

Yield and quality characteristics of maize-forage legume mixtures cultivated under different tillage systems

Poloko MOSEBI^{1,2} (✉), Casper MADAKADZE¹, Moeketsi NTAKATSANE², Ratsle RATSELE³

¹ Faculty of Agriculture and Natural Sciences, University of Pretoria, Pretoria, South Africa. Private Bag X20, Hatfield, Pretoria, 0028, South Africa

² Faculty of Agriculture, National University of Lesotho, Maseru, Lesotho. P.O. Roma 180, Maseru, Lesotho

³ Ministry of Forestry, Range and Soil Conservation, Maseru, Lesotho. P.O. Box 92, Maseru 100, Lesotho

✉ Corresponding author: pe.mosebi@tuks.co.za

Received: March 25, 2025; accepted: June 29, 2025

ABSTRACT

Planted forage grown under an appropriate cropping system and tillage practice can help to improve yield potential. This study was conducted to evaluate the effects of different tillage practices on the growth, nutrient composition and yield characteristics of maize-forage legume mixtures. Different forage types were represented by sole maize (*Zea mays* L.), sole common vetch (*Vicia sativa* L.), sole lablab (*Lablab purpureus*), maize + common vetch, and maize + lablab intercrops. Forage types were cultivated under different tillage systems, viz., conventional tillage (CT), deep ploughing with a depth of 30 cm, and reduced tillage (RT), shallow ploughing with a depth of 10 cm. Forage samples were collected to examine the growth indices, chemical composition and yield components. Reduced tillage showed lower values of crop growth rate, leaf area, and leaf area index (11.68 g/m²/d, 3.30 m², and 4.09 m²/m², respectively) in sole forages than conventional tillage. Higher dry matter production (35.66%) in forage intercrops and higher values of crude protein content (20.16% DM) in sole forage legumes were observed in the conventional tillage practice than in the reduced tillage practice. Fiber concentrations of sole forages were greatest in reduced tillage and lowest in conventional tillage practices. Higher values of total dry matter and grain yield, harvest index and plant density in forage mixtures were obtained in the conventional tillage than in the reduced tillage. The study concluded that growing sole forages and mixtures under different tillage systems can influence yield and nutritional characteristics.

Keywords: tillage practices, forage crops, growth indices, chemical composition, yield attributes

INTRODUCTION

In many parts of Southern Africa, more smallholder farmers grow maize due to its superior economic performance. Maize is a multipurpose crop that provides food for humans, feed for animals and poultry and fodder for livestock (Balehegn et al., 2020).

Farmers are looking to adopt appropriate cropping systems due to environmental and maize yield concerns. Considerable attention has been given to cropping strategies such as monocropping and intercropping. Among such systems, intercropping has been used to grow two or more crops in the same area, including cereal

with legumes, and has been shown to increase crop yields (Iqbal et al., 2019). Most previous studies suggest that growing maize with leguminous crops in intercropping systems is expected to produce more plant biomass than growing maize alone because of the more efficient use of available resources (Echarte et al., 2011; Liu et al., 2017).

Intercropping systems may facilitate other positive effects during the growing cycle of crops. For example, maize-legume intercrops have more environmental benefits, particularly due to legume nitrogen fixation, which facilitates intercropped cereals to absorb more

nitrogen from the soil than in sole cropping. Intercropped legumes with such nitrogen-fixing properties reduce the amount of nitrogen required by companion cereal crops and benefit the soil at different depths (Raza et al., 2019). This is especially attractive in the context of legume-cereal intercropping because relatively more yield components could be produced for the use of legumes as cover crops without any additional inputs. Legumes intercropping with cereal crops also positively affect soil organic matter and biological activity, both through green manuring or root and leaf residues, which enhance nutrient availability (Rodriguez et al., 2020).

Small-scale maize production in Lesotho takes place mostly with a very limited use of legumes as cover crops. The major gap is related to limited knowledge in the production of sole forages and cereal-legume mixtures under different tillage systems. Maize production is affected by the weather and interaction with other biological, physical and chemical properties of the soil. For example, the absence of a legume companion crop that can fix atmospheric nitrogen and directly transfer it in usable form to maize cereal crops. Soil physical and chemical properties are affected by inappropriate tillage operations that may provide undesirable results, such as decreased infiltration capacity, reduced pore volume, aeration and less efficient recycling of nutrients (Yin et al., 2021). This, in turn, decreases crop yield and consequently leads to low production of maize.

Maize-forage legumes in intercropping systems can be improved through appropriate tillage practices. Tillage is an operation that distracts the soil characteristics for crop production (Islam et al., 2020). Tillage operations improve soil physical parameters such as structure, chemical and biological parameters that affect maize-forage legumes (Wen et al., 2023). Tillage provides favourable soil conditions for plant growth, especially under circumstances where the soil presents zones of high strength and compaction (Wang et al., 2020). Several studies suggest that tillage is one of the most essential operations that usually affects soil chemical properties such as pH, cation exchange capacity, exchangeable

cations and soil total nitrogen (Lozano et al., 2016; Blanco-Canqui and Wortmann, 2020). The impact of tillage on soil biological properties is related to its effects on soil organic matter content, which in turn influences earthworm dynamics, as their burrowing activities aid in the improvement of soil aeration and water infiltration (De Moraes et al., 2016).

Tillage methods range from the conventional tillage method to the conservation tillage method, including zero tillage (no-till) and reduced (minimum) tillage (Zhai et al., 2021). The tillage operation method is considered to be the most important factor for the growth and yield of cereal-legume intercrops. The conventional tillage method resulted in higher yields because of better soil characteristics and demonstrated that conventional tillage operations increase soil aeration, residue decomposition, organic nitrogen mineralisation, and the availability of nitrogen for plant use (Ding et al., 2020). In some instances, the conservation tillage method has an important effect on crop yields because of reduced soil compaction, which increases the build-up of surface residue, which in turn influences soil moisture and temperature and affects plant growth and yield components (Kumara et al., 2020). The conservation tillage method was also found to be very effective in reducing soil and crop residue disturbance, moderating soil evaporation and minimising soil erosion losses (Zhang et al., 2016). In this study, it was hypothesised that the effects of different tillage practices do not necessarily have different growth and yield components of maize-forage legume mixtures. The present study was carried out to evaluate the effect of different tillage practices on the growth, nutrient composition and yield components of maize-forage legume intercrops.

