principles of CA must be applied simultaneously. When applied appropriately, CA improves soil porosity, which in turn reduces runoff and erosion hence enhancing biomass production. CA can increase yield by up to 56% compared to conventional tillage due to increased soil organic matter and reduced evapotranspiration (Thierfelder and Wall, 2012; Wakindiki et al., 2018). However, smallholder farmers often struggle to maintain the requisite amount of crop residue for soil cover due to competing uses. Moreover, most soils under smallholder farming are too poor to support optimum biomass production. However, the inclusion of crop rotation in no-till systems may boost biomass production thus ensuring the retention of optimum levels of residues, which may increase yield.

While it is generally agreed that conversion from conventional tillage to no-till has potential to increase crop productivity, its effectiveness is influenced by soil and climate factors. For instance, Toliver et al. (2012) analyzed data from 442 paired tillage experiments across the United States, examining six crops and various environmental factors such as geographic location, annual precipitation, soil texture, and time since conversion from tillage to no-till. The results indicated that no-till generally resulted in similar or higher yields than conventional tillage for sorghum and wheat. However, environmental factors influenced yield variations between the two tillage methods for other crops. Moreover, no-till tended to produce similar or greater yields than conventional tillage in warmer and more humid regions with loamy soils. Conversely, in drier regions with sandy soils, no-till yields were often lower than conventional tillage yields. This suggests that CA may be less beneficial on sandy; however, there is not sufficient evidence on this in South Africa. Moreover, the effects of CA may be mediated by environmental conditions and cropping systems. Therefore, this study aims to show that no-till can be a viable and beneficial agricultural practice, particularly for certain environmental conditions and crops particularly sorghum, which has attracted significant interest due to its resilience to harsh conditions.

Due to climate change, areas that are currently suited to maize in the African savannah may in the future transition to being suitable for sorghum (Lal, 2013). Summer crop production in South Africa is shifting from current production areas due to changes in rainfall and temperature regimes (Weepener et al., 2014). Sorghum thrives on low fertility soils with limited inputs for food and industrial use in breweries, production of animal feed, and as feedstock for biofuel production (Meki et al., 2013; Ikazaki et al., 2020). Moreover, sorghum is the fifth most important cereal crop after wheat (*Triticum aestivum*), rice (*Oryza sativa*), maize (*Zea mays*) and barley (*Hordeum vulgare*) (Bakari et al., 2023) with high tolerance to heat and drought. The crop can remain dormant during dry periods (Pinzi and Dorado, 2011). During the period 1998 to 2020, 58–64 Million tons of sorghum was grown on 43.2 Million hectares of land globally, which equates 6.4% of total cereal growing land and 2.7% of total cereal production (Bakari et al., 2023).

Despite this huge potential, there is a critical knowledge gap. Very few studies have reported the performance of sorghum under CA across diverse environments and soils particularly sandy soils in South Africa. Although South Africa is traditionally a maize growing nation, climate change suggests that the baseline could shift toward drought tolerant crops such as sorghum as a coping mechanism (Soga and Gaston, 2018). Adapting sorghum-planting dates to synchronize with potential shifts in rainfall and temperature patterns, which vary across seasons, has been proposed as an adaptation strategy. However, there is little evidence regarding the effectiveness of this approach in South Africa. To address this gap, this this study aimed to compare the effects of growing two sorghum cultivars on two different planting dates and two tillage practices on sorghum growth, nutrient uptake and yield in two areas with contrasting soil and climatic conditions over two seasons. This study will provide valuable insights for optimizing sorghum production under CA in South Africa.

2 Materials and methods

2.1 Site description

The study was conducted in Houtnek village (-29.0264; 26.8014) in Thaba Nchu, Free State and in Qongqo village (-28.0434; 31.6183) near the town of Nongoma, Kwa-Zulu Natal provinces, South Africa. The town of Thaba Nchu forms part of the Mangaung Metropolitan Municipality together with Bloemfontein and Botshabelo. The town is located at 1531m above sea level and receives approximately 692 mm of rainfall annually with an annual average temperature of 15.2 °C (Muthelo et al., 2019). The predominant farming activities are livestock (cattle and sheep) production and to a lesser extent cropping (oil seed crops). The area is characterized by duplex soils of the Valsrivier form, which translate to the chromic luvisol in the word reference base (WRB) for soil resources classification (van Huyssteen, 2020). These soils typically have dark brown to reddish brown topsoil and moderate to strong structured subsoil (Land Type Survey Staff, 1973–2004). The area is dominated by the Highveld grassland vegetation.

