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Short-term tillage management effects on grain sorghum growth, yield and selected properties of sandy soil in a sub-tropical climate, South Africa

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ABSTRACT

Poor soil fertility and water holding capacity, coupled with climate change, threaten smallholder agriculture under dryland conditions, particularly in sandy soils. The resilience of sorghum makes it an ideal candidate crop for conservation agriculture (CA), under these conditions, but its productivity and effectiveness could depend on the cultivar used, planting time, tillage, and rotation. This study determined the effects of these factors on selected soil properties, growth and grain yield of two sorghum cultivars in sandy soils, under semi-arid conditions. The trial was conducted between 2019 and 2022 on a sandy soil with <10 % clay and <1.0 % carbon, at Clau-Clau village in Mpumalanga province, South Africa. The experiment had a randomized complete block design (RCBD) set up, in a strip-split-split-plot treatment structure with three replications. The treatment factors were tillage (conventional tillage (CT) and no-till (NT)), planting date (early and late), and rotation (with cowpea or sorghum monoculture) and sorghum cultivar (Pan 8816 and Macia). In the second growing season, early planted sorghum outperformed the late planted crop, with 44.4 % greater height and 36.1 % higher 1000-seed weight. Furthermore, the grain yield (1.33 and 0.56 t/ha, respectively) and dry matter yield (2.38 and 1.10 t/ha, respectively) were significantly higher for early than late planting in season 2. The NT treatment had significantly higher SOC, available P and exchangeable K than CT treatment in season 2. In season 3, early planting had 30.4 % higher exchangeable K than late planting, while NT increased total N and SOC by 50 and 34.8 %, respectively than CT. The findings of this study show the positive effects of early planting and NT on sorghum grain and dry matter yields, while effects on soil properties were greater during the season with higher rainfall, with no effects of cultivar and rotation on this infertile sandy soil.

Abbreviations: ANOVA, analysis of variance; ARC, Agricultural Research Council; Ca, calcium; CA, conservation agriculture; CEC, cation exchange capacity; CT, conventional tillage; DALRRD, Department of Agriculture, Land Reform and Rural Development; EC, electrical conductivity; K, potassium; LAN, Limestone Ammonium Nitrate; MAP, Monoammonium Phosphate; Max, maximum; Min, minimum; Mg, magnesium; mg/kg, milligram per kg; NT, no tillage; P, phosphorus; PD1, early planting date; PD2, late planting date; R1, first rotation; R2, second rotation; RCBD, randomized complete block design; S-C-S, sorghum-cowpea-sorghum; SOC, soil organic carbon; S-S-S, sorghum-sorghum-sorghum; TN, total nitrogen; t/ha, tonnes per hectare; V1, Pan8816; V2, Macia.

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Introduction

The sustainability of crop production in Africa is threatened by multiple challenges such as low soil fertility, poor management strategies, and extreme weather events, due to climate change [1–3]. Increasing demand for food, feed, fibre and energy production, has led to the expansion of cultivation onto marginal land, including sandy soils. These soils are characterised by low soil organic carbon content (SOC), limited cation exchange capacity (CEC), and poor moisture retention (Huang and Hartemink, 2020). The low fertility and poor water-holding capacity of sandy soils limit crop productivity. Climate change amplifies these challenges, posing severe threat to sustainable crop production for many smallholder farmers in Africa, who continue to attain low yields. Prolonged droughts associated with climate change intensify water scarcity, significantly affecting crop production. Additionally, extreme weather events, including unexpected storms, accelerate nutrient depletion from agricultural soils through runoff and erosion, thus exacerbating soil fertility decline.

Conventional tillage (CT), which is commonly practised by smallholder farmers, enhances runoff and erosion, exacerbating nutrient losses particularly in sandy soils, consequently hampering crop production. Ekwue and Harrilal [4] reported that sandy soil experienced 87.6 % greater soil loss compared to clay loam soils resulting in reduced crop yields. This soil degradation, coupled with the impacts of climate change, poses significant challenges to agricultural productivity in Sub-Saharan Africa (SSA). Projections suggest a 3.2 % decline in cereal crop production by 2050 due to climate change [5]. However, the adoption of climate-resilient agricultural practices that can improve soil quality, water availability, mitigate erosion and improve organic matter can contribute to the sustainability of crop production in regions with sandy soils [6,7].

Conservation agriculture has a potential to enhance soil quality on sandy soils in marginal areas. By reducing soil disturbance, retaining crop residues as mulch and crop rotation, CA enhances soil nutrient cycling [8,9], improves soil moisture storage and minimises greenhouse gas emission [2]. The retention of crop residues improves the SOC concentration and enhances soil structure and nutrient cycling. However, this effect depends on the quality of the crop residues (C/N, lignin, polyphenols etc.), which governs the rate of decomposition [2]. The rotation of cereals with legume crops, such as cowpea, could enhance soil fertility status through biological nitrogen fixation. However, even greater benefits can be obtained by coupling CA with drought-tolerant cereal crops such as sorghum that offer stable yields in arid and semi-arid climates.