MATERIALS AND METHODS

Study site

A field experiment was conducted at St. Michael Lesotho (29° 25' 38 S, 27° 40' 50 E, and altitude 1,700 m above sea level), where maize (*Zea mays* L.) was intercropped with common vetch (*Vicia sativa* L.) or lablab

(*Lablab purpureus*) under rainfed conditions for two years (2022-2023). The site lies in a lowland region of Lesotho characterised by warm summers and cold winters. Rainfall ranges from 500 mm to 1000 mm per annum, with the highest values in the summer season (Lesotho Meteorological Services, 2023). Winters are generally dry and cold and are characterised by dry air and warm to moderate temperatures during the day, with a sudden cold temperature just after sunset. The average annual temperature ranges between 15.2 °C and 25.6 °C in the lowland region. Details of the average monthly climatic characteristics of the experimental region are given in Table 1. The predominant soils of the area are classified as fersiallitic soils with an orthic A horizon (Fey, 2010), and the basic soil physical and chemical characteristics are presented in Table 2.

Agronomic practices

Maize, lablab, and common vetch were grown as sole crops or as maize with a legume cover crop in 10 x 5 m plots replicated three times. A basal fertiliser (6:3:4 NPK) was applied to all maize plots at a rate of 75 kg/ha at

sowing. Legume-only plots received a combination of P and K at 80 kg/ha. The spacing for sole maize was 75 cm x 30 cm between rows of plants, respectively, and sole common vetch and lablab were 40 cm x 10 cm between rows of plants, respectively. Lablab and common vetch were intercropped between two maize rows at 37.5 cm away from the maize row with inter-row and 10 cm intra-row spacing. All necessary agronomic practices (weed, pest, and disease control) were kept uniform for all experimental plots during the cropping season.

Experimental design

Different forage types were prepared from sole maize (*Zea mays* L.), sole common vetch (*Vicia sativa* L.), sole lablab (*Lablab purpureus*), maize + common vetch, and maize + lablab intercrops. Forage types were cultivated under different tillage systems, viz., conventional tillage (CT), deep ploughing with a depth of 30 cm, and reduced tillage (RT), shallow ploughing with a depth of 10 cm. The experiment was designed as a completely randomised design with a 5 (forage types) x 2 (tillage systems) factorial treatment arrangement and three replicates.

Table 1. Average monthly rainfall, relative humidity, maximum, minimum, and average temperature at the experimental site

	August 2022	September 2022	October 2022	November 2022	December 2022	January 2023	February 2023	March 2023	April 2023	May 2023	June 2023	July 2023
T _{max} (°C)	17	23	26	29	31	30	28	29	22	21	18	14
T _{min} (°C)	7	7	16	20	21	20	16	12	11	9	5	2
T _{ave} (°C)	12	15	21	25	26	26	24	26	18	17	13	11
Rainfall (mm)	21	4	16	8	62	71	85	75	55	19	1.7	1.2
Humidity (%)	38	30	25	27	34	37	43	40	54	40	38	37

Table 2. Basic soil physical and chemical characteristics of the experimental site (0-30 cm depth)

Soil type	pH	Organic Matter (g/kg)	Bulk density (g/cm ³)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
Clay loam	6.9	16.8	1.4	27.7	26.8	122.5

Plant sampling and analyses

A 1 x 1 m area from each subplot was harvested at ground level 90 days after planting. Maize crop samples were separated into component fractions (roots, leaves, stems, tassel and cob), and legume samples (roots, leaves, stems, and pods) were placed in labelled brown paper bags. From these samples, biomass was measured by drying the forage crops at 70 °C for 48 hours. Total dry matter (TDM) was obtained by summing the weight of all the components.

The crop growth rate (CGR) was determined using the following formula:

$$CGR (g/m^2/d) = [(W_2 - W_1) / (T_2 - T_1)] \times 1 / GA \times 100$$

(Hunt, 1982)

where W_1 and W_2 represent the initial weight and last weight after sowing, respectively. T_1 and T_2 represent the seedling height at the start of the experiment and the end of the experiment, respectively. GA represents row-to-row distance by plant-to-plant distance by number of plants.

Prior to harvest, measurements of parameters such as the leaf area and leaf area index (LAI) and nutrient composition were taken 70 days after planting. An LI 3100 belt-driven leaf area meter was used by passing the individual leaves to measure leaf area (LICOR, Lincoln, NE, USA). The leaf area index (LAI) was calculated as the ratio of one-sided leaf surface area divided by the ground area using the LAI-2000 plant canopy analyser. LAI = leaf area/ground area (m^2/m^2). Forage samples were dried (55 °C, 48 h) and milled through a 1 mm screen for chemical analysis. Forage samples were analysed for dry matter (DM), crude protein (CP), acid detergent fiber (ADF) and neutral detergent fiber (NDF) by near infrared spectroscopy (FOSS NIR System 5000, Silver Springs, MD, USA).

A 1 x 2 m area from each subplot was harvested at maturity (100 days after plant sowing). Biological yield (shoot and roots) was measured by drying the samples at 70 °C for 48 hours. The cobs of maize were threshed for the calculation of grain yield.

Similarly, the harvest index (HI) of each subplot was calculated according to the following formula.

$$HI = (Grain\ yield / Biological\ yield) \times 100$$

The plant density was estimated before forage harvest, counting the total plants of the four central rows, each 3 m long, to determine plant population per m^2 at harvest.

Statistical analysis

Analyses of variance were performed on the data using the general linear model (GLM) procedures of the Statistical Analysis System (SAS Institute, 2023). The variance was apportioned to the tillage systems, forage type, and their interaction as expressed in the model. The dependent variables were growth indices, chemical composition and yield components. Treatment means were compared using a protected LSD ($P < 0.05$) test.