Nongoma is one of five towns that constitute the Zululand District Municipality. Annual rainfall in the area is reported to range from 800 to 1000 mm due to variation in topography, and the average temperature ranges between a minimum of 4 °C to a maximum of 20 °C (ZDM, 2018). Soils in the area are of the Swartland form (Protocalcic haplic luvisol in WRB) (van Huyssteen, 2020) with dark brown to grey topsoil transitioning to a moderate to strong blocky structured subsoil on weathering rock (Land Type Survey Staff, 1973–2004). The vegetation is described as the Natal lowveld bushveld. The major agricultural practices in the area livestock and cropping activities mainly beans and maize. The climatic characteristics of the two sites are presented on Table 1.

TABLE 1 Maximum and minimum average Temperature and Rainfall in KZN (2013–2022) and FS (2013–2021).

Month	Kwa-Zulu Natal			Free State		
	Max T (°C)	Min T (°C)	Rain (mm)	Max T (°C)	Min T (°C)	Rain (mm)
Jan	24.8	18.4	67.9	34.7	15.9	77.1
Feb	27.4	20.3	78.7	32.6	15.1	94.7
Mar	27	19.7	102	30.9	12.7	71.1
Apr	25.3	17.2	173	27.1	8.33	60.6
May	24.7	15.4	41.2	25.3	3.13	16.6
Jun	23.6	13.4	7.77	22.3	-1.03	8.24
Jul	22.8	12.5	46.8	22.1	-1.69	12.4
Aug	22.8	13.7	34.1	24.0	0.65	8.69
Sep	20.7	13.6	54.9	26.2	4.82	8.89
Oct	21.4	14.5	103	31.6	9.39	30.3
Nov	21.9	15.4	119	32.8	11.5	59
Dec	23.4	17.2	131	34.2	14.5	87.4
Annual average	23.8	15.9	799	28.7	7.77	401

2.2 Soil sampling and characterization

Soil samples were collected from 0–20 cm depth at each site for initial characterization prior to land preparation. The soil analysis results were used as a guide for fertilizer application recommendations. Soil pH and EC was measured in a 1:1.25 soil: water suspension using a laboratory pH meter and particle size distribution by the hydrometer method (Beretta et al., 2014). Essentially a soil-water-calgon suspension was used to separate particles of different sizes based on their settling velocity as determined by Stoke's law. Total N was determined by dry combustion using a Leco CN-2000 analyzer (Wright and Bailey, 2001).

The 1M neutral ammonium acetate method (Van Reeuwijk, 2002) was used to determine CEC. A 1M ammonium acetate solution (NH4OAc) at pH 7 was used to extract the cations from the soil samples and the solution was shaken for two hours and centrifuged to separate the liquid and solid phases and analysis of cations was done by inductively coupled plasma-optical emission spectrometry (ICP-OES). The CEC was determined as the sum total of the determined cations. The determination of soil organic carbon followed the Walkley-Black method (Wang et al., 2012), where soil organic matter was oxidized with 1N potassium dichromate in the presence of sulphuric acid and the percentage amount of organic carbon calculated from the amount of dichromate remaining after titration with ferrous sulphate.

Selected characteristics of the study soils are shown on Table 2. Soils from both study areas show that the two sites were acidic, with KZN (pH 5.17) being more acidic than FS (pH 5.71) and the EC fell in the range of non-saline in both FS (3.0 mS/m) and KZN (7.79 mS/m) (USDA-NRCS, 2020). The KZN soil had more cations than the soil from FS. Total N was similar at KZN (0.13%) and & FS (0.11%), while the soil in KZN had more P (6.59 mg/kg) than the 2.88 mg/kg P in the FS soil. The soil in FS was sandy loam and had more sand (74%) and less clay (20%) than the soil from KZN, which was sandy clay loam and had 56% sand and 38% clay.