Sorghum has received renewed interest from researchers due to its ability to withstand drought and other extreme climatic conditions [1,2,10]. Sorghum is the fifth most important cereal crop in the world after rice, wheat, corn/maize and barley, and is mostly cultivated for grain for human and animal consumption and bioenergy production in arid and semi-arid tropical regions including Africa [11]. Sorghum can contribute to household food security and secure livelihoods in marginal areas of South Africa [1]. The leaves of this crop are well protected by a waxy cuticle and roll-up to minimize transpiration during drought periods, while the crop becomes dormant when drought continues [11]. While several researchers have worked on sweet sorghum [2,10,12], there is limited knowledge about the performance of grain sorghum under CA in South Africa, especially on sandy soils under smallholder agriculture.

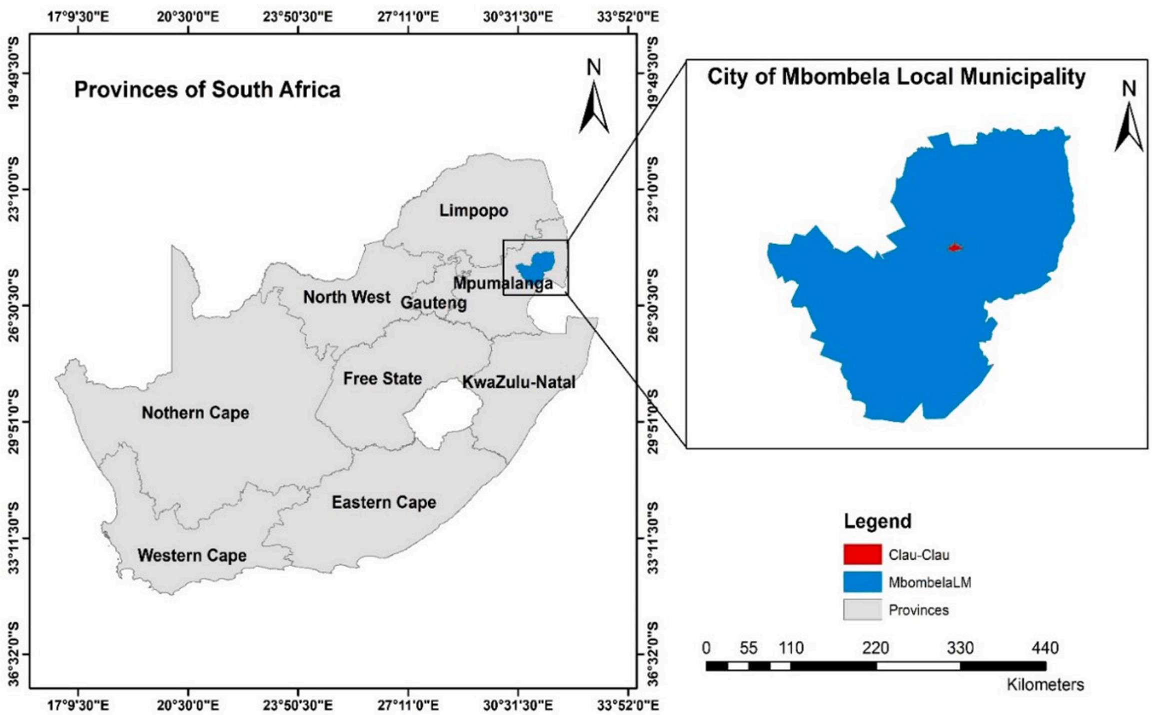

Fig. 1. The South African map showing the selected site as reported by the local municipalities.

Malobane et al. [13], showed that the adoption of CA can increase sorghum yields in drought-prone areas of South Africa. This therefore highlights the potential of sorghum for smallholder farmers who are largely located in dry areas. However, yield could depend on both the cultivar and cropping systems. Therefore, identifying suitable cropping systems that will foster resilience to climate change and improve the quality of sandy soils particularly in arid and semi-arid areas of South Africa, is crucial. Conservation agricultural practices and knowledge of appropriate sorghum cultivars, planting date and rotation could contribute to this goal.

The implementation of CA has the potential to improve soil structure, enhance nutrient availability, and increase moisture retention, leading to enhanced soil health and increased productivity particularly in poor soils, such as sandy soils. However, some studies have reported conflicting findings on the effects of CA on sandy soils [14]; (Mchunu et al., 2011); [15]. For example, da Silva et al. [15] observed a 6 % yield increase soyabean yields under NT compared to CT on sandy soils. In contrast, Lasisi and Aluko [14] reported a higher yield on CT than NT plots on similar soil types. These conflicting findings necessitates more research to elucidate the effects of CA on the performance of different sorghum cultivars on sandy soils on contrasting sites.

