

Full Length Research Paper

Impact of conservation agriculture on weed dynamics and maize grain yield in eastern Zambia

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Improved fallows of *Sesbania sesban* (*Sesbania*) have been known to improve soil physical and chemical properties and increase crop yield compared to traditional fallows. However, the effects of soil tillage practices after improved fallows on soil properties, weeds, labour and subsequent maize crop has not been assessed in Southern Africa. This study aimed to evaluate how tillage practices affect yield of maize and affect soil properties after two years of fallow and subsequent cropping phase. In this study, done at sites in eastern Zambia, maize yield from a two-year planted *Sesbania*, natural fallow, continuously fertilized and unfertilized maize were compared under conventional, flat till and zero tillage practices. A split plot experiment, with improved fallow systems in the main plot and the tillage practice in the subplot, was established at the sites. The results showed that the increases in grain yield under conventional tillage over zero tillage practice were 17.8 and 28.2% during 2000/2001 and 2001/2002 seasons, respectively, at Msekera. At Chadiza, the increases in grain yield under conventional tillage over zero tillage were 66.3 and 327.4% during 2000/2001 and 2001/2002 seasons, respectively. Greater maize yields were achieved under *Sesbania* planted fallows compared to the natural fallow and maize monoculture without fertilizer. Overall, zero tillage practice resulted in lower maize grain yield, higher bulk density, reduced water intake, higher weed infestation and high labour demand during weeding compared to conventional tillage.

Key words: Conventional tillage, flat till, grain yield, water intake, weeds, zero tillage.

INTRODUCTION

In traditional shifting and semi-permanent hand-hoe tillage systems, zero or minimum tillage operations are common among small-scale farmers. This is due to labour constraints and lack of draught power. Farmers in eastern Zambia are not exceptional as they are faced with problems of shortage of labour during the growing season. For this reason, maize, a staple crop, is planted

on flat land after the vegetation or crop residues are gathered and burned. Most resource poor farmers practice this system, traditionally known as "Galauza". In other cases, farmers leave fields fallow to natural vegetation for up to 5 years to restore soil fertility (Mafongoya and Bationo, 2006). After this period, farmers gather the natural or crop residues and make ridges or

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mounds using hand hoes by covering the mulch on which crops are planted. Labour shortage, especially at planting, make farmers to opt to plant on the flat.

At Msekera, maize in improved fallow trials is planted on the flat after the soil has been tilled and later ridges are made during weeding when the maize is 50 cm high (Mafongoya et al., 1999). In Zambia, there has been an increased interest in conservation farming because of its benefits in soil erosion control, soil moisture conservation, soil structure improvement and increased net return to farmers. There is little quantitative data, however, that is known about the effect of this tillage system on yield of maize in the farming system of eastern Zambia.

There is need, therefore, to come up with a practice that is both economical and practical under resource poor farmers' depleted soils where such fallows have a potential. Improved fallows of *Sesbania* have also been known to improve the chemical and physical conditions of the soil (Kwesiga et al., 2005) as well as suppressing weeds during fallow phase. Therefore, the objectives of this study were to (i) evaluate how tillage practices affect yield of maize, (ii) determine the effects of tillage practices on soil properties after two years of fallow and subsequent cropping phase.

MATERIALS AND METHODS

Site description

The study was conducted at two sites in eastern Zambia, at Msekera Research Station (32°34' E, 13°38' S, altitude 1030 m asl.) in Chipata and at Farmers' Training Center in Chadiza (32°30' E 14°03' S, altitude 1061 m asl.) between 1997 and 2001. The soils at Msekera in 0 to 20 cm top soil layer have 1% carbon content, 25 and 58% clay and sand, respectively, and a pH (CaCl₂) of 4.8. They are classified as Typic Haplustalfs (USDA, 1975) or Ferric luvisols (FAO, 1988). Msekera receives an average rainfall of 1092 mm per annum (unimodal, November to April). At Chadiza the soils (0 to 20 cm layer) have 0.4% carbon content, and a pH (CaCl₂) of 4.2, 6 and 71% clay and sand, respectively. They are classified as Typic Haplustults (USDA, 1975) or Ferric Acrisol (FAO, 1988). Chadiza receives an average rainfall of 900 mm per annum (unimodal, November to April).

Experimental design

The experiment was carried out using a split plot design with three replications. The main plots were: (1) Maize (*Zea mays* L.) after 2 years *Sesbania sesban* (prov. Chipata dam) fallow, (2) Maize after 2 years natural fallow, (3) Maize monoculture with recommended fertilizer (112 kg N, 18 kg P, and 17 kg K ha⁻¹), and (4) Maize monoculture without fertilizer. The sub-plots consisted of three practices of tillage: (1) Conventional tillage (farmers planting maize on ridges), (2) Flat tilled and (3) Zero tillage. The sub-plots measured 10 by 10 m.