2.3 Agronomic practices

Sorghum was sown in 6 x 4.5 m plots with 1 m spaces between them and 4 m between the tillage systems and 2 m between planting dates resulting in each block being 28 X 24 m or 672 m^2. Each plot consisted of 7 rows with 45 cm inter-row spacing. Mono-Ammonium Phosphate (MAP) was used as the pre-plant fertilizer and Lime Ammonium Nitrate (LAN) as the topdressing fertilizer at 3–4 weeks after planting. MAP was applied at a rate of 15.41 kg/block and LAN at a rate of 11.76 kg/block in FS. In KZN the application rates were 13.44 kg of MAP per block and 10.08 kg of LAN per block. The selective herbicide used was Sorgomil® Gold 600sc at 174.72 ml per block in FS and 201.6 ml per block in KZN, owing to the difference in texture between the 2 sites. Cypermethrin 200 EC was applied for the control of stalk borer at 23.5 ml per block and Decis® forte for the control of armyworm at a rate of 4.032 ml per block. The herbicide SLASH PLUS 540 SL was used at the start of each season for the control of perennial weeds at least 7 days prior to plant at a rate of 83.36 ml per block.

TABLE 2 Initial soil properties of the two study sites.

Soil property	Free State	KwaZulu-Natal
pH H_2O	5.71	5.17
EC (mS/m)	3.05	7.79
Exchangeable Ca (mg/kg)	455	868
Exchangeable Mg (mg/kg)	156	196
Exchangeable K (mg/kg)	217	232
Exchangeable Na (mg/kg)	6.88	14.0
CEC meq/100g	4.13	4.93
OC (%)	0.745	2.37
Total N (%)	0.108	0.134
P (mg/kg)	2.88	6.59
Clay (%)	20	38
Silt (%)	6.0	6.0
Sand (%)	74	56
Texture	Sandy loam	Sandy clay loam

2.4 Experimental set up

The two cultivars of sorghum used in this study were the bronze-grained, medium to late maturing PAN8816, known to be highly resistant to leaf disease and head smut and the early to a medium maturing open-pollinated variety (OPV), Macia. The common characteristic of the cultivars is that they are both low tannin, semi-dwarf hybrids.

The experiment was laid out in completely randomized block design with a strip-strip-split-plot treatment layout (Gomez and Gomez, 1984) and replicated three times. The factors of tillage and planting date were assigned to the vertically and horizontally arranged main strips. The two vertical strips were divided between conventional tillage (CT) and no-till (NT) while the horizontal strips were randomly assigned to early planting (December) and late planting (January). This vertical – horizontal arrangement of the strips resulted in intersection plots, which were split in two for the assignment of the two crop rotations, sorghum –sorghum-sorghum (S-S-S) and sorghum –cowpea-sorghum (S-C-S). The rotations were further split in two to accommodate both cultivars (PAN8816 and Macia) used in the trial. This resulted in 16 treatment combinations that were replicated three times. The field layout is visually depicted in the graphic below (Figure 1), showing a single block out of the total of three.

2.5 Measurements

The following parameters were measured at the end of each season, during the months of May and June in 2021 and 2022, respectively. Plant height was determined at harvest (end of the season) using a graduated rod from the bottom the highest leaf. Plants that fell within the boundaries of a 4 m x 3 m (three middle rows) net plot were harvested at the end of the growing season to determine grain yield. The harvested panicles from each plot were threshed and weighed to determine yield. At the end of the season, leaves were taken from three random plants (same plants as for plant height) for leaf tissue analysis for nitrogen, phosphorus and potassium following the method of Zekri et al (2015).

2.6 Statistical data analysis

The field trial was made up of 2 planting dates, 2 tillage systems, 2 cultivars and 2 rotations making the experiment a 2×2×2×2 factorial. The study was replicated three times and laid out in three blocks. The data from the field trial was subjected to Analysis of variance (ANOVA) and mean separation performed using least significant difference (LSD) at a confidence interval of 95%. The analysis was performed using JMP Pro Version 17 (JMP Statistical Discovery LLC, 2022).

