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Effects of Tillage and Intercropping with Grass on Soil Properties and Yield of Rainfed Maize

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ABSTRACT

Maize is grown as a rainfed crop during wet and dry seasons in Lampung, Indonesia and gives low yield. This study was conducted to determine the effects of intercropping with grasses and tillage practices on soil physical properties and grain yield in the wet season. Three tillage methods i.e. no tillage, conventional tillage and deep tillage and four cropping patterns; sole maize, maize intercropped with clump grass (*Vetiveria zizanoides*), elephant grass (*Pennisetum purpureum*), and lemon grass (*Cymbopogon citratus*) were tested. Both conventional and deep tillage increased yield components and harvest index of maize compared to no tillage, but grain yield remained unchanged among cropping patterns. Deep tillage maintained lower bulk density and greater porosity and organic C in deep soils than conventional and no tillage. Maize intercropped with clump grass decreased bulk density and increased porosity and organic C compared to other cropping patterns. This enhanced the soil capacity to store and mobilizes water and nutrients in deep soil profiles, which is likely to enhance growth and yield of the succeeding maize crop.

Key Words: Tillage; Cropping pattern; Soil properties; Maize yield

INTRODUCTION

Maize is the second most important cereal crop after rice in terms of the percentage area occupied relative to the total area for all food crops in Indonesia (Swastika *et al.*, 2004). Rainfall and water available from other sources are the factors determining the success of rainfed maize production in dry agro-ecological zones. Lampung province of the Sumatra Island is one of the major maize producing areas in Indonesia contributing to about 12% of national maize production. This province receives approximately 2,455 mm of rainfall per year during October to April and the remaining period receives lesser than 60 mm per month (Swastika *et al.*, 2004). Therefore, maize is grown as a sole crop in both wet and dry seasons. Rainfed maize gives an average grain yield of around 2 t ha^{-1} in the wet season, but in the dry season (April to October) it yields around 1 t ha^{-1} due to water stress, thereby affecting the income of maize growers (Swastika *et al.*, 2004). Therefore, it was a long felt need to identify suitable measures for improving maize yields in the dry season.

To increase maize yields in dry lands, there is a need to integrate soil and water conservation and efficient water use in crop husbandry (Maraux, 1998; Rusan, 1998). Furthermore, knowledge of water demand for maize crop during the period of severe drought is needed to develop strategies for water management (Hook, 1994). Scopel *et al.* (2001) reported that tillage and mulching can increase water storage in the soil profile under both intense and relatively rare rainfall events. Subsoil tillage in some cases has improved maize root growth and water availability as larger root mass pulls moisture from deeper soils (Khan *et al.*, 2001; McWilliams, 2003). Seasonal addition of shoots and roots to the plough layer and their decomposition improves physical characteristics of the upper soil layer (Marinari *et al.*, 2000; Shaver *et al.*, 2003), increase water storage (Arvidsson, 1998; Shaver *et al.*, 2003) and root proliferation (Grimshaw and Helfer, 1993; Snap and Borden, 2005). Even some farmers use appropriate maize cultivars, tillage methods and soil moisture conservation measures (mulching etc.) to retain more water in the top soil layers, but it has not been sufficient to support maize crop during dry growth periods. Therefore, it is essential to utilize soil moisture in deep soil profiles to support the maize crop. Two options remain to be explored; first is to promote maize root development into deep soil layers, and second is to promote entrapping upward moving water in the deep soil layers. Both of these aspects would require the development of soil structure at a depth below the usual plough layer, decrease bulk density and increase porosity. As deep tillage is not pragmatic, the growing of either crops or other plants species capable of producing deep roots and high root biomass and allowing the total or part of these roots to decompose prior to or at the beginning of dry season would be a suitable strategy. This is likely to improve soil properties in terms of hydraulic conductivity and moisture

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retention in the lower soil profiles, since this is better time to get prepared for drought (Bouwer, 1988).