This study investigated the effects of planting date, tillage, and crop rotation on the growth, dry matter, yield of two sorghum cultivars, and selected soil properties on sandy soil under sub-tropical climatic conditions. By studying these factors, this study aims to provide valuable insights into the adaptability and performance of different sorghum cultivars and CA practices. Overall, this study is important for smallholder farmers in regions with sandy soils, as it aims to provide evidence-based recommendations for improving crop yields, enhancing soil health, and building resilience to climate change. By identifying the most effective combination of CA practices, sorghum cultivars, and planting dates, farmers can optimize their agricultural production and enhance soil health and build resilience to climate change.

Materials and methods

Site description

The study was conducted at Clau-Clau village in Mpumalanga province, South Africa (Fig. 1). Clau-Clau village is situated within the Mbombela Local Municipality in Mpumalanga Province of South Africa. The area has as a sub-tropical climate and receives a mean annual rainfall of approximately 748 mm, which occurs between November and February [16]. The mean minimum and maximum temperatures range from −2.0 °C and 41.7 °C, respectively [17]. The area is characterised by predominantly sandy soils with <10 % clay [16]. The soil at Clau-Clau had grey to grey-brown sandy topsoil over yellowish brown sandy subsoil, classified as Fernwood which is equivalent to Hyperdystric Stagnic Regosols [18]. Prior to the study, the standard practice in the area was conventional tillage using a mouldboard plough, with maize being grown annually. Temperature and rainfall conditions are shown in Figs. 2 and 3, respectively. The rainfall was above average between October and March, except November and December in the 2020–2021 season and February in the 2021–2022 season (Fig. 3).

Experimental design

The experiment was carried out in randomized complete block design with a strip-split-split-plot treatment structure, replicated three times [19]. Planting date (early and late) and tillage system were assigned to the horizontal and vertically arranged main strips, respectively (Fig. 4). Early planting was done in the first week of December, whilst late planting was done in the second week of January in every growing season. The two tillage systems were conventional tillage (CT) with crop residue removal and no-till (NT) with crop residue retention. This vertical-horizontal split plots gave intersection plots, which were split into two and assigned to the two crop rotations i.e. sorghum-sorghum-sorghum (S-S-S) and sorghum-cowpea-sorghum (S-C-S). The rotations were divided in two to accommodate the two selected cultivars i.e. Pan 8816 and Macia. These cultivars are known to have the ability to tolerate dry weather condition and are characterized by low tannin and are semi-dwarf hybrids. The experiment consisted of 16 treatments with three replicates, which resulted in 48 experimental plots, of 6 × 4.5 m size. The experiment was conducted across three growing seasons,

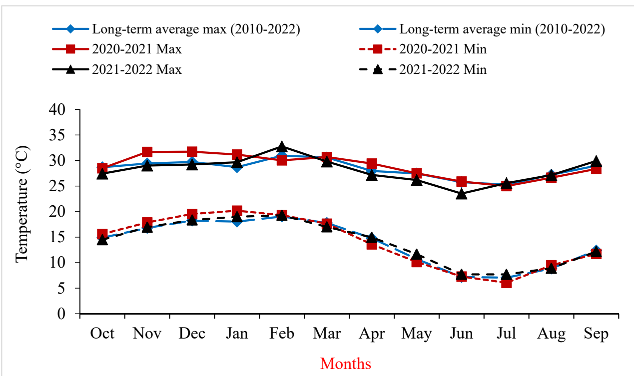

Fig. 2. Long-term (2010 – 2022) and seasonal (2020 – 2021 and 2021 – 2022) temperature conditions.

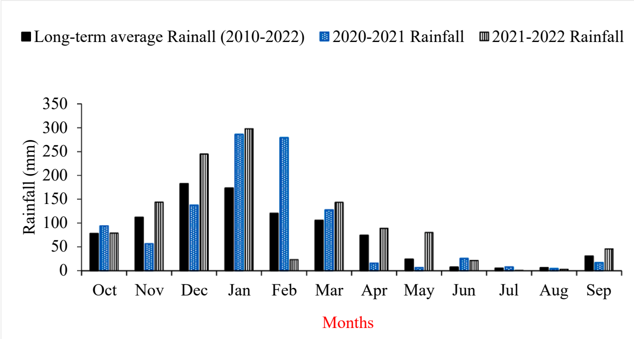

Fig. 3. Long-term (2010 – 2022) and seasonal (2020 – 2021 and 2021 – 2022) rainfall conditions.

between 2019/20 – 2021/22.