The model is presented as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \epsilon_{ijk}$$

where Y_{ijk} is the variable response, μ the general mean, α_i the tillage system effect, β_j the forage type effect, $\alpha\beta_{ij}$ the tillage system by forage type interaction, and ϵ_{ijk} the residual error.

RESULTS

Growth attributes

The growth indices of planted forages under different tillage practices are presented in Table 3. Tillage systems had a significant effect ($P < 0.05$) on growth traits. The crop growth rate, leaf area, and leaf area index of different tillage practices varied between 14.84 – 16.62 $g/m^2/d$, 3.50 – 3.65 m^2 and 4.36 – 4.43 m^2/m^2 , respectively. The crop growth rate of forages planted under conventional tillage was higher ($P < 0.05$) than that of the reduced tillage. Lower leaf area was found in forages planted under reduced tillage compared to conventional tillage practice. The conventional tillage showed a higher leaf area index as compared to the reduced tillage.

Table 3. Effect of tillage practices on the growth attributes of maize-forage legume intercrops

Forage systems ¹	Tillage practices ²	CGR ³ (g/m ² /d)	LA ³ (m ²)	LAI ³ (m ² /m ²)
MZ	CT	16.89 ^c	3.70 ^a	4.17 ^a
	RT	15.26 ^{cb}	3.62 ^a	4.15 ^a
CV	CT	11.23 ^{cd}	3.30 ^a	4.05 ^a
	RT	9.53 ^d	3.18 ^a	4.03 ^a
LB	CT	11.58 ^{cd}	3.24 ^a	4.11 ^a
	RT	10.25 ^d	3.21 ^a	4.09 ^a
MZ+CV	CT	20.84 ^{ab}	3.98 ^a	4.88 ^a
	RT	18.23 ^b	3.81 ^a	4.74 ^a
MZ+LB	CT	22.54 ^a	4.01 ^a	4.96 ^a
	RT	20.95 ^{ab}	3.80 ^a	4.78 ^a
SEM ⁴ (±)		0.94	1.02	0.18
p-value		0.02	0.07	0.06

^{a-d} Values with different letters within the same column are significantly different ($P < 0.05$).

¹ Five forage systems are Maize (MZ), Common vetch (CV), Lablab (LB), Maize and Common vetch (MZ+CV), and Maize and Lablab (MZ+LB).

² Two tillage practices are conventional tillage (CT) and reduced tillage (RT).

³ CGR: Crop growth rate, LA: Leaf area and LAI: Leaf area index.

⁴ SEM: Standard error of mean.

Different forage systems had a significant effect ($P < 0.05$) on growth parameters. The crop growth rate, leaf area, and leaf area index across forage systems ranged from 10.38 to 21.75 g/m²/d, 3.24 to 3.91 m², and 4.04 to 4.87 m²/m², respectively. Sole forages had a lower crop growth rate than mixtures. The leaf area and leaf area index of forage mixtures were higher compared with those of sole forages. The forage systems × different tillage practices interaction for crop growth rate was statistically significant ($P < 0.05$) but did not affect leaf area and leaf area index measures. Reduced tillage had a significantly ($P < 0.05$) lower crop growth rate in sole forages than conventional tillage.

Forage chemical composition

The chemical composition of planted forages is presented in Table 4. It was found that DM and CP values were significantly ($P < 0.05$) variable among different

tillage practices and forage systems. For the tillage practices, the DM and CP contents ranged from 34.15 to 36.95 and 8.95 to 10.17% DM, respectively. The highest and lowest values of DM content were found in conventional and reduced tillage practices, respectively, and the CP content also showed a similar trend. The DM and CP contents in the forage systems varied from 17.56 to 36.74% and 8.15 to 22.34% DM, respectively. Sole CV and LB forages had lower DM content, and the greater values were recorded in MZ+LB and MZ+CV intercrops. Forage intercrops and sole MZ forage had lower CP concentration than sole CV and LB forages. The interaction of tillage practices and forage systems had significant effects on the DM and CP values. Higher production of DM values in forage intercrops and higher values of CP concentration in sole forage legumes were observed in the conventional tillage than in the reduced tillage practice.

Table 4. Chemical composition of maize-forage legume intercrops under different tillage practices

Items (% DM)	Forage systems					Tillage practices			p - value		
	MZ	CV	LB	MZ+CV	MZ+LB	CT	RT	SEM (±)	FS	TP	FS × TP
DM	32.78 ^c	17.56 ^e	20.66 ^d	34.58 ^b	36.74 ^a	36.95 ^a	34.15 ^b	0.84	0.03	0.01	0.02
CP	8.15 ^d	22.34 ^a	17.98 ^b	9.58 ^c	9.37 ^c	10.17 ^a	8.95 ^b	0.76	<0.01	0.02	0.03
NDF	27.54 ^d	31.85 ^b	35.82 ^a	25.25 ^c	25.88 ^c	26.98 ^a	27.55 ^a	1.12	0.02	0.06	0.02
ADF	39.26 ^a	21.74 ^d	25.80 ^c	37.22 ^b	36.95 ^b	35.89 ^a	36.02 ^a	0.99	<0.01	0.07	0.01

Note: ^{a-e} Values with different letters within the same row are significantly different ($P < 0.05$). MZ: Sole Maize; CV: Sole Common Vetch; LB: Sole Lablab; MZ+CV: Maize and Common Vetch Intercrops; MZ+LB: Maize and Lablab Intercrops; DM: Dry matter; CP: Crude protein; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; CT: Conventional Tillage 12; RT: Reduced Tillage; SEM: Standard error of mean; FS: Forage systems; TP: Tillage Practices; FS × TP: Forage systems × Tillage Practices interaction.