Land preparation and crop management

Sesbania was planted in the field from nursery raised bare rooted seedlings at the age of 5 weeks. The spacing between plants was 1.0 by 1.0 m (10 000 plants ha⁻¹). Trees were felled to ground level

after two years of growth in October 1999. Stumps and root systems were left in the soil. The above ground biomass of trees was measured at fallow clearing by separating the biomass components into foliage (leaves and twigs), branches and stems. These components were then weighed as green after which samples of each component were collected on plot basis and oven dried at 70°C to constant moisture.

The plots with conventional tillage practice were prepared by covering the natural vegetation or crop residues with soil by making ridges as a common practice in eastern Zambia using hand hoes. The plots with flat tilled practice were ploughed by digging and burying the natural vegetation or crop residues on the surface to 20 cm depth with a hand hoe. On the zero tillage practice, a 3 cm diameter bamboo stick was used to open a fallow to a depth of 5 cm, where maize seed was placed at planting. Biomass production of natural fallow at the end of two years was assessed using four quadrants of 0.50 by 0.50 m (0.25 m²) each (Klingman, 1971). Weeds during the cropping phase were only estimated at Msekera before each weeding by the procedure mentioned above. Predominant weeds were *Acanthospermum hispidum* DC, *A. conyzoides*, *Bidens pilosa* L. and *Cassia obtusifolia* L. (Fabaceae). Weeds were controlled in the conventional tillage practice by re-ridging. In the flat tilled plots, the weeds were controlled by hand hoeing, and in the zero tillage plots by cutting the weeds at ground level with hand hoe. All plots were weeded twice during the crop season. Hybrid maize (*Zea mays* L. var. MM 604) was sown by hand in all tillage practices at 25 cm within the rows and 100 cm between the rows (44 444 plant ha⁻¹). Fertilizer to the 'fertilized maize control plots' was applied at the rate of 20, 18, and 17 kg N, P and K ha⁻¹, respectively, using Compound D at sowing and 92 kg N ha⁻¹ using urea, four weeks after sowing. The experiment was done over 2 seasons, in the 2000/2001 and 2001/2002 seasons.

Sample collection and analyses

Six replicate samples were taken from 0 to 20 cm soil depth in all plots for determination of total inorganic N. The first sampling was taken at fallow clearing (post-fallow pre-season sampling, October 2000) and the second sampling was done in February 2001 (wet season sampling). Ammonium N was determined by colorimetric method (Anderson and Ingram, 1993). Nitrate concentrations were determined by cadmium reduction (Dorich and Nelson, 1984). The sum of NH₄⁺-N and NO₃⁻-N constituted the total inorganic N.

Soil samples for determination of bulk density from all plots were collected using standard core rings (100 cm³) from 0 to 20 cm soil layer at fallow clearing (October 2000) and start of the second crop season (October, 2001) and oven-dried to constant weight at 105°C and weighed. Infiltration was monitored only at Msekera at fallow clearing towards the end of the dry season (October, 2000) and before start of the second cropping season (October, 2001) using the double ring infiltrometer (Bouwer, 1986). Measurements were recorded from 3 double rings inserted diagonally in a systematic design in the net plot for three hours at 0, 5, 10, 15, 20, 30, 45, 60, 90, 120, 150 and 180 min. The average readings were used to calculate infiltration rate per plot using Kostiaikov (1932) model.

The data were subjected to analysis of variance (ANOVA) using the generalized linear model (Proc GLM) of the Statistical Analysis System, SAS (1996). The least significant difference (LSD) method was used at 5% to separate treatment means in case of a significant F-test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Above ground tree biomass

At both sites, no significant difference was recorded in

Table 1. Above ground biomass (tha^{-1}) at fallow clearance at Chadiza and Msekera as affected by fallow system and tillage practice in October 2001.