3 Results

3.1 Effects planting date, tillage and sorghum cultivar on plant height in FS

Yield parameters, panicle length and 1000 seed weight did not show significant treatment effects in FS. The three-way interaction effect of planting date, tillage and sorghum cultivar did not have significant effects ($p>0.05$) on plant height in the first season. Only the tillage × cultivar interaction effects, and the main effects of planting date and cultivar significantly ($p<0.05$) affected plant height in FS. Greater plant heights were observed in early (131 cm) than late (110 cm) planted crop, PAN8816 (125 cm) than Macia (116 cm), in the first season, and the trend was the same in the second season. Under NT, Pan8816 had the significantly taller plants than the Macia both when planted early or later (Figure 1), while under CT, the difference was only observed when planted late (Figure 2). The only difference in plant height between the tillage systems was for Macia, when planted early, where CT had taller plants than NT (Figure 2). Under NT, the sorghum-cow pea-sorghum rotation resulted in significantly shorter plants than the sorghum-sorghum-sorghum rotation, under NT but not CT, when planted early but not later (Figure 3). When planted early, there were no significant differences between the rotations irrespective of tillage system (Figure 4). However, when planted late, the sorghum-cow pea-sorghum rotation resulted in significantly taller plants than the sorghum-sorghum-sorghum rotation, for PAN8816 but not Macia (Figure 4).

3.2 Effects planting date, tillage and sorghum cultivar on plant height in KZN

Only the planting date × tillage interaction had a significant effect on plant height in KZN in the first season. There were no significant tillage effects for early planted crops, while for late

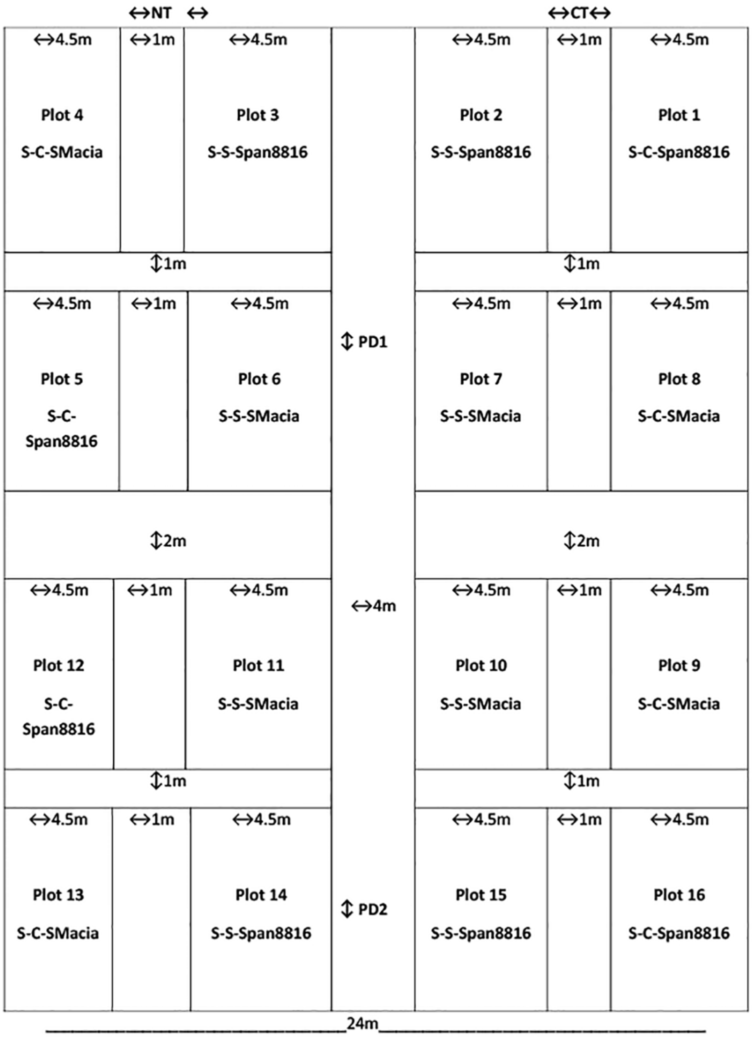

FIGURE 1
Schematic representation of a single block of out of three in the field.