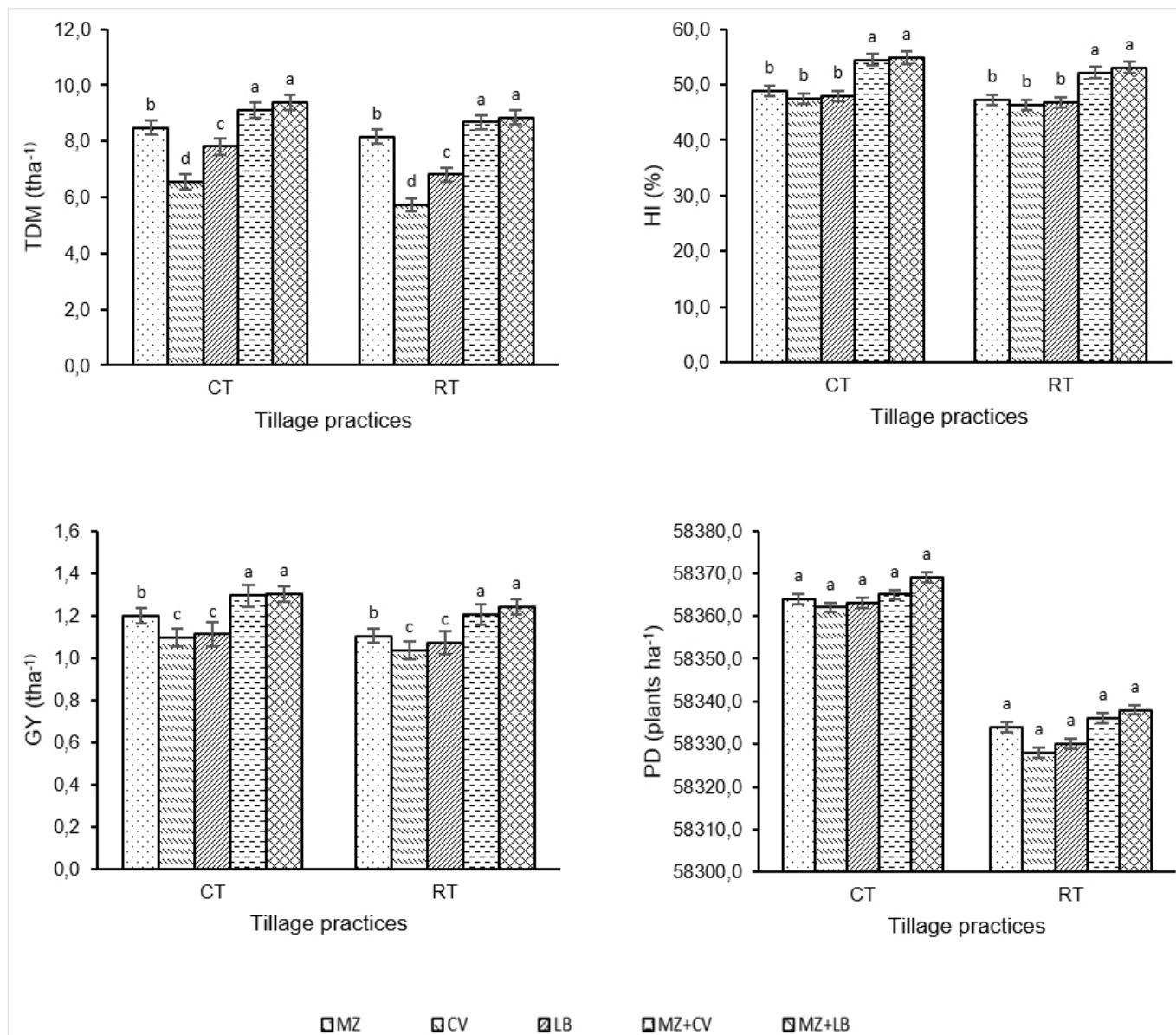
Fiber content was significantly ($P < 0.05$) affected by the forage systems; however, not significantly different among tillage practices treatments. The NDF and ADF contents of the planted forages across forage systems ranged from 27.54 to 35.82 and 21.74 to 39.26% DM, respectively. Sole LB and CV forages had higher NDF content than forage intercrops and sole MZ forage. The ADF concentrations of sole legume forages were lower compared to those of sole MZ forage and forage intercrops. The tillage practices and forage systems interaction for NDF and ADF measures was statistically significant ($P < 0.05$). NDF and ADF concentrations of sole forages (LB and MZ) were greatest in reduced tillage and lowest in conventional tillage practices.

Biomass yield

The biomass production of the planted forages under different tillage practices is presented in Figure 1. The total dry matter and grain yield for different tillage practices ranged from 5.73 to 9.37 t/ha and from 1.03 to 1.31 t/ha, respectively. The lowest total dry matter content was found in forages planted under reduced tillage, followed by conventional tillage. The conventional tillage showed a higher grain yield compared to the reduced tillage. The total dry matter and grain yield across forage systems were

6.14 to 9.12 t/ha and 1.06 to 1.27 t/ha, respectively. Sole forages produced lower total dry matter content than mixtures. The grain yield was higher in mixtures than in sole forages. The interaction of different tillage practices and forage systems had significant ($P < 0.05$) effects on the total dry matter and grain yield. The conventional tillage showed a higher total dry matter and grain yield in mixtures than the reduced tillage.

The harvest index and plant density for different tillage practices varied between 46.26 – 54.85% and 58328 – 58369 plants/ha, respectively. The reduced tillage showed a lower harvest index as compared to the conventional tillage. The highest plant density was found in conventional tillage, followed by reduced tillage. The harvest index and plant density across forage systems ranged from 46.82 to 53.93% and 58317 to 58348 plants/ha, respectively. The harvest index was higher ($P < 0.05$) in mixtures than in sole forages. Lower plant density was obtained in sole forages compared to mixtures. The interaction of different tillage practices and forage systems had significant effects on the harvest index and plant density. The reduced tillage demonstrated a lower harvest index and plant density in sole forages than the conventional tillage.



^{a-d} Values with different letters within the bar charts are significantly different ($P < 0.05$). The error bar represents the standard error of the mean (SEM). Five forage systems are Maize (MZ), Common vetch (CV), Lablab (LB), Maize and Common vetch (MZ+CV), and Maize and Lablab (MZ+LB). Two tillage practices are conventional tillage (CT) and reduced tillage (RT). TDM: Total dry matter, GY: Grain yield, HI: Harvest index and PD: Plant density.