The management of non-experimental variables

The whole experimental field was ploughed with a mouldboard plough and harrowed to breakdown large clods to make a fine tilth at the onset of the experiment in 2019, marking the first growing season. Residue retention was only applied on the NT plots after each harvest whereas the CT plots were left bare throughout the experimental period. The CT plots were ploughed to a depth of approximately 30 cm at the beginning of each growing season using a mouldboard plough and harrowed. During the second growing season (2020/2021), cowpea was planted in some plots, followed by sorghum in the third season (2021/2022) as part of a crop rotation strategy. The conventional tillage plots were ploughed using a mouldboard plough and harrowed. In both CT and NT plots, hand hoes were used to open rows for planting. To ensure optimal nutrient levels, fertilizer was applied based on the initial soil analysis. Monoammonium Phosphate (MAP) fertilizer (218 kg/ha) was applied at planting to supply N (24 kg/ha) and P (48 kg/ha) while Limestone Ammonium Nitrate (LAN) fertilizer (259 kg/ha) was applied as top-dressing after six weeks of planting to supply an additional 72.5 kg N/ha. Glyphosate (N-(phosphono-menthyl) glycine, 360 g/L) was used to kill the weeds in all plots after harvest and before the next growing season. Cylam 50 EC (Lambda-cyhalothrin (pyrethroid), 50 g/L) was used to control pests in the grain sorghum crops. Sorghomil Gold (600 SC) was used to control weeds in all the NT plots whereas hand hoes were used to remove weeds in the CT plots.

Soil sampling and analysis

Three soil samples were collected randomly before and after each harvest using an auger at 0 – 20 cm depth in each experimental plot, and were mixed to make a composite sample, making a total of 48 samples from the 48 plots. The samples were air-dried and sieved (<2 mm) before analysis. Soil pH and electrical conductivity (EC) were measured at 1:2.5 soil: water ratio (Okalebo et al. 2012). Soil organic carbon (SOC) was determined following the Walkely-Black method [20]. Soil particle size distribution was determined following the hydrometer method after dispersion with 1 M sodium hexametaphosphate [21]. Total N (TN) was determined following the dry combustion method using the Flash 2000 organic Elemental Analyzer (Milan, Italy). Soil available P was determined following the P-Bray 1 method [22]. Exchangeable Ca, K and Mg were determined by the ammonium acetate method [23]. The initial soil properties are presented in Table 1.

Sorghum growth and dry matter yield

Plant measurements included plant height, grain yield, 1000 seed mass and aboveground dry matter yield. Plant height was measured using a tape measure from the base to the tip of the plants at the harvest stage. Grain yield was harvested from a net plot measuring 2.5 m × 4 m. The harvested grain was then threshed, weighed and expressed as t/ha. To determine the average weight of individual seeds, a representative sample of 1 000 seeds was weighed. This weight was reported as 1000-seed weight in grams. The above ground dry matter was also harvested from the net plot and dried in an oven at 60 °C for 24 h, weighed and expressed as t/ha. The results section of this study presents data from the second (2020–2021) and third (2021–2022) growing seasons after the treatments were implemented. In season 1, the whole experimental field was ploughed before the treatments were implemented and the crop residues produced from season 1 were used to cover the soil under no-tillage.

Statistical analysis

Analysis of variance (ANOVA) was performed using JMP 16 statistical package software (SAS Institute, Inc., Cary, NC, USA, [24] to assess the effects of tillage, planting date, cultivar and rotation on the soil and yield parameters of sorghum. Mean separations were performed using Duncan's Multiple Range Test at a significance level of $p < 0.05$.