| Fallow system (FS) | Tillage practice | | |
|--|----------------------|-----------|--------------|
| | Conventional tillage | Flat till | Zero tillage |
| <i>Msekera</i> | | | |
| Two years Sesbania fallow | | | |
| Leaf and twig | 0.4 | 0.4 | 0.5 |
| Stem | 6.6 | 7.4 | 6.2 |
| Total above ground biomass | 7.0 | 7.8 | 6.7 |
| Two years natural fallow | | | |
| Total above ground biomass | 7.1 | 7.9 | 8.5 |
| LSD _(0.05 level) : FS = NS, Tillage = NS, F x Tillage = NS | | | |
| Chadiza | | | |
| Two years Sesbania fallow | | | |
| Leaf and twig | 0.4 | 1.0 | 0.3 |
| Stem | 15.7 | 12.0 | 8.3 |
| Total above ground biomass | 16.1 | 13.0 | 8.6 |
| Two years natural fallow | | | |
| Total above ground biomass | 6.1 | 6.4 | 6.2 |
| LSD _(0.05 level) : FS = NS, Tillage = NS, FS x Tillage = NS | | | |

LSD = least significant difference; FS = Fallow system; NS = not significant.

above ground biomass in relation to tillage practice or land use system (LUS) (Table 1). Despite this, sesbania had the highest standing total above ground biomass of 16.1 tha^{-1} under conventional tillage practice and 7.8 tha^{-1} under flat till practice at Chadiza and Msekera respectively (Table 1). Conventional tillage practice at Chadiza had biomass of 15.7 tha^{-1} and 0.4 tha^{-1} for wood and foliage (leaf + twigs), whereas wood biomass was 7.4 tha^{-1} and foliage (leaf + twigs) was 0.4 tha^{-1} for flat till practice at Msekera.

The above ground biomass reported in this study relates well to that reported by Kwesiga et al. (1995) and Mafongoya et al. (1999) under similar conditions. The high sesbania biomass at Chadiza site was attributed to the good rainfall (1144.4 mm p.a.) of 1997/1998 followed by another good season with a total of 1062 mm p.a. The other reason is that the type of soils at Chadiza has a top 40 cm sand layer followed by a clay subsoil which traps leached nutrients.

Top soil nitrogen dynamics

Pre-season inorganic NO_3^- - N before sowing crop was not significantly affected by LUS or tillage practice at Msekera (Table 2). However, NO_3^- - N and total inorganic N in both October 2000 and February 2001 was highest under conventional tillage compared to zero or flat till practice (Table 2). The interaction between LUS and tillage practice was not significant. This could be attributed to the dry conditions experienced at the time of

soil sampling. During the wet season sampling at Msekera, significant differences were observed for LUS and tillage practice. There was also significant interaction between LUS and tillage practices.

At Chadiza site, there was no significant difference at both times of sampling in relation to soil nitrogen (Table 3). Despite this, zero tillage practice had generally lower concentrations of NO_3^- - N in the top 20 cm. This is in contrast to Khant (1971), who proposed greater N concentration in zero tillage plots due to less uptake and movement as a result of the absence of thorough land preparation. The low NO_3^- - N levels under Sesbania at both sites during wet season sampling could be a result of rapid N uptake by growing maize and rapid leaching of NO_3^- - N during high rainfall of 2000 (1342 mm p.a.). Okonkwo et al. (2008) reported similar results of NO_3^- - N being leached beyond rooting depth of maize.

Cumulative water intake

Significant difference ($p < 0.05$) was found in all LUS and tillage practices in both October 1999 and October 2000 seasons (Table 4). Cumulative water intake by the LUS was 14.9 and 12.7% higher under conventional tillage than zero tillage practice in both years after three hours (Table 4). Natural fallow under conventional tillage practice had significantly higher cumulative water intake than under flat till or zero tillage practice in 1999 season (Table 4). This could be attributed to less runoff, high root mass, less compaction during the fallow period (Sjogren

Table 2. Inorganic soil NO₃⁻-N and total inorganic-N (mg N kg⁻¹), at 0 to 20 cm depth, before sowing crop and during the wet season of first post-fallow crop (2000/2001) as affected by cropping system and tillage practice at Msekera.