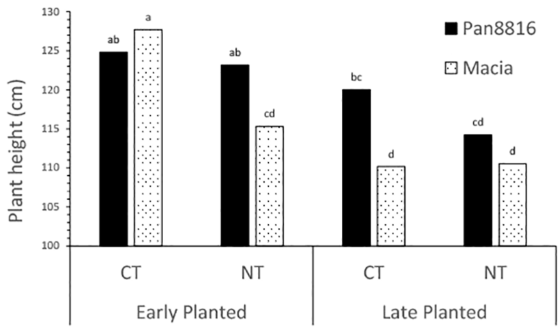

FIGURE 2
Effect of planting date×tillage×cultivar on plant height in FS in season 2021/22. Different letters on the bars indicate significant differences at p < 0.05.

planting, NT resulted in taller plants than CT (Figure 5). Late planting resulted in significantly shorter plants only under CT but not under NT (Figure 5). For the second season (2021/22), the 4-way interaction effects of planting date × tillage × cultivar × rotation were significant ($p<0.05$) on plant height. In the second season, PAN8816 resulted in taller plants than Macia, in the sorghum-cowpea-sorghum rotation, under CT but not under NT, for both planting times (Figure 6). The PAN8816 also had taller plants than Macia, in the sorghum-sorghum-sorghum rotation under NT only when planted early, with no differences for late planting. Overall, the Pan8816 (140 cm) grew significantly taller than Macia (113 cm) in the second season (Figure 6). All the major and interactive treatment effects were not significant for 1000 seed weight and panicle length in both seasons.

3.3 Grain yield and primary nutrient uptake in FS

There were no interactive effects of PD, tillage, cultivar on yield in FS for the first season. The early planted sorghum (1.15 t/ha) had 2.66 times higher yield than late planted (0.434 t/ha) sorghum in the

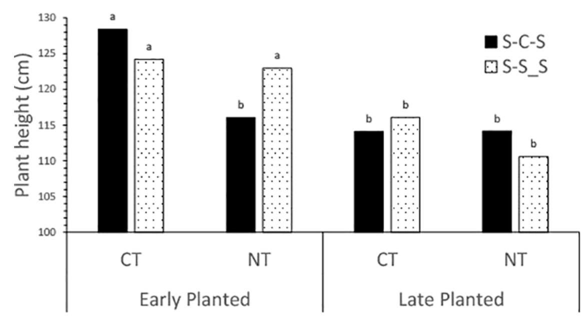

FIGURE 3
Effect of planting date×cultivar×rotation on plant height in in FS in season 2021/22. Different letters on the bars indicate significant differences at p < 0.05.

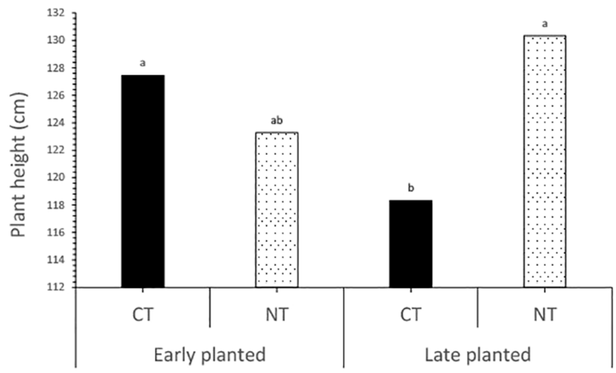

FIGURE 5
Effect of planting date×tillage on plant height in KZN in 2020/21. Different letters on the bars indicate significant differences at p < 0.05.

first season. In the second season (2021/22), early planting (3.39 t/ha) resulted in significantly (p<0.05) higher yield than late planting (0.91 t/ha), while plants grown under CT (2.61 t/ha) produced significantly higher yield than under NT (1.70 t/ha) in FS (Figure 7).

Early planting resulted in significantly (p<0.05) higher uptake of all three nutrients (Figure 8), i.e., higher N (16 kg/ha), K (15 kg/ha) and P (3 kg/ha) uptake than late planted crops. There was also a significant effect of cultivar on P uptake where Pan8816 (2.7 kg/ha) took up 1.74 times more than Macia (1.6 kg/ha). All the treatment factors had no significant (p>0.05) effects on the uptake of all the nutrients in KZN for the same season.