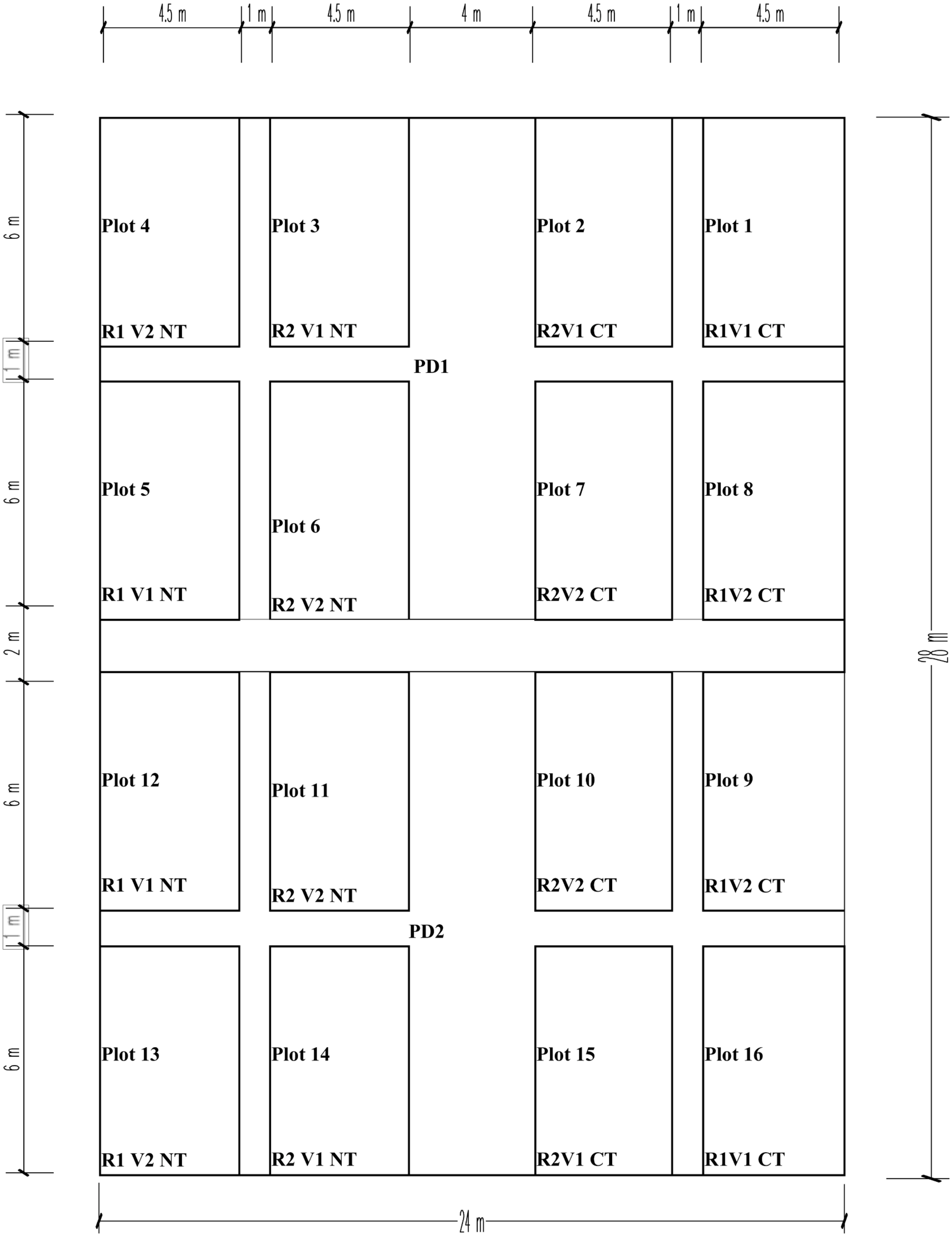

Fig. 4. The field experimental design map. PD1 and PD2 – early planting date and late planting date, respectively; NT and CT – No-Till and conventional tillage, respectively; R1 and R2 – sorghum-cowpea-sorghum and sorghum-sorghum-sorghum, respectively; V1 and V2 – Pan8816 and Macia, respectively.

Table 1
Initial soil properties at Clau-Clau village.

Parameters	Clau-Clau
pH (H_2O)	5.57
EC (mS/m)	0.97
P (mg/kg)	7.6
K (mg/kg)	16
Ca (mg/kg)	57
Mg (mg/kg)	20
Total N (%)	0.05
SOC (%)	0.39
Sand (%)	88
Silt (%)	4
Clay (%)	8
Textural Class	Sand

Note: pH (H_2O) – pH measured in water; EC – electrical conductivity; P – available phosphorus; K – exchangeable potassium; Ca – exchangeable calcium; Mg – exchangeable magnesium; N – total nitrogen; SOC – soil organic carbon;; mS/m – millisiemens per meter; mg/kg – milligram per kg; % – percent.

Results

Effects of planting date, tillage, and rotation on selected soil properties

The interactions between planting date, tillage and rotation had no significant effects on any of the measured soil properties. Additionally, planting date did not have significant effects on soil properties measured in the second season of the study. However, tillage significantly affected phosphorus (P), potassium and SOC in season 2 of the study. Phosphorus was significantly higher ($p < 0.05$) under NT (22.8 mg/kg) than CT (16.2 mg/kg) plots (Table 2). A significantly higher ($p < 0.05$) potassium (K) was also observed under NT than CT plots (43.8 to 36.0 mg/kg, respectively) (Table 2). Furthermore, SOC was significantly higher under NT compared to CT plots (0.53 and 0.39 %, respectively) (Table 2). Similar, to the second season, all the measured soil properties in season 3 were not significantly affected by the interactions of the planting date, tillage and rotation. In additions, rotation did not significantly affect any of the measured soil properties. However, significantly higher K was observed at early than late planting (49.31 and 37.79 mg/kg, respectively) (Table 3). Moreover, tillage significantly affected total nitrogen (N) and SOC, with NT having 50 % increased total N and 34.8 % higher SOC than CT plots in season 3 (Table 3).