Growing deep rooting grass species in the wet season would help first to establish them and develop deeper roots as the water shortage begins with the subsidence of rainfall and shifting towards dry season. Degeneration and decomposition of root would improve soil properties in deep soils, promote root growth of the succeeding maize crop, extract soil moisture available in deep profiles restrict upward movement of water. This will help maize to meet its water requirements, thus avoiding drought stress and producing satisfactory grain yields. Grasses with dense root systems are known to improve infiltration by enhancing the soil porosity (Prihar *et al.*, 2000). Intercropping these grasses between maize rows in the wet season would ensure their establishment and bringing long term benefits to dry season grown maize crop. However, introducing grasses along with maize would be a constraint in terms of competition between maize and grasses, which may hamper maize yields in the wet season, thus discouraging the farmers to intercrop maize and grasses. Objectives of this study was to assess the effects of tillage methods and intercropping grasses with maize on soil properties and grain yield of maize during wet season.

MATERIALS AND METHODS

This study was conducted in Metro Kibang sub-district of Lampung province, Indonesia, during December 2005 – April 2006 (rainy season). During this period the location received an average monthly rainfall of 441 mm. The topography of the study area is flat with an approximate slope of 0 – 5%. The soil texture was sandy clay loam with friable consistency and pH of 4.85. The experimental treatments comprised 3 x 4 factorial combinations of three tillage methods viz. no tillage (NT), conventional tillage (CT) (20 cm depth) and deep tillage (DT) (30 cm depth) and four cropping patterns viz. sole maize, maize + lemon grass [*Cymbopogon citratus* (D.C.) Stapf], maize + clump grass [*Vetiveria zizanioides* (L.) Nash], and maize + elephant grass (*Pennisetum purpureum* Schum) and arranged in a split plot design with three replicates. Three tillage methods were assigned to main plots (40 m x 10 m) and cropping patterns to subplots (9 m x 10 m). Subplots were 1 m a part strips and main plots by a 1.5 m. Each subplot had 12 rows of maize.

In CT, the land was ploughed once, harrowed twice and levelled with standard implements. The DT soil was tilled to a depth of 30 cm. Glyphosate was applied at the rate of 480 g L^{-1} to control weeds. The plots of conventional and deep tillage treatments were finally prepared as ridge (15 cm height) and furrow system with a ridge to ridge distance of 75 cm. Three maize seeds were dibbled on the ridge on an intra-row spacing of 25 cm. Seeding rate was 15 kg ha^{-1}. In no-till plots, the same number of maize seeds was directly dibbled on the flat surface with same inter- and intra-row spacing and plant population. In intercropping treatments the second crops i.e. clump grass (C), elephant grass (E) and lemon grass (L) were established. Each plot received N, P and K at the rate of 65, 28 and 14 kg ha^{-1} using urea (46% N), triple super phosphate (19.8 % P) and muriate of potash (50% K), respectively as a basal dressing, seven days after sowing. The seedlings were thinned out to one plant per hill 14 days after emergence. At second top dressing 65 kg ha^{-1} of urea was applied 6 weeks after sowing. No pest or diseases attack was observed during growing period. Weeds were manually controlled every 2 weeks until silking.

At the end of land demarcation and land preparation soil samples were taken randomly from three furrows in each replicate to a depth of 0-30 and 30-70 cm using an open-end soil probe. Soil pH was determined by Electrometric method using soil to water ratio of 1:2.5 and pH meter (Model EIL 7045/46 of Kent Scientific, USA). Total C content was determined from the soil within the depth of 30 cm using Walkley and Black method (Nelson & Sommers, 1982). At harvest, the soil samples were collected from each plot at 0-10, 10-20, 20-30, and 30-40cm depths using a core sampler, and bulk density was determined (Blake & Hartge, 1986). Soil porosity (E) was computed as: $E = 1- (\rho_b/\rho_p)$; where ρb is the bulk density of soils and ρ_p is the particle density (Lal & Shukla, 2004).