| Cropping system (CS) | Tillage practice | | | | | |
|---|----------------------|-------------------|-----------|-------------------|--------------|-------------------|
| | Conventional tillage | | Flat till | | Zero tillage | |
| | Nitrate-N | Total inorganic-N | Nitrate-N | Total inorganic-N | Nitrate-N | Total inorganic-N |
| Inorganic nitrogen in October 2000 | | | | | | |
| Maize with fertilizer | 5.12 | 6.99 | 1.90 | 3.22 | 2.60 | 4.24 |
| Maize after Sesbania fallow | 3.44 | 4.64 | 2.98 | 3.14 | 3.52 | 5.22 |
| Maize after natural fallow | 1.88 | 3.18 | 2.84 | 4.82 | 1.40 | 3.30 |
| Maize without fertilizer | 2.52 | 3.97 | 3.06 | 4.01 | 1.47 | 2.24 |
| Inorganic nitrogen in February 2001 | | | | | | |
| Maize with fertilizer | 15.16 | 19.64 | 1.81 | 4.99 | 1.94 | 6.23 |
| Maize after Sesbania fallow | 2.26 | 7.55 | 1.63 | 4.93 | 1.04 | 3.64 |
| Maize after natural fallow | 2.36 | 6.96 | 1.84 | 5.87 | 1.76 | 6.03 |
| Maize without fertilizer | 1.97 | 3.08 | 1.22 | 2.94 | 1.84 | 4.56 |
| Nitrate-N: LSD _(0.05 level) : CS = 1.82, Tillage = 0.72, CS x Tillage = 2.00 | | | | | | |
| Total-N: LSD _(0.05 level) : CS = 2.80, Tillage = 1.23, CS x Tillage = 3.18 | | | | | | |

LSD = least significant difference; CS = Cropping system; NS = not significant.

et al., 2010). Natural vegetation regrowth consists of many plant species with different types of root systems, which have the capacity to increase infiltration of water in the soil. Fallowing with various legumes and grass cover crops is known to improve soil infiltration (Chintu, 2004). Low cumulative water intake in maize with or without fertilizer on zero tillage practice could be attributed to deterioration of soil physical properties leading to high bulk density and reduced porosity.

Similarly, Good and Beatty (2011) reported a decline in cumulative water intake in continuous maize with fertilizer, which they attributed to high soil bulk density, and penetrometer resistance under no till treatment. Generally there was a decline in all LUS in cumulative water intake in the second post fallow season (October, 2000) than

the first post fallow season (October, 1999). This decline could be attributed to break down of soil physical properties. The benefits accrued during fallowing are easily lost by cultivation (Wilkinson and Aina, 1976). This decline was more pronounced for natural vegetation fallow under conventional tillage practice and the least was for unfertilised, monocultivated maize under zero tillage practice. Continuous cultivation has been reported by several researchers (Liu et al., 2006) as being responsible for structural degradation, decrease in soil organic matter content.

Soil bulk density

The bulk density measured at fallow clearance

was lowest under the maize planted after the natural fallow (1.14 gcm⁻³) and sesbania fallow (1.23 gcm⁻³) flat till practice compared to maize monoculture with fertilizer (1.54 gcm⁻³) and maize after natural fallow (1.53 gcm⁻³) on zero tillage practice (Table 5). The higher bulk density under zero tillage practice could be attributed to the non-incorporation of organic matter which was left on the soil surface. These soils are normally compacted if no tillage is used.

Therefore, where minimum tillage or mixing of soil with organic matter is employed, bulk density is bound to be lowered. This is contrary to other researchers (Diana et al., 2008) who reported that the presence of residue on the soil surface is responsible for maintaining low soil bulk density. Bulk density measured after one year of cropping

Table 3. Inorganic soil NO_3^- -N and total inorganic-N (mg N kg^{-1}), at 0 to 20 cm depth, before sowing crop and during the wet season of first post-fallow crop (2000/2001) as affected by cropping system and tillage practice at Chadiza.

| Cropping system (CS) | Tillage practice | | | | | |
|---|----------------------|-------------------|-----------|-------------------|--------------|-------------------|
| | Conventional tillage | | Flat till | | Zero tillage | |
| | Nitrate-N | Total inorganic-N | Nitrate-N | Total inorganic-N | Nitrate-N | Total inorganic-N |
| Inorganic nitrogen in October 2000 | | | | | | |
| Maize with fertilizer | 4.91 | 7.63 | 2.20 | 5.68 | 2.04 | 4.12 |
| Maize after Sesbania fallow | 4.94 | 7.51 | 5.67 | 8.11 | 5.77 | 10.24 |
| Maize after natural fallow | 1.35 | 4.96 | 1.63 | 5.47 | 1.12 | 5.60 |
| Maize without fertilizer | 5.40 | 8.24 | 1.88 | 4.39 | 1.12 | 3.84 |
| Inorganic nitrogen in February 2001 | | | | | | |
| Maize with fertilizer | 1.49 | 7.30 | 3.1 | 6.22 | 2.9 | 6.58 |
| Maize after Sesbania fallow | 2.55 | 6.48 | 0.55 | 4.26 | 0.59 | 4.43 |
| Maize after natural fallow | 1.21 | 5.77 | 0.52 | 2.93 | 0.27 | 3.38 |
| Maize without fertilizer | 2.03 | 4.80 | 0.19 | 2.55 | 0.46 | 3.85 |
| Nitrate-N: $\text{LSD}_{(0.05 \text{ level})}$: CS = NS, Tillage = NS, CS x Tillage = NS | | | | | | |
| Total-N: $\text{LSD}_{(0.05 \text{ level})}$: CS = NS, Tillage = NS, CS x Tillage = NS | | | | | | |

LSD = least significant difference; CS = Cropping system; NS = not significant.