Effects of planting date, tillage, cultivar and rotation on plant height

Early planting generally resulted in taller sorghum plants during the second season (Table 4). The magnitude of the difference was significantly influenced by interaction with planting date, tillage and cultivar. For instance, early planting × NT × Pan8816 had the highest average height (138 cm), whilst several other combinations with early planting including both cultivars and tillage practices also had significantly taller plants compared to late planting × NT × Macia (56.67 cm) and late planting × CT × Pan8816 (62 cm) (Fig. 5). Examples of this include early planting × NT × Macia (133 cm), early planting × CT × Pan8816 (133 cm) and early planting ×

Table 2
Selected soil properties in season 2 (2020–2021) as affected by planting date and tillage.

Treatment	Total N %	P (mg/kg)	K (mg/kg)	SOC %	Ca (mg/kg)	Mg (mg/kg)	pH (H_2O)
Planting date							
Early	0.05	18.9	40.1	0.47	157	42.9	5.20
Late	0.05	20.1	39.7	0.44	111	33.4	5.07
	ns	ns	ns	ns	ns	ns	ns
Tillage							
NT	0.06	22.8a	43.8a	0.53a	151	38.7	5.26
CT	0.05	16.2b	36.0b	0.39b	117	37.6	5.10
	ns	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	ns	ns

Note: Different letters (a and b) – significant differences ($p < 0.05$); ns – no significant; NT – no-till; CT – conventional tillage; pH (H_2O) – pH measured in water; N – total nitrogen: P – available phosphorus: K – exchangeable potassium: SOC – soil organic carbon: Ca – exchangeable calcium: Mg – exchangeable magnesium: % – percent; mg/kg – milligram per kg.

Table 3
Selected soil properties in season 3 (2021–2022) as affected by planting date, tillage and rotation.

Treatment	Total N %	P (mg/kg)	K (mg/kg)	SOC %	Ca (mg/kg)	Mg (mg/kg)	pH (H_2O)
Planting date							
Early	0.06	26.1	49.3a	0.56	148	38.1	4.65
Late	0.05	31.1	37.8b	0.52	122	25.8	4.96
	ns	ns	$p < 0.05$	ns	ns	ns	ns
Tillage							
NT	0.06a	30.3	45.7	0.62a	139	29.1	4.90
CT	0.04b	26.8	41.5	0.46b	130	34.8	4.72
	$p < 0.05$	ns	ns	$p < 0.05$	ns	ns	ns
Rotation							
S-C-S	0.054	25.8	40.6	0.54	127	30.0	4.99
S-S-S	0.055	31.4	46.5	0.54	142	33.9	4.62
	ns	ns	ns	ns	ns	ns	ns

Note: Different letters (a and b) – significant differences ($p < 0.05$); ns – no significant; NT – no-till; CT – conventional tillage; S-C-S – sorghum-cowpea-sorghum; S-S-S – sorghum-sorghum-sorghum; pH (H_2O) – pH measured in water; N – total nitrogen: P – available phosphorus: K – exchangeable potassium: SOC – soil organic carbon: Ca – exchangeable calcium: Mg – exchangeable magnesium: % – percent; mg/kg – milligram per kg.

Table 4
The effects of planting date, tillage and cultivar on plant height, dry matter, yield and 1000 seed weight in the second growing season.

		Second growing season (2020 – 2021)			
Treatment		Plant height (cm)	Dry matter (t/ha)	Yield (t/ha)	1000 seeds weight (g)
Planting date	Early	133 a	2.38 a	1.33 a	48.3 a
	Late	92.1 b	1.10 b	0.56 b	35.5 b
		$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
Tillage	NT	115	1.96	0.88	43.3
	CT	110	1.51	1.00	37.5
		ns	ns	ns	ns
Cultivar	Pan8816	116	1.98	1.07	45.8
	Macia	108	1.49	0.82	35.0
		ns	ns	ns	ns

Note: Different letters (a and b) – significant differences ($p < 0.05$); ns – no significant; NT – no-till; CT – conventional tillage; cm – centimeters; t/ha – tonnes per hectare; g – gram.

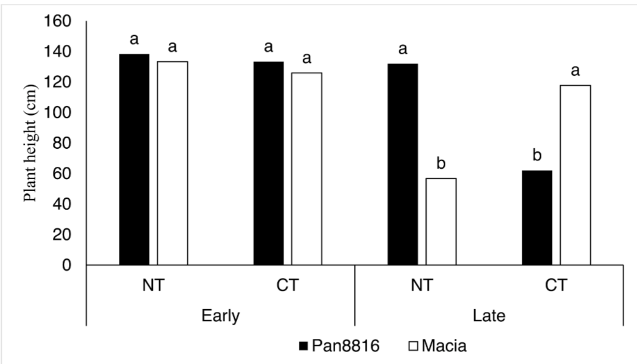

Fig. 5. The interaction effects of planting date, tillage and cultivar on plant height in the second growing season. Different letters (a and b) show significant differences ($p < 0.05$); NT: no-till; CT: conventional tillage.