Crop development data such as plant height, leaf area, root dry weight, root length, vertical and lateral distance of roots, dry weight of plant biomass and yield were recorded. Yield components of maize were determined from 10 consecutive plants within a single maize row out of 12 rows leaving two corners most rows and 50 cm strip from either ends of each plots as border area. Plant height was measured from the ground level up to the collar of the flag leaf (Garcia *et al.*, 2003). Leaf area was estimated as described by McKee (1964), and leaf area index (LAI) was computed dividing leaf area by land area subtending the corresponding leaf area. Root data was recorded from randomly selected plants in each plot by digging a trench around the selected plant by digging out the soils laterally and vertically. All the roots were collected during digging the pit around maize plant root mass collected and washed. Roots were initially air- and later oven-dried at 80°C to record dry weight. Root length was determined using root intersection method (Bohm, 1979).

Above ground dry matter, except grains, at harvest was collected using ten randomly selected maize plants from each treatment, and dry weight was recorded after oven-drying (Lorens *et al.,* 1987). Yield components, i.e. number of kernels per cob and 100-kernel weight were also estimated from the same sub-sample. Final yield was recorded by harvesting the cobs and grains from all remaining plants (total of 240 plants) within each plot leaving a border area. Grain yield and moisture content was estimated from ten sub-samples to convert the grain weight at harvest to grain weight at negligible moisture, and then adjusted to 15% grain moisture content. Harvest index was calculated using grain weight and total biomass as reported by Black and Watson (1960). All data were analyzed by using Analysis of Variance procedure (Steel & Torrie, 1980). Treatment means were compared using LSD when interaction among the factors was significant and Duncan's Multiple Range Test was used in case when only factors were significant.

RESULTS

Weather conditions. Extent of rainfall was around 200 and 100 mm per month during wet (rainy) and dry seasons respectively, relative humidity 80-60%, while temperature (maximum & minimum) range between 30-33^oC and 18-20^oC, respectively. This showed that the maize did not suffer from water deficit or unfavourable weather.

Soil properties. Soil pH in the experimental site was acidic: pH value at 0-30 and 30-70 cm profiles were 4.85 and 4.69, respectively. No liming was adopted and the productivity under inherent conditions was assessed. Tillage and cropping pattern had non-significant effect on soil bulk density except in 20-30 cm depth, where bulk density values were greater in the order of no tillage > conventional tillage > deep tillage (Fig. 1). The bulk density did not significantly differ among cropping systems. At 0-10 cm depth, maize + clump grass had the lowest bulk density followed by maize + lemon grass (Fig. 2). Maize + clump grass intercropped soil had the lowest bulk density in 10-20 cm profile, while the others had at or greater than 1.60 g cm^{-3}. At 10-20 and 20-30 cm depths, both clump grass and lemon grass intercropped with maize had the lowest bulk densities. Elephant grass showed lowest while maize alone had the highest bulk density at 30-40 cm depth (Fig. 2).

Although soil porosity was not significantly different within tillage methods and cropping patterns, some variation was evident. No tillage had the lowest while deep tillage followed by conventional tillage had the highest porosity, showing that soils in no-till plots were more compact than conventional and deep-tilled plots (Fig. 3). Among the cropping patterns, 0-10 cm soil layer in maize + clump grass intercropping had the highest porosity, which decreased with the depth of soil. Maize + elephant grass intercropping showed an increasing porosity in soil depth 30-40 cm, whereas the other intercrops had slightly decreased porosity (Fig. 4). There was no significant effect of both tillage methods and cropping patterns on soil organic carbon (OC) in the rainy season. However, deep and conventional tillage had 0.49 and 0.47 % OC respectively, while no tillage had the lowest OC (Fig. 5). Among intercropping systems, OC varied from 0.43 % in maize + elephant grass to 0.48 % in sole maize and maize + clump grass intercrop (Fig. 6).