Plants grown under CT (17 kg/ha) took up significantly more K than those grown on NT (8 kg/ha) plots in FS, in the second season. Planting date is again the only treatment that has significant effect (P < 0.05) on all the three measured nutrients, in FS, in the 2021/22 season. Early planted sorghum took up significantly more NPK than late planted sorghum (Figure 9).

3.4 Grain yield and primary nutrient uptake in KZN

The interactions and main factor did not significantly affect (p>0.05) sorghum grain yield and uptake of N, P and K in KZN in both seasons, except cultivar in the second season, where Pan8816 (4.40 t/ha) produced 3.3 times higher yield than Macia (1.32 t/ha). Cultivar had a significant effect (p<0.05) of on N, P and K uptake in KZN, for both seasons, with Pan8816 having higher of N (84 kg/ha), K (64 kg/ha) and P (8 kg/ha) uptake when compared to Macia in the second season (Figure 10).

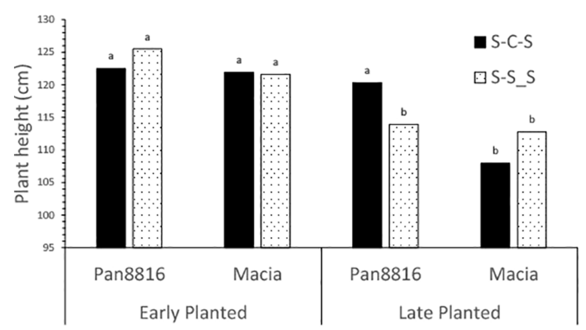

FIGURE 4
Effect of planting date×cultivar×rotation on plant height in FS in Season 2021/22. Different letters on the bars indicate significant differences at p < 0.05.

4 Discussion

The planting date, cultivar and planting date × tillage factors were the most influential factors affecting plant height across all treatments. Early planted crops consistently grew taller than their late planted counterparts due to longer growing season with more conducive environmental conditions for growth such as temperature and moisture. Optimal environmental conditions positively influence plant growth (Irawan et al., 2022). This effect was particularly pronounced in the drier FS province. Early planting in FS allowed plants to benefit from availability of more soil moisture for extended periods. Conversely, the absence of significant height differences between early and late planting in KZN province, which generally receives higher rainfall, and a naturally longer growing season supports this observation. Table 1 shows that the annual rainfall of KZN (799 mm) is higher than of FS (401 mm).

Sorghum cultivar also played a role in plant height. Pan8816 consistently produced taller sorghum plants for than Macia in both seasons and locations. This suggests inherent genetic differences among the cultivars (Irawan et al., 2022). Pan8816 is a medium to late maturing hybrid while Macia is early to medium maturing open-pollinated variety (OPV) (Weepener et al., 2014; Hadebe et al., 2017). Pan8816 being a hybrid has been bred to have the best traits for a number of different parent lines while the OPV Macia only have the traits of the parent because the pollination occurs naturally. According to Gosh et al. (2015), differences in plant height among cultivars are due to genetic differences. While planting date and tillage interaction influenced plant height in KZN during the first season, cultivar and the interaction of all treatment factors had significant effects in the second season. This suggests

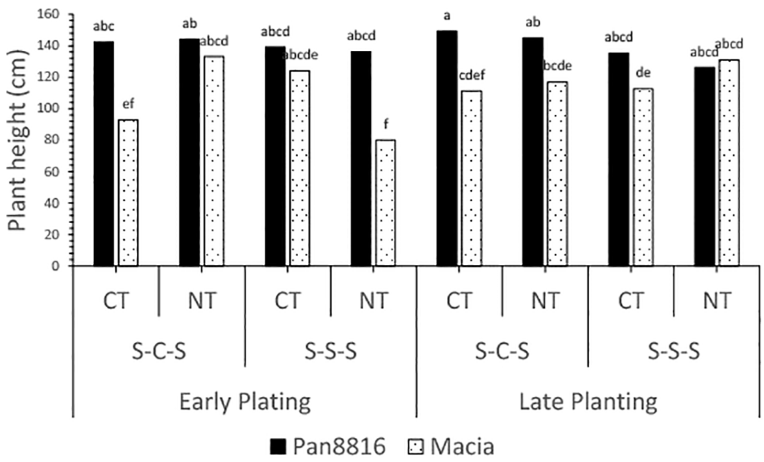

FIGURE 6
Effect of plating date×tillage×cultivar×rotation on plant height in KZN in season 2021/22. Different letters on the bars indicate significant differences at $p < 0.05$.

that selecting the most appropriate cultivar, such as the taller PAN8816 in this study is more critical than time of planting in KZN under a particular set of conditions. Furthermore, regional adaptability also plays a role in the plant height of sorghum crops (Gosh et al., 2015; Sebetha and Modisapudi, 2019).