Table 4. Cumulative water intake (mm) after 3 hours before sowing the first crop (October 2000) and before sowing second crop (October 2001) as affected by cropping system and tillage practice at Msekera.

| Cropping system (CS) | Tillage practice | | |
|--|----------------------|-----------|--------------|
| | Conventional tillage | Flat till | Zero tillage |
| Water intake in October 2000 | | | |
| Maize with fertilizer | 190.0 | 154.3 | 152.3 |
| Maize after Sesbania fallow | 255.0 | 251.7 | 234.7 |
| Maize after natural fallow | 306.0 | 256.7 | 262.7 |
| Maize without fertilizer | 140.3 | 130.3 | 126.0 |
| $\text{LSD}_{(0.05 \text{ level})}$: CS = 7.1, Tillage = 4.2, CS x Tillage = 9.2 | | | |
| Water intake in October 2001 | | | |
| Maize with fertilizer | 108.7 | 102.0 | 96.7 |
| Maize after Sesbania fallow | 170.7 | 160.0 | 111.0 |
| Maize after natural fallow | 158.3 | 179.0 | 174.3 |
| Maize without fertilizer | 95.0 | 94.7 | 93.0 |
| $\text{LSD}_{(0.05 \text{ level})}$: CS = 17.5, Tillage = 12.6, CS x Tillage = 25.0 | | | |

LSD = least significant difference; CS = Cropping system.

(October, 2000) was lowest in maize planted after natural fallow (1.27 g cm^{-3}) and highest under maize monoculture with fertilizer (1.62 g cm^{-3}) under zero tillage practice (Table 5). In this study, bulk density measured after one year of cultivation led to progressive deterioration of the soil structure under all LUS. The results from this experiment confirm the earlier findings by Liu et al. (2006) who reported high bulk density after continuous

monocropping. The increased bulk density could be linked to high soil compaction under the zero tillage practice, which could have impeded root growth to exploit nutrients hence lower maize grain yields. No tillage, although advantageous through reduction of erosion and soil organic matter maintenance, could eventually lead to soil compaction with shallow rooting crops and insufficient residue return (Juo et al., 1996).

Table 5. Dry bulk density (g cm^{-3}) before sowing the first crop (October 2000) and before sowing second crop (October 2001) as affected by land-use system and tillage practice at Msekera.

| Cropping system (CS) | Tillage practice | | |
|--|----------------------|-----------|--------------|
| | Conventional tillage | Flat till | Zero tillage |
| Dry bulk density in October 2000 | | | |
| Maize with fertilizer | 1.30 | 1.36 | 1.54 |
| Maize after Sesbania fallow | 1.33 | 1.23 | 1.45 |
| Maize after natural fallow | 1.38 | 1.14 | 1.53 |
| Maize without fertilizer | 1.38 | 1.31 | 1.36 |
| LSD _(0.05 level) : CS = NS, Tillage = 0.07, CS x Tillage = 0.16 | | | |
| Dry bulk density in October 2001 | | | |
| Maize with fertilizer | 1.42 | 1.50 | 1.62 |
| Maize after Sesbania fallow | 1.45 | 1.37 | 1.57 |
| Maize after natural fallow | 1.48 | 1.27 | 1.59 |
| Maize without fertilizer | 1.52 | 1.45 | 1.47 |
| LSD _(0.05 level) : CS = NS, Tillage = 0.06, CS x Tillage = 0.17 | | | |

LSD = least significant difference; CS = Cropping system; NS = not significant.

Maize grain yields

At Chadiza site, there was no interaction between land use system and tillage practice with respect to maize grain yield in both crop seasons. However, the maize yields of maize monoculture with fertilizer during 2000 season under conventional tillage practice performed better than the rest of the LUS and tillage practices (Table 6). During 2000 season the maize yields of fertilised monocultivated maize, maize after Sesbania fallow, maize after natural fallow and maize monoculture without fertilizer from conventional tillage practice were 49, 46, 42 and 47% above the zero tillage system respectively. On the other hand, maize yields from the flat till practice were not significantly different ($p > 0.05$) from the zero tillage practice. Similarly, maize yields during 2000/2001 season were highest in maize monoculture with fertilizer under conventional tillage compared to zero tillage or flat till practice (Table 6).