Figure 1. Effect of tillage practices on yield components of maize-forage legume intercrops

DISCUSSION

Growth Indices

Planting forage mixtures with different tillage practices might result in distinct growth and yield components. Therefore, it is important to identify suitable tillage practices and cropping systems for forage production. The crop growth rate, leaf area, and leaf area index are reliable parameters for plant growth (Novelli et al., 2019).

In the present study, the values of crop growth rate, leaf area, and leaf area index were lower in reduced tillage compared to conventional tillage. A possible reason could be explained by an increased weed pressure and a slower nutrient mineralisation in reduced tillage (Hofmeijer et al., 2019). Furthermore, the sole forages produced lower values of crop growth rate, leaf area, and leaf area index than mixtures. The reason might be associated with a lower absorption of nutrients such as nitrogen in sole

forages. Therefore, these results are similar to those reported by Maitra et al. (2020) when intercropping maize cereal with forage legume. In the present study, the forage systems × different tillage practices interaction for crop growth rate was statistically significant ($P < 0.05$). The reason may be attributed to the tillage improving soil pore conditions and surface soil moisture content, which might play a crucial role in the growth and development of crops. Conventional tillage, in particular, can increase water infiltration and reduce surface soil bulk density, while conservation tillage can improve soil moisture levels due to the presence of straw cover and stubble that delay runoff (Ramos et al., 2019).

Nutrient composition

It is well known that DM and CP are important indicators reflecting the quality characteristics of forage (Tassone et al., 2022). In the present study, the conventional tillage had higher DM compared with the reduced tillage. The possible reason might be related to better aeration. Under conventional tillage, better aeration in the soil surface can improve the exchange of water, nutrients and energy between the forage crop roots and the soil surface. Therefore, these results agree with Debska et al. (2020) that there was a dry matter content difference between different tillage systems. However, these findings are not similar to those of Sohail et al. (2021), who observed comparable dry matter of cereal-legume combinations on different tillage systems.

In this study, sole forages produced lower DM content compared with forage intercrops. The reason might be associated with better resource utilisation in intercrops. When two or more different forage crops, especially legumes and non-legume companion crops, are grown together, it can lead to more efficient use of resources like water, nutrients, and sunlight. The non-legume companion crop can benefit from atmospheric nitrogen fixed by legumes in an intercrop (Ibrahim, 2021). Ginwal et al. (2019) also noted a difference in DM content between sole forage and intercrops. Bacchi et al. (2021) also reported higher DM content in forage intercrops compared to sole forage.

Generally, CP in forage crops includes true protein and non-protein nitrogen essential for livestock growth and provides the building blocks (amino acids) needed for various bodily functions (Zurak et al., 2023). In the present study, forage CP contents were lower in reduced tillage compared to conventional tillage. The reason might be the potentially due to factors like reduced nitrogen availability leading to decreased CP. Reduced tillage tends to cause an increase in the N immobilisation process in the soil surface, leading to decreased nutrient concentration in forage crops, especially N (Zurak et al., 2023). Studies done by Wang et al. (2024) also proved the disadvantage of reduced tillage for a lower maize quality achievement and lower grain quality, especially in the crude protein content.

As expected, the highest CP concentration was with sole legumes (CV and LB). Legumes have a high crude protein (CP) concentration due to their ability to establish a symbiotic relationship with nitrogen-fixing bacteria, primarily *Rhizobium*, in their root nodules. This helps legumes to convert atmospheric nitrogen into a usable form, leading to increased protein synthesis (Abd-Alla et al., 2023). This agrees with Zaeem et al. (2021), who reported higher CP levels in forage legumes than soybean–maize mixtures.

The contents of NDF and ADF of forages may be affected by the cropping systems during the growth process (Manoj et al., 2021). In this study, forage intercrops were characterised by lower NDF and higher ADF content compared to the sole forage legumes. Lower NDF concentrations may be attributable to efficient use of resources associated with optimum plant maturity and cell wall development. As forage crops mature, their cell walls, composed of NDF components like cellulose and hemicellulose, develop and become more prominent (Moore et al., 2020). In forage intercrops, efficient use of resources like sunlight, nutrients, and water can influence forage crop growth and cell wall development. This efficient use of resources can lead to a more balanced forage crop growth pattern, potentially delaying intercrop maturity and reducing NDF content compared to sole forages (Salama et al., 2022).

Furthermore, lower ADF in sole legumes in this study might be due to lower fiber content, leading to better forage digestibility. Studies consistently show that legumes have the least digestible parts of a plant, including cellulose and lignin (Keskin et al., 2022; Kurniawan et al., 2025). When forage legumes are grown as sole crops, they exhibit lower ADF content compared to other forage crops like cereals. This lower fiber content translates to higher palatability and digestibility of forage, which contributes to greater intake of the forage by livestock (Mganga et al., 2021). Similarly, the results of this study agree with Folina et al. (2025) that there is a difference between sole forage legumes and intercrops in terms of ADF concentration.

Yield components

The values of total dry matter and grain yield reflect the development achieved during the growth period (Yang et al., 2020). In the present study, the yield components of forages were characterised by higher total dry matter and grain yield when forages were planted through conventional tillage compared to reduced tillage. The reason might be the alleviation of soil compaction, causing increased root growth, uptake of the essential nutrient, and improved crop yield. In addition, mixtures and sole forages differ in total dry matter and grain yield. Mixtures were higher in total dry matter and grain yield than sole forages. Similar to a previous study (Atumo, 2022), a significant increase in biological yield was observed when intercropping cereal and lablab mixtures. A possible reason for a relatively higher biological yield could be more efficient use of available growth resources because intercrops have different rooting ability, canopy structure and nutrient requirements.

Harvest index and plant density help to measure the yield of the crop and the difference between the potential and actual yield (Chen et al., 2021). It was observed that harvest index and plant density were variable among different tillage practices. In the present study, reduced tillage had a lower harvest index and plant density compared with conventional tillage. The reason might be due to lower bulk density under conventional

tillage, which might have facilitated the proliferation and development of root systems in the soil and increased the rate of water, air, and essential nutrients movement (Sha et al., 2023). Therefore, these results agree with Xue et al. (2019) that there is a yield component difference among different tillage practices.