Lateral and vertical root distance. Lateral root distance ranged from 18.6 cm in no tillage to 20.2 cm in deep tillage and from 17.8 cm in maize + lemon grass to 21.0 cm in maize + clump grass, and sole maize having moderate value (Table I). This showed that there was no effect of both

Table I. Selected plant growth and root parameters of rainfed maize as influenced by tillage and cropping pattern.

Treatments	Lateral root distance (cm)	Total root length (cm)	Plant height (cm)	Leaf area index	Above ground dry matter (kg $plot^{-1}$) [1]
Tillage					
No tillage	18.6 ± 1.4	1791.2 ± 450.6 b	162.2 ± 6.3 b	3.0 ± 0.3 b	38.4 ± 5.6 b
Conventional tillage	18.9 ± 1.5	2518.1 ± 462.0 a	184.4 ± 10.6 a	3.8 ± 0.4 a	44.6 ± 3.3 a
Deep tillage	20.2 ± 2.9	2010.5 ± 377.9 b	179.1 ± 19.7 a	3.8 ± 0.3 a	43.3 ± 2.7 b
Cropping pattern					
Sole maize	19.6 ± 0.8	2594.3 ± 739.8 a	173.6 ± 16.4	3.4 ± 0.4	41.5 ± 3.7
Maize+clump grass	21.0 ± 2.9	2224.8 ± 780.0 a	173.7 ± 6.4	3.6 ± 0.5	41.2 ± 3.6
Maize+elephant grass	18.5 ± 1.5	1465.7 ± 514.4 b	176.8 ± 18.9	3.6 ± 0.2	42.7 ± 3.6
Maize+lemon grass	17.8 ± 1.2	2141.6 ± 708.8 a	176.8 ± 10.0	3.5 ± 0.2	42.9 ± 4.6
CV (%)	NS	16.75	6.92	9.90	6.74

1/ Estimated from 240 plants in each treatment per replicate and excludes grain weight
Values sharing similar letters do not differ significantly at $p<0.05$, according to Duncan's multiple range test
NS, non-significant

Table II. Maize yield, yield components and harvest index as influenced by tillage and cropping pattern

Treatments	Mean number of kernels per ear (n)	Mean 100-kernelweight (g)	Mean grain yield (kg $plot^{-1}$) [1]	Harvest index
Tillage				
No tillage	370.6 ± 40.2 b	19.6 ± 1.2 b	24.0 ± 1.4	0.21± 0.02 b
Conventional tillage	486.3 ± 38.0 a	25.1± 1.3 a	27.1 ± 5.3	0.17± 0.01 c
Deep tillage	485.4 ± 16.6 a	24.6 ± 0.6 a	27.3 ± 4.1	0.26± 0.01 a
Cropping pattern				
Sole maize	427.6 ± 82.4	22.4 ± 3.2	26.8 ± 4.0	0.21± 0.03
Maize+clump grass	438.7 ± 45.7	22.0 ± 1.6	24.4 ± 4.6	0.21 ± 0.03
Maize+elephant grass	456.8 ± 101.2	23.6 ± 4.3	26.0 ± 3.6	0.23 ± 0.03
Maize+lemon grass	466.6 ± 47.0	23.5 ± 3.2	27.4 ± 6.6	0.22 ± 0.04
CV (%)	9.05	10.05	NS	14.57

1/ Estimated from 240 plants in each treatment per replicate
Values sharing similar letters do not differ significantly at $p<0.05$, according to Duncan's multiple range tests. NS, non-significant

Fig. 1. Mean soil bulk density at 10 cm depths in the 0 to 40 cm profile as influenced by tillage method.