The increases in grain yield under conventional tillage over zero tillage respectively were 66.3 and 327.4% during 2000/2001 and 2001/2002 seasons. In both cropping seasons at Chadiza site, zero tillage decreased maize grain yields compared to conventional tillage. This could be due to weed infestation, outbreak of *Cercospora* grey leaf spot disease during grain filling period and deterioration of soil properties under continuous zero tillage practice. Madal et al. (1994) reported higher yields under conventional tillage practice, which they associated with better root growth and higher water use. No till has also been reported to cause significant reductions in maize yield compared with conventional cultivation and deep tillage (Arora et al., 1991; Archarya and Sharma, 1994). At Msekera, in both 2000/2001 and 2001/2002

seasons, maize yields were significantly different ($p < 0.05$) among the LUS and tillage practices. No interaction between LUS and tillage practice with respect to maize grain yield in both seasons was recorded at Msekera site. In spite of this, the highest yields, irrespective of tillage practice were from maize monoculture with fertilizer in 2000 and 2001 season. The increases in grain yield under conventional tillage over zero tillage practice respectively were 17.8 and 28.2% during 2000 and 2001 season respectively (Table 6).

Kwesiga et al. (2005) showed that improved fallow of sesbania of one to three year duration has the capacity to increase yield of subsequent maize crops on N-deficient soils. Sesbania leaf biomass is higher in N and decomposes rapidly to supply N to maize crops in the first season. Mafongoya and Bationo (2006) reported similar benefits of sesbania leaf biomass on subsequent maize grain yield. Whereas high maize yields in the control with fertilizer could be ascribed to N from fertilizer. Maize yields under conventional tillage practice surpassed yields from other tillage practices and this could be attributed to the improved soil fertility, concentration of organic matter along the ridge, and reduced weed infestation. On the other hand, low maize yields from zero tillage were a result of high weed infestation and pests or disease outbreaks (Sileshi, personal communication, Chitedze Research Station, Zambia).

Dry weed biomass

Significant differences ($p < 0.05$) were observed in weed infestation among the LUS and the tillage practices at fallow clearance and at the two weeding times (Table 7).

Table 6. Maize grain yields (t ha⁻¹) at Chadiza and Msekera as affected by cropping system and tillage practice.

| Cropping system (CS) | Tillage practice | | |
|--|----------------------|-----------|--------------|
| | Conventional tillage | Flat till | Zero tillage |
| Chadiza 2001 | | | |
| Maize with fertilizer | 4.23 | 3.13 | 2.14 |
| Maize after Sesbania fallow | 3.76 | 3.77 | 2.01 |
| Maize after natural fallow | 1.07 | 0.86 | 0.60 |
| Maize without fertilizer | 1.42 | 1.03 | 0.75 |
| LSD _(0.05 level) : CS = 0.43, Tillage = 0.37, CS x Tillage = 0.74 | | | |
| Chadiza 2002 | | | |
| Maize with fertilizer | 1.65 | 0.50 | 0.32 |
| Maize after Sesbania fallow | 0.99 | 0.99 | 0.32 |
| Maize after natural fallow | 0.74 | 0.37 | 0.26 |
| Maize without fertilizer | 0.55 | 0.21 | 0.03 |
| LSD _(0.05 level) : CS = 0.41, Tillage = 0.36, CS x Tillage = NS | | | |
| Msekera 2001 | | | |
| Maize with fertilizer | 4.31 | 3.97 | 3.65 |
| Maize after Sesbania fallow | 3.35 | 3.28 | 3.39 |
| Maize after natural fallow | 2.12 | 2.06 | 1.92 |
| Maize without fertilizer | 1.15 | 0.96 | 0.86 |
| LSD _(0.05 level) : CS = 0.50, Tillage = NS, CS x Tillage = NS | | | |
| Msekera 2002 | | | |
| Maize with fertilizer | 4.77 | 4.15 | 3.98 |
| Maize after Sesbania fallow | 1.69 | 1.70 | 1.67 |
| Maize after natural fallow | 1.10 | 1.02 | 0.93 |
| Maize without fertilizer | 0.67 | 0.53 | 0.38 |
| LSD _(0.05 level) : CS = 0.28, Tillage = 0.32, CS x Tillage = NS | | | |

LSD = least significant difference; CS = Cropping system; NS = not significant.