Furthermore, the harvest index was higher in mixtures than in sole forages. While the lowest plant density was obtained in sole forages than in mixtures. This finding agrees with Iqbal et al. (2019) when intercropping legumes with cereal mixtures. In the current study, the interaction of different tillage practices and forage systems had significant effects on the biomass yield. The reason might be related to more mineralisation of organic N in the tilled area. Furthermore, greater levels of soil N have been mineralised due to unrestricted aeration in the tilled plots; as a result, there could be higher availability and consequent higher uptake in the crop (Schlüter et al., 2022). It has been reported that conventional and conservation tillage achieved lower bulk density, higher water holding capacity and porosity that increased root depth and yield of maize compared to zero tillage (Farahani et al., 2022).

CONCLUSIONS

The growth indices of forage planted under reduced tillage were lower than those of conventional tillage. Forage mixtures produced higher growth attributes compared to sole forages. The results showed that conventional tillage can reduce weed infestation, allowing the accessibility of essential nutrients to be absorbed by maize-forage legume mixtures. The nutrient composition of intercrops was more than that of sole forage crops. In addition, chemical composition was enhanced in the conventional tillage compared to reduced tillage. These data demonstrate that maize can be intercropped with forage legumes under deep tillage to give high-quality forage. The reduced tillage showed lower yield components with smaller values of total dry matter and grain yield compared to conventional tillage. Sole forages also had lower yield components than mixtures. The results revealed that forage mixtures planted under

conventional tillage could improve the yield components and make forage a source of feed for livestock.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support for this research project through a capacity-building competitive grant, Training the next generation of scientists, provided by Carnegie Corporation of New York through The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM). We are grateful to the University of Pretoria and the National University of Lesotho for their institutional support towards this study.

REFERENCES

- Abd-Alla, M.H., Al-Amri, S.M., El-Enany, A.W.E. (2023) Enhancing rhizobium-legume symbiosis and reducing nitrogen fertilizer use are potential options for mitigating climate change. *Agriculture*, 13 (11), 2092. DOI: <https://doi.org/10.3390/agriculture13112092>
- Atumo, T.T. (2022) Maize-lablab intercropping date improves yield and suppress parthenium weed. *Cogent Food & Agriculture*, 8 (1), 2055270. DOI: <https://doi.org/10.1080/23311932.2022.2055270>
- Bacchi, M., Monti, M., Calvi, A., Lo Presti, E., Pellicanò, A., Preiti, G. (2021) Forage potential of cereal/legume intercrops: Agronomic performances, yield, quality forage and LER in two harvesting times in a Mediterranean environment. *Agronomy*, 11 (1), 121. DOI: <https://doi.org/10.3390/agronomy11010121>
- Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A.A., Issa, S., Karimou, M., Zampaligré, N., André, K., Gnanda, I., Varijakshapanicker, P., Kebreab, E. (2020) Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. *Global Food Security*, 26, 100372. DOI: <https://doi.org/10.1016/j.gfs.2020.100372>
- Blanco-Canqui, H., Wortmann, C.S. (2020) Does occasional tillage undo the ecosystem services gained with no-till? A review. *Soil and Tillage Research*, 198, 104534. DOI: <https://doi.org/10.1016/j.still.2019.104534>
- Chen, J., Engbersen, N., Stefan, L., Schmid, B., Sun, H., Schöb, C. (2021) Diversity increases yield but reduces harvest index in crop mixtures. *Nature Plants*, 7 (7), 893-898. DOI: <https://doi.org/10.1038/s41477-021-00948-4>
- De Moraes, M.T., Debiasi, H., Carlesso, R., Franchini, J.C., Da Silva, V.R., Da Luz, F.B. (2016) Soil physical quality on tillage and cropping systems after two decades in the subtropical region of Brazil. *Soil and Tillage Research*, 155, 351-362. DOI: <https://doi.org/10.1016/j.still.2015.07.015>
- Debska, B., Jaskulska, I., Jaskulski, D. (2020) Method of tillage with the factor determining the quality of organic matter. *Agronomy*, 10 (9), 1250. DOI: <https://doi.org/10.3390/agronomy10091250>
- Ding, J., Hu, W., Wu, J., Yang, Y., Feng, H. (2020) Simulating the effects of conventional versus conservation tillage on soil water, nitrogen dynamics, and yield of winter wheat with RZWQM2. *Agricultural Water Management*, 230, 105956. DOI: <https://doi.org/10.1016/j.agwat.2019.105956>
- Echarte, L., Della Maggiora, A., Cerrudo, D., Gonzalez, V.H., Abbate, P., Cerrudo, A., Sadras, V.O., Calvino, P. (2011) Yield response to plant density of maize and sunflower intercropped with soybean. *Field Crops Research*, 121 (3), 423-429. DOI: <https://doi.org/10.1016/j.fcr.2011.01.011>
- Farahani, E., Emami, H., Forouhar, M. (2022) Effects of tillage systems on soil organic carbon and some soil physical properties. *Land Degradation & Development*, 33 (8), 1307-1320. DOI: <https://doi.org/10.1002/ldr.4221>
- Fey, M. (2010) *Soils of South Africa*. Cambridge University Press.
- Folina, A., Stavropoulos, P., Mavroeidis, A., Roussis, I., Kakabouki, I., Tsiplakou, E., Bilalis, D. (2025) Optimizing fodder yield and quality through grass-legume relay intercropping in the Mediterranean region. *Plants*, 14 (6), 877. DOI: <https://doi.org/10.3390/plants14060877>
- Ginwal, D.S., Kumar, R.A., Ram, H.A., Meena, R.K., Kumar, U., (2019) Quality characteristics and nutrient yields of maize and legume forages under changing intercropping row ratios. *Indian Journal of Animal Science*, 89 (3), 281-286. DOI: <https://doi.org/10.56093/ijans.v89i3.88079>
- Hofmeijer, M.A., Krauss, M., Berner, A., Peigné, J., Mäder, P., Armengot, L. (2019) Effects of reduced tillage on weed pressure, nitrogen availability and winter wheat yields under organic management. *Agronomy*, 9 (4), 180. DOI: <https://doi.org/10.3390/agronomy9040180>
- Hunt, R. (1982) Plant growth curves. The functional approach to plant growth analysis, pp. 248.
- Ibrahim, M. (2021) Role of arbuscular mycorrhizal fungi in biological nitrogen fixation and nitrogen transfer from legume to companion species. *Journal of Stress Physiology & Biochemistry*, 17 (2), 121-134. DOI: <https://doi.org/10.12692/ijb/7.4.31-46>
- Iqbal, M.A., Hamid, A., Hussain, I., Siddiqui, M.H., Ahmad, T., Khaliq, A., Ahmad, Z. (2019) Competitive indices in cereal and legume mixtures in a South Asian environment. *Agronomy Journal*, 111 (1), 242-249. DOI: <https://doi.org/10.2134/agronj2017.11.0658>
- Iqbal, N., Hussain, S., Ahmed, Z., Yang, F., Wang, X., Liu, W., Yong, T., Du, J., Shu, K., Yang, W., Liu, J. (2019) Comparative analysis of maize-soybean strip intercropping systems: a review. *Plant Production Science*, 22 (2), 131-142. DOI: <https://doi.org/10.1080/1343943X.2018.1541137>
- Islam, S.F.U., Sander, B.O., Quilty, J.R., De Neergaard, A., Van Groenigen, J.W., Jensen, L.S. (2020) Mitigation of greenhouse gas emissions and reduced irrigation water use in rice production through water-saving irrigation scheduling, reduced tillage and fertiliser application strategies. *Science of the Total Environment*, 739, 140215. DOI: <https://doi.org/10.1016/j.scitotenv.2020.140215>
- Keskin, S.O., Ali, T.M., Ahmed, J., Shaikh, M., Siddiq, M., Uebersax, M.A. (2022) Physico-chemical and functional properties of legume protein, starch, and dietary fiber - A review. *Legume Science*, 4 (1), 117. DOI: <https://doi.org/10.1002/leg3.117>
- Kumara, T.K., Kandpal, A., Pal, S. (2020) A meta-analysis of economic and environmental benefits of conservation agriculture in South Asia. *Journal of Environmental Management*, 269, 110773. DOI: <https://doi.org/10.1016/j.jenvman.2020.110773>
- Kurniawan, D.N., Nahrowi, N., Yanza, Y.R., Niderkorn, V., Jayanegara, A. (2025) Classification of legume quality based on chemical composition and digestibility values using multivariate analysis. *Advance Animal Veterinary Science*, 13 (3), 573-583. DOI: <https://dx.doi.org/10.17582/journal.aavs/2025/13.3.573.583>
- Lesotho Meteorological Services (LMS). (2023) Standardized precipitation index user guide, Maseru, Lesotho.