CT × Macia (126 cm) (Fig. 5). For early planting, there was no differences in plant height between the two cultivars under either NT or CT (Fig. 5). However, under late planting and NT, Pan8816 plants were taller than Macia (Fig. 5). Conversely, the opposite was true under conventional tillage (CT) (Fig. 5). Early planting had significantly higher plant height than late planting in season 2 (133 and

92.1 cm, respectively) (Table 4). In season 3, planting date, tillage, cultivar, rotation and their interactions had no significant effects on sorghum plant height (Table 5).

Effects of planting date, tillage, cultivar and rotation on sorghum dry matter

Planting date, tillage, cultivar, rotation and their interactions had no significant effects on sorghum dry matter in the third growing season (Table 5). However, planting date significantly ($p < 0.05$) affected dry matter in the second growing season. Early planting resulted in a significant increase in sorghum dry matter weight compared to late planting. Dry matter weight was nearly double at early planting (2.38 t/ha) compared to late planting (1.10 t/ha) (Table 4).

Effects of planting date, tillage, cultivar and rotation on sorghum grain yield

In season 2, planting date significantly ($p < 0.05$) affected sorghum grain yield with higher grain yield observed at early planting than late planting (1.33 and 0.56 t/ha, respectively) (Table 4). Contrary to this, tillage and cultivar had no significant effects on sorghum grain yield in season 2. Planting date, tillage, cultivar, rotation and their interactions had no significant effects on sorghum grain yield in season 3 (Table 5).

Effects of planting date, tillage, cultivar and rotation on 1000 seeds weight

Tillage, cultivar and their interactions had no significant effects on 1000 seeds weight in season 2. However, 1000 seeds weight was 36.1 % significantly ($p < 0.05$) greater at early planting compared to late planting (Table 4). Similar to season 2, planting date significantly ($p < 0.05$) affected the 1000 seed weight by the in season 3. The late planted sorghum was significantly ($p < 0.05$) greater than early planted sorghum (28.73 and 23.15 g, respectively) (Table 5). Moreover, significantly ($p < 0.05$) greater 1000 seeds weight was observed when sorghum was planted under NT compared to CT plots (29.44 and 22.44 g, respectively) (Table 5).

Discussion

The significantly higher P and K levels under NT in the second growing season could be attributed to crop residue retention. Crop residue retention improves the availability of P by reducing its adsorption onto mineral surfaces [25]. Consistent with these findings, previous studies have also reported improvements in P and K under NT with crop residue retention [2,26,27]. NT minimizes soil disturbance, preserving soil structure and promoting the activity of beneficial microbial communities that contribute to nutrient cycling and availability. Similarly, the elevated SOC observed under NT plots in season two and three could be due to the combination of crop residue retention and low soil disturbance. Plant residue retention and low soil disturbance improve soil organic carbon through decomposition process, consequently, increases SOC content [28,29]. The results of this study were consisted with the findings by Villamil et al. [29] who reported improved SOC within the 15 cm soil depth under NT with biomass residue retention compared to CT treatment on a silt loam soil. Dou et al. [30] found that, SOC was 34 – 37 % higher under NT treatment than CT treatment in grain sorghum production on a silty clay loam soil. Moreover, the increase in total N under NT in the third growing season could be attributed to the addition of crop residues, which might have increased the activity of microbes, which are responsible for nitrogen fixation [2,27,31]. The results of this study are consisted with the previous study by Malobane et al. [2] who reported that total N was 15.85 % higher under NT than CT plots in sandy clay loam soil under sweet sorghum production system. The non-significant effects of rotation on the measured soil properties suggest that other factors may have played a larger role. Moreover, the short duration of the study may have limited the potential of the treatments to have any meaningful impact. Additionally, poor crop residue retention due to extreme temperature and limited vegetative growth, particularly under crop rotation with cowpea likely masked the potential benefits of residue retention. When plants are experiencing water stress and extreme temperatures they stop growing and quickly start flowering hence switching to the reproductive stage to quickly complete their life cycle [32]. This poor biomass production may also have masked any potential effects of tillage and rotation on nutrient cycling and soil health.

The results of this study suggest that the taller sorghum plants observed in the second growing season could be attributed to the observed higher K content at early planting. The taller sorghum plants observed when Pan8816 cultivar was planted under NT system in the second growing season should be attributed to low soil disturbance and the addition of the plant residues, which might have improved P, K, and SOC. Thus, phosphorus, potassium and SOC were higher under NT plots in the second growing season, which might have played an important role to enhance the growth development of the sorghum. The plant residues retention might also improve soil water availability by reducing evaporation and runoff. Moreover, the results show that Pan8816 did well under NT whereas Macia performed better under CT in the second season, which might be attributed to the cultivar's genotype adaptation under different tillage systems. However, both cultivars performed well under both NT and CT when planted early, thus highlighting the importance of timeous planting.