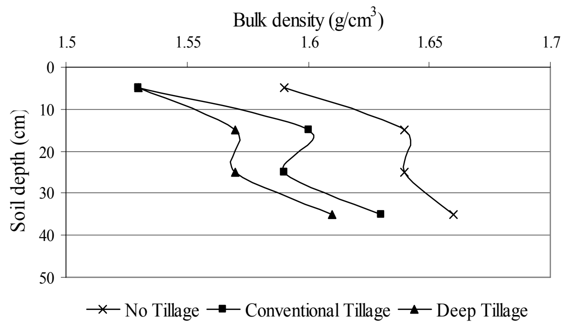


Fig. 2. Mean soil bulk density at 10 cm depths in the 0 to 40 cm profile as influenced by cropping System.

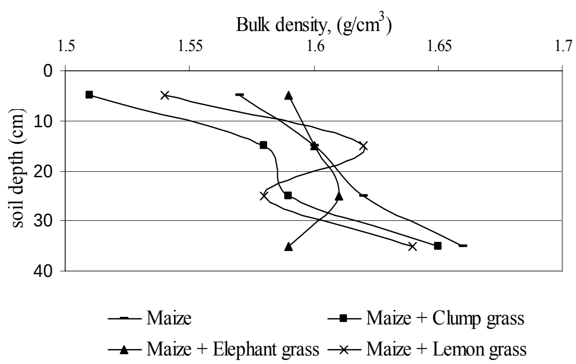
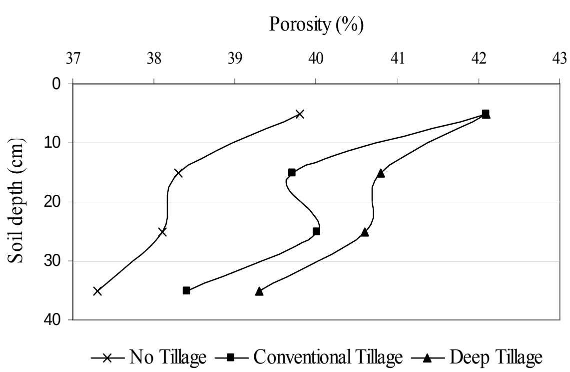


Fig. 3. Mean soil porosity at 10 cm depths in the 0 to 40 cm profile as influenced by tillage methods



tillage and cropping pattern for lateral distance of maize root in the rainy season. However, there was an interaction of tillage and cropping pattern for vertical root distance. Sole cropped maize grown under conventional tillage had the deepest roots, which were not much different from those of maize grown in maize + clump grass intercropping under no tillage and deep tillage (Fig. 7). Maize + clump grass intercropping had significantly greater vertical root distance than other cropping patterns under no tillage. Within each cropping pattern, except in maize + clump grass, conventional tillage had higher vertical root distance than deep tillage, but the differences were not significant in maize + lemon grass intercrop.

Total root length. The total root length was significantly influenced by tillage and cropping pattern interaction ($p < 0.05$). Among the tillage practices, conventional tillage had greatest, deep tillage intermediate and no tillage the lowest root length (Table I). Among the cropping patterns, sole maize crop and maize + clump grass had the highest total root length. However, the lowest total root length of maize was in maize + elephant grass intercrop.

Root dry weight at harvest. Conventional tillage had the highest root dry weight in each cropping pattern (Fig. 8). In both no-tillage and deep tillage methods, root dry weight had a variable results depending upon the cropping pattern. Therefore, root penetration of maize appeared to have been interfered by the root systems of three grass species.