The higher yield for early planted than late planted crops in Free State in both seasons, is likely due to the longer growing season, which allows for greater biomass accumulation, flowering and grain filling. This aligns with findings by Shoyer et al. (1998) and Hadebe et al. (2017) who reported that planting after the first rains in dry to semi-arid summer grain growing regions results in much greater yields. Sorghum thrives in soil temperatures around 15°C at a depth of 10 cm (Murdy et al., 1994). However, late planting in FS coincides with the occurrence of frost, usually occurring between March and April (Moeletsi et al., 2016). These cooler temperatures impact sorghum emergence and early growth by delaying panicle initiation and flowering, ultimately reducing yield (Emendack et al., 2021). In the current study, the prevailing temperatures in FS fell below the optimal range reported by other researchers (Balota et al., 2010; Emendack et al., 2021) (Table 1). Moreover, sorghum tends to do well in warmer climates (Sebetha and Modisapudi, 2019). The higher yields observed under conventional tillage can be attributed to the relatively short period during which no-till was practised at the site. Findings by Pittelkow et al. (2015) suggested the full benefits of no-till agriculture may take up to four years to be realized. The observed similarity between yield and uptake of N, P and K, suggested that the enhanced uptake of these nutrients under conventional tillage contributed to the greater yield.

Nitrogen is the most limiting nutrient for sorghum production (Teshome et al., 2023). Tillage practices and cultivar selection can significantly affect short-term nitrogen use (Ramadhan and Mushin, 2021). In this study, conventionally tilled plots exhibited higher porosity and lower bulk density compared to NT plots. Another notable observation was the similar N and P uptake patterns across both sites. Similarly, Ortas et al. (1996) found that ammonium-based nitrogen fertilisers like monoammonium phosphate (MAP) used in this study promoted the uptake of phosphorus. Therefore, the MAP used as the pre-planting

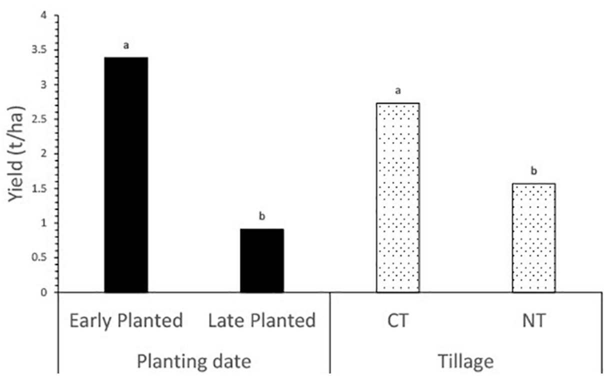

FIGURE 7
Effect of planting date and tillage on yield in FS in Season 2021/22. Different letters on the bars indicate significant differences at $p < 0.05$.

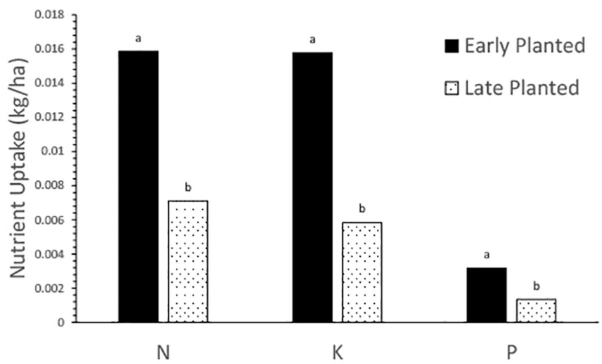

FIGURE 8
Effect of planting date on NPK uptake in FS in 2020/21. Different letters on the bars indicate significant differences at $p < 0.05$.