Table 7. Total dry weed biomass production (kg ha⁻¹) as affected by cropping system and tillage practice at Msekera, Zambia.

| Cropping system (CS) | Tillage practice | | |
|---|----------------------|-----------|--------------|
| | Conventional tillage | Flat till | Zero tillage |
| Weed biomass at fallow clearance | | | |
| Maize with fertilizer | 2440 | 2200 | 2667 |
| Maize after Sesbania fallow | 0 | 0 | 0 |
| Maize after natural fallow | 7063 | 7920 | 8450 |
| Maize without fertilizer | 2577 | 2713 | 2703 |
| LSD _(0.05 level) : CS = 370, Tillage = 453, CS x Tillage = 412 | | | |
| Weeds at 2 WAP | | | |
| Maize with fertilizer | 1920 | 2033 | 2200 |
| Maize after Sesbania fallow | 223 | 277 | 303 |
| Maize after natural fallow | 3133 | 3217 | 3333 |
| Maize without fertilizer | 1917 | 2030 | 2117 |
| LSD _(0.05 level) : CS = 499, Tillage = 35, CS x Tillage = 500 | | | |

Table 7. Contd.

| Weeds at 7 WAP | | | |
|---|------|------|------|
| Maize with fertilizer | 193 | 240 | 263 |
| Maize after Sesbania fallow | 157 | 240 | 327 |
| Maize after natural fallow | 1970 | 2060 | 2563 |
| Maize without fertilizer | 603 | 707 | 780 |
| LSD _(0.05 level) : CS = 153, Tillage = 131, CS x Tillage = NS | | | |
| Total weed biomass | | | |
| Maize with fertilizer | 26.7 | 47.3 | 43.3 |
| Maize after Sesbania fallow | 29.0 | 40.0 | 70.0 |
| Maize after natural fallow | 41.0 | 57.7 | 87.3 |
| Maize without fertilizer | 24.7 | 44.3 | 54.3 |
| LSD _(0.05 level) : CS = 11.5, Tillage = 6.5, CS x Tillage = 14.4 | | | |

LSD = least significant difference; CS = Cropping system; NS = not significant.

Sesbania planted fallow had no weed biomass at fallow clearance compared to natural fallow. In general the highest and lowest weed cover was found in natural fallow and sesbania fallow, respectively. Overall, the zero tillage practice and the natural fallow system had significantly high weed infestation at all times during the 2000/2001 season. The low weed infestation under sesbania LUS at fallow clearance could be attributed to its ability to suppress weeds in relation to other LUS. These results conform to Sileshi and Mafongoya (2003) findings under similar conditions. Significant difference in weed biomass was recorded for LUS and tillage practice at 2 and 7 WAP (Table 7).

Higher weed infestation occurred under natural fallow for zero tillage practice, compared to other LUS during the first and second weeding. Similarly, total weed biomass was also significantly affected by LUS and tillage practice. The zero tillage practice under the natural fallow practice had the highest total weed infestation (Table 7). This could be as a result of weed seeds, which were still in the soil, which came up after the soil was slightly disturbed at weeding. Conventional tillage was able to suppress weeds more than other tillage practices throughout the subsequent weeding times during the crop growth. Whereas crop residues from maize monoculture with or without fertilizer, mostly consisted of stalks which were not able to suppress weeds. Böhringer (1991) reported that mulch morphology plays an important role in controlling weeds and facilitating hand hoe weeding.

Total labour requirement

At land preparation, the zero tillage practice was the easiest to prepare and took less man hours compared to the flat till or conventional tillage practice (Table 8). The low labour for sesbania under zero tillage practice could

be attributed to low weed infestation as well as the improved soil structure, which made it easier to make fallows with a wooden peg. On the overall, the maize monoculture with fertilizer on the flat till tillage practice took 115.3 man hours ha⁻¹ to prepare compared to 5.3 man hours ha⁻¹ for sesbania fallow zero tillage practice (Table 8).

Tillage practice had no significant difference ($p > 0.05$) in the time it took to do the planting operation. Despite this, more time was spent in the natural fallow zero tillage practice compared to maize monoculture without fertilizer under conventional tillage practice during planting (Table 8). Under Sesbania zero tillage practice weeds germinated earlier than other LUS because of the improved fertility of the soil. Whereas under natural fallow there were a lot of weed seeds in the soil, which germinated after favourable conditions were met such as good rainfall and soil condition. The high weed infestation consequently led to increasing labour demand at weeding. Addati and Cassirer (2008) reported that farmers in Africa spent about 40% of their work hours weeding. This is because farmers using hand hoes for weeding would like to clean weed their small areas of land in order to get a good yield.