- Liu, X., Rahman, T., Song, C., Su, B., Yang, F., Yong, T., Wu, Y., Zhang, C., Yang, W. (2017) Changes in light environment, morphology, growth and yield of soybean in maize-soybean intercropping systems. *Field Crops Research*, 200, 38-46.
DOI: <https://doi.org/10.1016/j.fcr.2016.10.003>
- Lozano, L.A., Soracco, C.G., Villarreal, R., Ressa, J.M., Sarli, G.O., Filgueira, R.R. (2016) Soil physical quality and soybean yield as affected by chiseling and subsoiling of a no-till soil. *Revista Brasileira de Ciência do Solo*, 40, 0150160.
DOI: <https://doi.org/10.1590/18069657rbc20150160>
- Maitra, S., Shankar, T., Banerjee, P. (2020) Potential and advantages of maize-legume intercropping system. *Maize-Production and Use*, 1-14. DOI: <https://doi.org/10.5772/intechopen.91722>
- Manoj, K.N., Shekara, B.G., Sridhara, S., Jha, P.K., Prasad, P.V. (2021) Biomass quantity and quality from different year-round cereal-legume cropping systems as forage or fodder for livestock. *Sustainability*, 13 (16), 9414.
DOI: <https://doi.org/10.3390/su13169414>
- Mganga, K.Z., Ndathi, A.J., Wambua, S.M., Bosma, L., Kaindi, E.M., Kioko, T., Kadenyi, N., Musyoki, G.K., Van Steenberghe, F., Musimba, N.K. (2021) Forage value of vegetative leaf and stem biomass fractions of selected grasses indigenous to African rangelands. *Animal Production Science*, 61 (14), 1476-1483.
DOI: <https://doi.org/10.1071/AN19597>
- Moore, K.J., Lenssen, A.W., Fales, S.L. (2020) Factors affecting forage quality. *Forages: The Science of Grassland Agriculture*, 2, 701-717.
DOI: <https://doi.org/10.1002/9781119436669.ch39>
- Novelli, F., Spiegel, H., Sandén, T., Vuolo, F. (2019) Assimilation of sentinel leaf area index data into a physically-based crop growth model for yield estimation. *Agronomy*, 9 (5), 255.
DOI: <https://doi.org/10.3390/agronomy9050255>
- Ramos, M.C., Pareja-Sánchez, E., Plaza-Bonilla, D., Cantero-Martínez, C., Lampurlanés, J. (2019) Soil sealing and soil water content under no-tillage and conventional tillage in irrigated corn: Effects on grain yield. *Hydrological Processes*, 33 (15), 2095-2109.
DOI: <https://doi.org/10.1002/hyp.13457>
- Raza, M.A., Feng, L.Y., Van Der Werf, W., Iqbal, N., Khan, I., Hassan, M.J., Ansar, M., Chen, Y.K., Xi, Z.J., Shi, J.Y., Ahmed, M. (2019) Optimum leaf defoliation: A new agronomic approach for increasing nutrient uptake and land equivalent ratio of maize soybean relay intercropping system. *Field Crops Research*, 244, 107647.
DOI: <https://doi.org/10.1016/j.fcr.2019.107647>
- Rodríguez, C., Carlsson, G., Englund, J.E., Flöhr, A., Pelzer, E., Jeuffroy, M.H., Makowski, D., Jensen, E.S. (2020) Grain legume-cereal intercropping enhances the use of soil-derived and biologically fixed nitrogen in temperate agroecosystems. A meta-analysis. *European Journal of Agronomy*, 118, 126077.
DOI: <https://doi.org/10.1016/j.eja.2020.126077>
- Salama, H.S., Nawar, A.I., Khalil, H.E. (2022) Intercropping pattern and N fertilizer schedule affect the performance of additively intercropped maize and forage cowpea in the Mediterranean region. *Agronomy*, 12 (1), 107. DOI: <https://doi.org/10.3390/agronomy12010107>
- SAS Institute (2023) The SAS system for Windows (Release 9.4). Cary, NC: SAS Institute.
- Schlüter, S., Roussety, T., Rohe, L., Guliyev, V., Blagodatskaya, E., Reitz, T. (2022) Land use impact on carbon mineralization in well aerated soils is mainly explained by variations of particulate organic matter rather than of soil structure. *Soil*, 8 (1), 253-267.
DOI: <https://doi.org/10.5194/soil-8-253-2022>
- Sha, Y., Liu, Z., Hao, Z., Huang, Y., Shao, H., Feng, G., Chen, F., Mi, G. (2023) Root growth, root senescence and root system architecture in maize under conservative strip tillage system. *Plant and Soil*, 1-17. DOI: <https://doi.org/10.21203/rs.3.rs-2675962/v1>