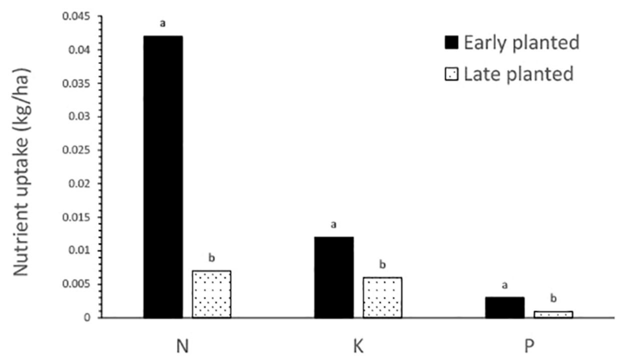

FIGURE 9
Effect of planting date on NPK uptake in FS in 2021/22. Different letters on the bars indicate significant differences at $p < 0.05$.

fertilizer in this study, implies greater availability of phosphorus owing to the ammonia in the MAP.

The significantly higher yield of PAN8816 compared to Macia is likely due to its greater uptake of N, P and K. This enhanced uptake could be attributed to inherent genetic differences between the cultivars. In KZN, cultivar was the most prominent factor influencing yield. Pan8816, a hybrid, has been demonstrated to have small canopy size, which allows it to maintain a higher chlorophyll content (Manyathi, 2014), which in turn translates to increased levels of photosynthesis ultimately supporting higher yields. The lack of tillage, time of planting and rotation effects in KZN could be due to the higher rainfall received in the region. This translates to greater available moisture throughout a longer growing season compared to FS.

A drawback of this short-term study is the potential for increased competition between sorghum crops and weeds for vital resources such as nutrients and moisture (Giller et al., 2009). Despite applications of pre-planting and post-planting herbicides, significant weed presence was observed at both sites. Short-term studies can also be susceptible to challenges like poor germination, higher prevalence of crop pests and nutrient immobilization (Giller et al., 2009). These challenges arise due to the complex interaction between crop requirements, climate and soil characteristics. For instance, the presence of plant residues can cause temporary nutrient immobilization by soil microbes especially when the climatic conditions allow (Dabeux and Sollenberger, 2020).

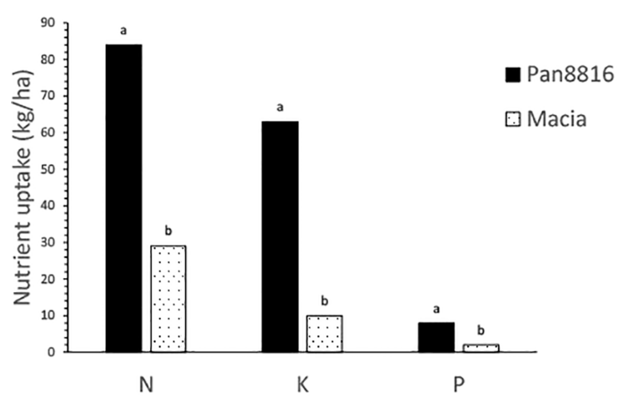

FIGURE 10
Effect of cultivar on N, P and K uptake in KZN in 2021/22. Different letters on the bars indicate significant differences at $p < 0.05$.

5 Conclusion

This study identified key factors influencing sorghum performance in some parts of FS and KZN. In FS, planting date and cultivar, significantly influenced plant height, yield and nutrient uptake. Early planting and selection on PAN8816 cultivar is the most favorable combination to avoid frost and maximize yield. In KZN, cultivar was the primary factor, influencing yield, with Pan8816 outperforming Macia. However, planting date had minimal impacts in KZN, suggesting a greater flexibility for farmers. Therefore, farmers at the KZN site can plant sorghum across the tested dates without significant yield penalties. Early planting is recommended for FS to avoid the frost season. Additionally, PAN8816 is recommended at both sites, especially under conventional tillage. However, longer-term studies are necessary to determine the influence of no-till practices, as the benefits may not be realized within the two-season timeframe of this study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KM: Data curation, Formal Analysis, Investigation, Methodology, Software, Writing – original draft. AN: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing – review & editing. PM: Conceptualization, Investigation, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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