Plant growth characteristics of maize. Tillage method and cropping pattern of maize showed no significant ($p > 0.05$) effects on plant height and above ground dry matter. Among tillage methods, plant height ranged from 162.2 cm in no-tillage to 184.4 cm in conventional tillage, with deep tillage giving a moderate plant height of 179.1 cm. Among the cropping systems this attribute ranged from 173.6 cm in sole cropped maize to 176.8 cm in maize + elephant grass and maize + lemon grass intercrops (Table I). Total above ground dry matter at harvest ranged from 38.4 kg plot^{-1} in no tillage to 44.6 kg plot^{-1} in conventional tillage, while 41.2 kg plot^{-1} in maize + clump grass to 42.9 kg plot^{-1} in maize + lemon grass inter crop (Table I). Mean leaf area index (LAI) per plant was not affected by cropping pattern, which ranged from 3.4 in sole cropped maize to 3.6 in both maize + clump grass and maize + elephant grass intercrops. However, LAI in conventional tillage was significantly ($p < 0.05$) greater than no tillage, but there was no significant difference between conventional and deep tillage in LAI (Table I). The lower LAI in no tillage shows exposure of maize plants to some stressful conditions compared to both conventional and deep tillage methods.

Yield and yield components, and harvest index. Of the two factors, only tillage had significant ($p < 0.05$) effects on yield components, such as number of kernels per ear, and 100-kernel weight, but not on total grain yield. Grain yield calculated from 10 plant samples was higher than that of 240 plants each treatment plot. Number of kernels per ear and 100-kernel weight decreased under no tillage by 23.7 and 21.6% respectively compared to both conventional and deep tillage (Table II). There were no differences ($p > 0.05$) in the number of kernels per ear and 100-kernel weight between conventional and deep tillage. Average number of kernels ranged from 427.6 in sole maize crop to 466.6 in maize + lemon grass intercrop, while mean 100-kernel weight was in the range of 22.0 g in maize + clump grass to 23.6 g in maize + elephant grass intercrop (Table II).

The difference in average grain yield between no-till and other tillage was approximately remain insignificant. Gain yield had no significantly different effect under

Fig. 4. Mean soil porosity at 10 cm depths in the 0 to 40 cm profile as influenced by cropping patterns

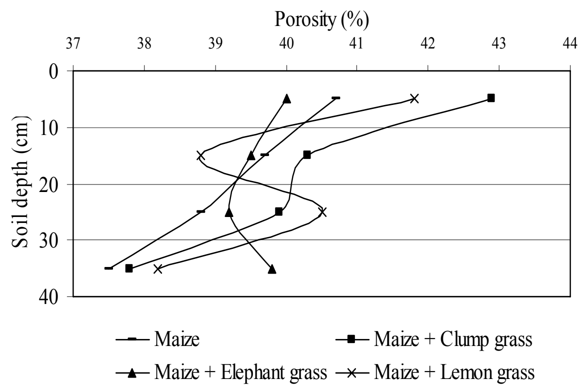


Fig. 5. Mean Organic C at 30 cm depths in soil profile as influenced by tillage methods

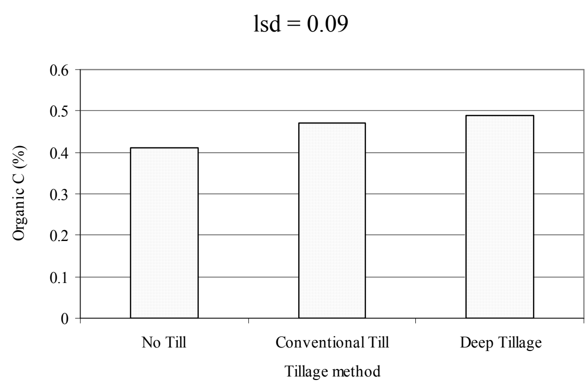
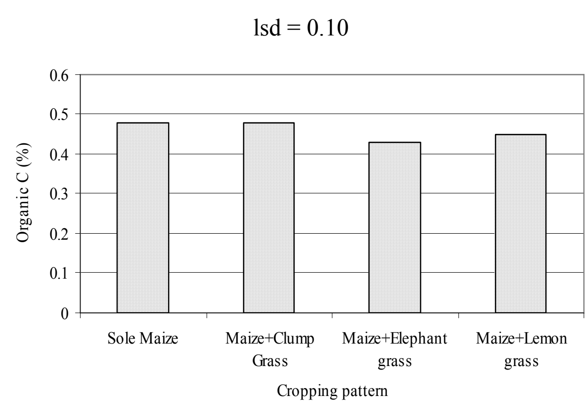