The significantly higher dry matter observed with early planting in the second season could be attributed to the taller sorghum plants produced at early planting date. Plant height has a positive relationship with dry matter yield, indicating that, taller plant accumulates more dry matter [33]. The higher yield at early planting in season two could be attributed to the observed improved plant morphology. Early planting resulted in taller sorghum plant, greater dry matter yield and 1000 seeds weight compared to late planting. Plant height, dry matter and 1000 seeds weight were consistent with the results for sorghum yield in season two of this study. Generally, taller plants with a greater dry matter accumulation are better equipped for water extraction, which promotes crop growth

Table 5
The effects of planting date, tillage, cultivar and rotation on plant height, dry matter, yield and 1000 seed weight in the third growing season.

Third growing season (2021 – 2022)					
Treatment		Plant height (cm)	Dry matter (t/ha)	Yield (t/ha)	1000 seeds weight (g)
Planting date	Early	106	2.60	1.51	23.2 b
	Late	104	2.21	1.32	28.7 a
		ns	ns	ns	$p < 0.05$
Tillage	NT	103	2.31	1.29	29.4 a
	CT	107	2.50	1.54	22.4 b
		ns	ns	ns	$p < 0.05$
Cultivar	Pan8816	105	2.12	1.39	27.4
	Macia	105	2.69	1.43	24.5
		ns	ns	ns	ns
Rotation	S-C-S	106	2.21	1.45	24.0
	S-S-S	103	2.60	1.37	27.9
		ns	ns	ns	ns

Note: Different letters (a and b) – significant differences ($p < 0.05$); ns – no significant; NT – no-till; CT – conventional tillage; S-C-S – sorghum-cowpea-sorghum; S-S-S – sorghum-sorghum-sorghum; cm – centimeters; t/ha – tonnes per hectare; g – gram.

development through enhance photosynthesis, grain filling and hence higher grain yield [5]. The lower grain yield for late planting may also be attributed to the crop physiological stress, which might have been caused by the extreme temperatures towards the end of the crop growth [34]. These findings suggest that planting date can directly affect crop yield in Clau-Clau. Therefore, early planted sorghum could have received enough rainfall and time for development and growth.

Greater 1000 seeds weight observed at early planting in the second growing season could be attributed to several factors such as enhanced assimilate accumulation due to improved morphology e.g. taller plants, higher dry matter, and sorghum grain yield. Early planting allows for a longer growth duration from the emergence stage to the flowering and panicle initiation, which promotes higher nutrient assimilation [35]. This could have positively influenced the seed weight. Early planting also ensures improved resource utilisation through the establishment of stronger root systems and better access to soil moisture and nutrients. According to Hadebe et al. [5], a higher plant biomass accumulation enhances water extraction for growth and photosynthesis. This improved resource utilization ultimately contributes to larger and heavier seeds during the crucial grain filling stage. The greater 1000 seeds weight under NT plots could be attributed to the low soil disturbance and crop residue retention, which might have improved soil water availability in the third growing season. Crop residue retention improves soil temperature and water availability by decreasing soil water loss through evaporation and runoff, consequently, enhanced seed weight during grain filling stage. Soil water is one of the vital factors to influence crop growth and yield [36]. Similarly, higher seed weight was reported under NT compared to CT treatment which was attributed to the improvement of soil water under NT by reducing water evaporation [37].

Conclusion

This study provides insights into the short-term effects of CA on sorghum production in sandy soils. The results demonstrated that sorghum-based CA systems can significantly improve crop yield, SOC and total nitrogen in some sandy soils in the short-term (3 years). While CA alone does not consistently improve crop yield in the short term, the findings also highlight that its combination with optimal planting date significantly improves crop yields and soil properties, with better results being realised during seasons with higher rainfall. This study also demonstrated cultivar-specific responses of sorghum to planting date and tillage, with better performance for Pan8816 under NT and Macia under CT when planted late. Therefore, this finding provides a new perspective on maximising the benefits of CA on yield in similar environments. These observations provide valuable, location-specific guidance for farmers in the Clau-Clau region and similar environments. The lack of short-term rotation effect observed in this study suggests that for sandy soil, short-term external applications of organic fertilizers, such as manure, may be more beneficial than crop rotation. The varied effects of planting date and tillage across seasons highlights the need for site-specific management strategies. Whilst this study provides critical short-term insights, long-term studies are necessary to fully understand the effects of tillage and rotation on soil properties and sorghum yield. This long-term research will enable the development of optimised site-specific agronomic practices, ultimately enhancing agricultural planning and decision making in similar environments.

CRediT authorship contribution statement

H.Z. Mabasa: Conceptualization, Methodology, Data curation, Writing – original draft, Visualization, Investigation, Software, Validation, Writing – review & editing. **A.D. Nciizah:** Conceptualization, Methodology, Data curation, Writing – original draft, Visualization, Investigation, Supervision, Writing – review & editing. **P. Muchaonyerwa:** Conceptualization, Methodology, Data curation, Writing – original draft, Visualization, Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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