At 2 WAP the weed infestation was higher under the zero tillage practice and as such more time was spent for clean weeding in the maize after natural fallow and sesbania fallow with zero tillage practices compared to maize mono culture with and without fertilizer under conventional tillage practice (Table 8). The reason has already been mentioned above. After 7 WAP (second weeding) the maize after natural fallow and sesbania fallow with zero tillage still had higher weed infestation as such more time was spent for clean weeding compared to the conventional tillage (Table 8). The major reason has also been mentioned before.

The total labour requirement for land preparation,

Table 8. Labour requirements (man hours ha⁻¹) for different operations as affected by cropping system and tillage practice.

| Cropping system (CS) | Tillage practice | | |
|---|----------------------|-----------|--------------|
| | Conventional tillage | Flat till | Zero tillage |
| Labour at land preparation | | | |
| Maize with fertilizer | 75.3 | 115.3 | 35.3 |
| Maize after Sesbania fallow | 103.3 | 103.7 | 5.3 |
| Maize after natural fallow | 77 | 112 | 60.7 |
| Maize without fertilizer | 73.0 | 103.7 | 46.0 |
| LSD _(0.05 level) : CS = NS, Tillage = 22.6, CS x Tillage = NS | | | |
| Labour at planting | | | |
| Maize with fertilizer | 26.0 | 48.0 | 54.3 |
| Maize after Sesbania fallow | 26.0 | 46.0 | 58.0 |
| Maize after natural fallow | 26.0 | 54.3 | 60.0 |
| Maize without fertilizer | 17.3 | 29.0 | 47.7 |
| LSD _(0.05 level) : CS = NS, Tillage = 12.7, CS x Tillage = NS | | | |
| Labour at 1st weeding | | | |
| Maize with fertilizer | 20.3 | 41.0 | 37.7 |
| Maize after Sesbania fallow | 23.3 | 35.7 | 64.7 |
| Maize after natural fallow | 36.7 | 54.7 | 89.9 |
| Maize without fertilizer | 20.3 | 38.7 | 50.3 |
| LSD _(0.05 level) : CS = 12.3, Tillage = 6.3, CS x Tillage = 14.7 | | | |
| Labour at 2nd weeding | | | |
| Maize with fertilizer | 26.7 | 47.3 | 43.3 |
| Maize after Sesbania fallow | 29.0 | 40.0 | 70.0 |
| Maize after natural fallow | 41.0 | 57.7 | 87.3 |
| Maize without fertilizer | 24.7 | 44.3 | 54.3 |
| LSD _(0.05 level) : CS = 11.5, Tillage = 6.5, CS x Tillage = 14.4 | | | |
| Total labour | | | |
| Maize with fertilizer | 148.3 | 251.7 | 170.7 |
| Maize after Sesbania fallow | 181.7 | 224.7 | 198.0 |
| Maize after natural fallow | 181.0 | 278.7 | 265.7 |
| Maize without fertilizer | 135.3 | 215.7 | 198.3 |
| LSD _(0.05 level) : CS = 34.4, Tillage = 33.4, CS x Tillage = NS | | | |

LSD = least significant difference; CS = Cropping system; NS = not significant.

planting and two weeding in one season under different LUS and tillage practice was highest under the maize after natural fallow with the flat till and zero tillage practices compared to the maize mono culture with or without fertilizer under conventional tillage (Table 8). Fertilized plots offered good crop stand, which eventually helped to suppress weeds and reduce labour demands. Low fertility under maize without fertilizer contributed to low weed infestation and less labour demand at weeding. Flat till and zero tillage practice required high labour input because traditionally most of the surface area is weeded, even in the case of scattered weed growth as reported by Vogel (1994).

Generally maize monoculture without fertilizer under conventional tillage practice resulted in low labour demand during land preparation, planting, first and second weeding. This could be ascribed to reduced biomass from maize stalks from previous season, which could have interfered with land preparation, planting and weeding operations.

Conclusions

This study illustrates the various tillage practices and their implication on labour in relation to maize production

under smallholder enterprise. Zero tillage practice resulted in lower maize grain yield, higher bulk density, reduced water intake, higher weed infestation and high labour demand during weeding compared to conventional tillage. Despite zero tillage having less labour demand at land preparation, a farmer will need to invest in herbicides in order to control the weeds if this tillage practice is to be adopted. Conventional tillage improved the soil environment and resulted in increased maize yield in all LUS. Flat till practice has higher labour demand at land preparation in relation to other tillage practices and will cause a serious hindrance to households with shortage of labour.

Conflict of Interests

The authors have not declared any conflict of interests.

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