Fig. 6. Mean Organic C at 30 cm depths in soil profile as influenced by cropping pattern



different tillage methods and in different cropping patterns. Grain yield ranged from 24.0 kg plot^{-1} in no tillage to around 27 kg plot^{-1} in both conventional and deep tillage and 24.4 kg plot^{-1} in maize + clump grass to 27.4 kg plot^{-1} maize + lemon grass intercropping (Table II). Harvest index had not much different due to tillage method and cropping pattern. Harvest index ranged from 0.17 in conventional tillage to 0.26 in deep tillage and 0.21 in sole maize and maize + clump grass intercrop to 0.23 in maize + elephant grass intercrop (Table II).

DISCUSSION

Both conventional and deep tillage decreased soil bulk density (Fig. 1 & 2), increased soil porosity (Fig. 3 & 4) and soil organic matter contents (Fig. 5 & 6) compared to no-tillage. Furthermore, bulk density in deep profiles was lower in maize + grass intercrops than sole maize crop, although differences were insignificant. Fan *et al.* (2006) reported increase in soil porosity after intercropping due to increased root biomass. This may be partly attributed to the stimulatory effects of living roots on microbial activities that enhancing soil organic matter decomposition (Cheng & Coleman, 1990). A slight reduction in bulk density may favour satisfactory aeration, water storage and drainage (Khurshid *et al.*, 2006). Soil OC also showed slight increase in maize + clump grass intercropped plots. These changes are considered favourable, as decrease in bulk density favours aeration and water storage.

Maize grown in no tillage conditions may have experienced soil compactness, which impeded the acquisition of both water and nutrients and growth of roots. In both deep and conventional tillage, soil disturbance by tillage practices increased porosity and penetrability thus allowing roots to have better access to water and nutrients. Carlesso *et al.* (2002) also reported that LAI was higher in maize cultivated under conventional tillage as a result of improved access to soil moisture than no tillage. Present results indicated that maize intercropping with clump grass, elephant grass and lemon grass or as a sole crop will not make a difference in the presence of ample water in the wet season.

There was no significant difference in lateral root distance, although no-tillage had the lowest lateral root spread. However, deep root growth was more enhanced by conventional than deep and no tillage (Fig. 7). Prihar *et al.* (2000) and Hasan (2000) also observed greater rooting depth and root density in conventionally tilled plots than no tillage. In the sub soil from 30-70 cm depth, the pH was 4.69, and mostly the roots were prolific and restricted to upper soil layers (Ryan *et al.*, 1993; Hairiah *et al.*, 2000). Among the cropping patterns, sole maize crop under conventional tillage and maize intercropped with clump grass under no-tillage had significantly greater root depth than the rest of the treatments (Fig. 7). Kramer and Boyer (1995) also reported that the size of root systems is usually reduced when they are grown in competition with other plants possibly due to competition for nutrients and water (Ghaley *et al.*, 2005). However, depth and lateral distribution of roots depend on both heredity and soil environment (Kramer & Boyer, 1995). Deep root penetration is not required for crops under ample water availability in the surface soils due to from frequent rainfall.

Fig. 7. Vertical root distance as influenced by tillage and cropping pattern interaction.