- Simić, M., Dragičević, V., Mladenović Drinić, S., Vukadinović, J., Kresović, B., Tabaković, M., Brankov, M. (2020) The contribution of soil tillage and nitrogen rate to the quality of maize grain. *Agronomy*, 10 (7), 976. DOI: <https://doi.org/10.3390/agronomy10070976>
- Sohail, S., Ansar, M., Skalicky, M., Wasaya, A., Soufan, W., Ahmad Yasir, T., El-Shehawi, A.M., Brestic, M., Sohildul Islam, M., Ali Raza, M., EL Sabagh, A. (2021) Influence of tillage systems and cereals-legume mixture on fodder yield, quality and net returns under rainfed conditions. *Sustainability*, 13 (4), 2172.
DOI: <https://doi.org/10.3390/su13042172>
- Tassone, S., Mabrouki, S., Barbera, S., Glorio Patrucco, S. (2022) Laboratory analyses used to define the nutritional parameters and quality indexes of some unusual forages. *Animals*, 12 (18), 2320. DOI: <https://doi.org/10.3390/ani12182320>
- Wang, L.Q., Yu, X.F., Gao, J.L., Ma, D.L., Liu, H.Y., Hu, S.P. (2024) Regulation of tillage on grain matter accumulation in maize. *Frontiers in Plant Science*, 15, 1373624.
DOI: <https://doi.org/10.3389/fpls.2024.1373624>
- Wang, Z., Li, Y., Li, T., Zhao, D., Liao, Y. (2020) Tillage practices with different soil disturbance shape the rhizosphere bacterial community throughout crop growth. *Soil and Tillage Research*, 197, 104501. DOI: <https://doi.org/10.1016/j.still.2019.104501>
- Wen, L., Peng, Y., Zhou, Y., Cai, G., Lin, Y., Li, B. (2023) Effects of conservation tillage on soil enzyme activities of global cultivated land: A meta-analysis. *Journal of Environmental Management*, 345, 118904. DOI: <https://doi.org/10.1016/j.jenvman.2023.118904>
- Xue, L., Khan, S., Sun, M., Anwar, S., Ren, A., Gao, Z., Lin, W., Xue, J., Yang, Z., Deng, Y. (2019) Effects of tillage practices on water consumption and grain yield of dryland winter wheat under different precipitation distribution in the loess plateau of China. *Soil and Tillage Research*, 191, 66-74. DOI: <https://doi.org/10.1016/j.still.2019.03.014>
- Yang, H., Wu, G., Mo, P., Chen, S., Wang, S., Xiao, Y., Ma, H., Wen, T., Guo, X., Fan, G. (2020) The combined effects of maize straw mulch and no-tillage on grain yield and water and nitrogen use efficiency of dry-land winter wheat (*Triticum aestivum* L.). *Soil and Tillage Research*, 197, 104485.
DOI: <https://doi.org/10.1016/j.still.2019.104485>
- Yin, B., Hu, Z., Wang, Y., Zhao, J., Pan, Z., Zhen, W. (2021) Effects of optimized subsoiling tillage on field water conservation and summer maize (*Zea mays* L.) yield in the North China Plain. *Agricultural Water Management*, 247, 106732.
DOI: <https://doi.org/10.1016/j.agwat.2020.106732>
- Zaeem, M., Nadeem, M., Pham, T.H., Ashiq, W., Ali, W., Gillani, S.S.M., Moise, E., Elavarthi, S., Kavanagh, V., Cheema, M., Galagedara, L. (2021) Corn-soybean intercropping improved the nutritional quality of forage cultivated on Podzols in boreal climate. *Plants*, 10 (5), 1015. DOI: <https://doi.org/10.3390/plants10051015>
- Zhai, L., Wang, Z., Song, S., Zhang, L., Zhang, Z., Jia, X. (2021) Tillage practices affect the grain filling of inferior kernel of summer maize by regulating soil water content and photosynthetic capacity. *Agricultural Water Management*, 245, 106600.
DOI: <https://doi.org/10.1016/j.agwat.2020.106600>
- Zhang, Z., Qiang, H., Mchugh, A.D., He, J., Li, H., Wang, Q., Lu, Z. (2016) Effect of conservation farming practices on soil organic matter and stratification in a mono-cropping system of Northern China. *Soil and Tillage Research*, 156, 173-181.
DOI: <https://doi.org/10.1016/j.still.2015.10.008>
- Zurak, D., Kljak, K., Aladrović, J. (2023) Metabolism and utilisation of non-protein nitrogen compounds in ruminants: a review. *Journal of Central European Agriculture*, 24 (1), 1-14.
DOI: <https://doi.org/10.5513/JCEA01/24.1.3645>