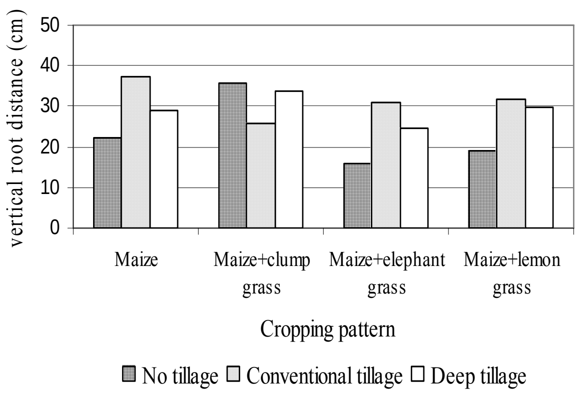
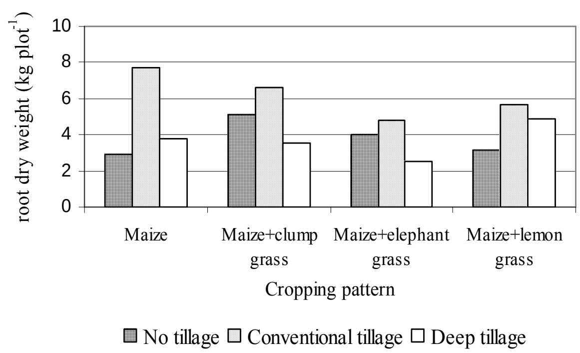


Fig. 8. Root dry weight as influenced by tillage and cropping pattern interaction.



This may be the reason for relatively shallow root development of maize associated with elephant grass and lemon grass (Figs. 7 & 8).

Tillage methods showed significant difference in mean number of kernels per ear, 100-grain weight and harvest index, but not for the final grain yield. Both the yield components were significantly lower in no-tillage than conventional and deep tillage the latter having nearly the same values (Table II). Grain yields in the no-tilled plots were also lower compared to other two tillage methods although differences were small. This may be partly attributed to reduced vertical root distance in no-tilled plots, which reduced the soil depth explored by maize roots, except in maize + clump grass intercropped plots. This indicated that certain stress prevailed in no-tilled plots although water was ample during the season. Scopel *et al.* (2001) also observed significantly higher yields under tillage (disk plowing) than no-tilled, and noted that the yield response to tillage methods depends on the agro-ecological zone and the rainfall pattern during crop growth. Tillage-based management usually has relatively little effects on soil water content at planting (Unger *et al.*, 1998). Soza *et al.* (2000) and Emerson (2003) reported that the yield level under the no-tillage and conventional tillage was dependent upon the production technologies in terms of inputs use and practices adopted.

Cropping patterns did not differ in the yield and its components and harvest index. Light, water and nutrient are often used more efficiently in intercropping than sole cropping (Willey, 1979). Intercrops are also known to increase the water availability through greater canopy cover and protection of the soil surface from raindrop impact (Walker & Ogindo, 2002), and hence favouring high plant dry matter and yields (Jensen *et al.*, 2006). In the current study, there were no significant differences in grain yields due to cropping patterns. This showed that yield and yield components of maize were not affected by intercropping with grasses (Table II). As maize yields are not affected in the wet season, any practice bringing long term benefits would be acceptable to maize growers. Formation of large, stable and continuous pores in the soil profile, decrease in soil bulk density, and increase in infiltration rates and hydraulic conductivity resulted due to grasses with dense root systems (Prihar *et al.*, 2000), which would greatly influence root growth and access to water and nutrients of not only in the currently growing crop, but also in the succeeding crops (Kramer & Boyer, 1995). This is likely to provide opportunities for farmers to grow maize in the following dry season, so avoiding water stress and its adverse effects causing low yields.

CONCLUSION

Maize could be intercropped with deep rooting grasses without yield reduction compared to sole cropping. Three tillage methods did not differ in their effects on grain yield. Vertical root growth was superior in maize + clump grass intercrop in conventional tillage than both no-tillage and deep tillage, and also in the maintenance of relatively greater OC compared to other cropping patterns and tillage methods. Furthermore, maize + clump grass intercropping had lower bulk density and higher porosity in the deep soil profile. Maize + clump grass intercrop even with no tillage can explore deep soils profiles, improve soil physical properties and help the succeeding maize crop in the dry season. This cropping pattern would be preferred as there was no reduction in grain yield in the wet season.

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