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Evaluation of Tillage Practices for Maize (*Zea mays*) Grown on Different Land-Use Systems in Eastern Zambia

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Abstract

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 have 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.

Keywords: conventional tillage, flat till, grain yield, water intake, weeds, zero tillage

1. Introduction

The practice of intensive tillage can be effective for weed management. However, it increases the risk of soil erosion. Frequent tillage can increase land degradation, soil erosion and soil compaction, and these are major challenges that smallholder farmers are facing in crop production (Hamza & Anderson, 2005). The increase of land degradation has brought an interest of practicing conservation agriculture and there is need to increase the practice of conservation tillage practices, including conservation agricultural practices, amongst smallholder farmers in South Africa.

Conservation tillage is the use of agricultural practices that have minimal soil disturbances (Sarker et al., 2012). Conservation agriculture is defined as a farming system where there is a permanent soil cover, minimal soil disturbance and where crop rotation is practiced (Act et al., 2003). It also includes the use cover crops as a soil amelioration measure (Mariki, 2003). Small resource poor farmers who have adopted conservation tillage methods cite the reduction in labour inputs and drudgery as major drivers for adoption (Landers et al., 2002). The three of conservation agricultural practices pillars are sustainable and environmentally friendly, conserving natural resources such as soil nutrients and water (Chauhan et al., 2012). Conservation agriculture is also known to improve crop yields, reduce soil erosion, soil fertility improvement, and reduces labour requirements (Giller et al., 2009).

Weed management in conservation tillage practices is more problematic than in conventional tillage practices because weeds that are not buried deep in the soil have the ability to germinate and emerge vigorously (Singh et al., 2015), especially perennial weeds, and this results in loss of crop yield (Mader & Biere, 2011; Capinera, 2005). The use of herbicides is a common practice to control in conservation agriculture. However, the continuous application of herbicides with the same mode of action is problematic and could lead to herbicide resistance (Vencil et al., 2012). This is particularly a major problem on smallholder farmers practicing no-till who cannot afford herbicides. Although herbicide application can be effective in weed suppression, smallholder farmers should be aware that the effectiveness of herbicide can decrease with the amount of residues left on the soil surface after harvest (Karki & Shestha, 2014).

The use of cover crops can be used as an alternative to herbicide application by the smallholder farmers. Cover crops are important for sustainable crop production providing various benefits such as improvement of soil quality by improving biological, chemical and physical properties such as organic matter content (Dabney et al., 2001). Legume cover crops help in improving soil fertility (Matusso et al., 2014). Legume cover crops have the potential to utilize low available nutrients compared to cereal cover crops that utilize a lot of nitrogen (Fageria & Bailey, 2005). Smallholder framers can use legumes as cover crops because it results in high economic returns with minimal fertilisers application in maize production (Murungu, 2012). A number of legumes have been tested for weed suppression and can be applicable for smallholder farmers practicing conservation agriculture. Cowpea is known to be effective in weed suppression and can be suitable to be used in maize production. Its ability to suppress weeds is influenced by its growth habit. Cowpea develops over ground runners which can result in decreases light interception for weeds, thus reducing weed biomass and weed density (Bilalis et al., 2010). Cowpea has been found to be effective in suppressing amaranthus weed species (Zaviehmaradat et al., 2013). Grazing vetch is also known to be effective in weed suppression reducing weed species diversity. A study done in South Africa found that grazing vetch reduced weed density by 80% (Murungu et al., 2010).

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 et al., 2006). After this period, farmers gather the natural or crop residues and make ridges or 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.

2. Materials and Methods

2.1 Site Description

The study was conducted at two sites in eastern Zambia, at Msekera Research Station (32^{o}34’ E, 13^{o}38’ S, altitude 1030 m above sea level) in Chipata and at Farmers’ Training Center in Chadiza (32^{o}30’ E 14^{o}03’ S, altitude 1061 m above sea level) between 1997 and 2002. The top soil (0-20 cm) at Msekera has 1% carbon content, 25 % and 58 % clay and sand, respectively, and a pH ($CaCl_2$) 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, Nov-April). At Chadiza the soils (0-20 cm layer) have 0.4% carbon content, and a pH ($CaCl_2$) 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 - April).

2.2 Experimental Design

The experiment was carried out using a split plot design with three replications at each site. The main plots were: (1) maize (*Zea mays* L.) after a two year *Sesbania sesban* (prov. Chipata dam) (Sesbania) fallow, (2) maize after 2 years natural fallow, (3) maize monoculture with recommended fertilizer (112 kg N ha^{-1}, 18 kg P ha^{-1}, 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 (farmers planting maize on ploughed field with no ridges) and (3) zero tillage. The sub-plots measured 10 by 10 m.

2.3 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 m by 1.0 m (10 000 plants ha^{-1}). Trees were felled to ground level after two years of growth in October 2000. 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^{o}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 m^2) each (Klingman, 1971). Weeds, during the cropping phase, were noted before each weeding by the procedure mentioned above. Predominant weeds were *Acanthospermum hispidium* 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 plants 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 maize was planted over 2 seasons, in the 2000/2001 and 2001/2002 seasons. Maize yield was measured at the end of each season.

2.4 Sample Collection and Analyses

Six replicate samples were taken from 0-20 cm soil depth in all plots for determination of total inorganic N. The first sampling was taken at fallow clearing (post-fallow preseason sampling, October 2000) and the second sampling was done in February 2001 (wet season sampling). Ammonium N was determined by colorimetric method (Anderson & Ingram, 1993). Nitrate concentrations were determined by cadmium reduction (Dorich & Nelson, 1984). The sum of NH_4^+-N and NO_3^--N constituted the total inorganic N.

Soil samples for determination of bulk density from all plots were collected using standard core rings (100 cm^3) from 0-20 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^{o}C and weighed. Infiltration was monitored 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 minutes. The average readings were used to calculate infiltration rate per plot using Kostiakov (1932) model.

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

3. Results and Discussion

3.1 Above Ground Tree Biomass

At both sites, no significant difference was recorded in above ground biomass in relation to tillage practice or fallow system (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.

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
Msekera			
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.

Table 2. Inorganic soil NO_3^--N and total inorganic-N (mg N kg^{-1}), at 0 – 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.

The above ground biomass reported in this study relates well to that reported by Kwesiga et al. (1995), Sileshi et al. (2006) 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 1997/98 followed by another good season with a total of 1062 mm per annum in the 1998/1999 season. 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.

3.2 Top Soil Nitrogen Dynamics

At Msekera site, nitrate 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 cropping system and tillage practice was significant ($P<0.05$). This could be attributed to the dry conditions experienced at the time of soil sampling. During the wet season sampling, significant differences were observed for cropping season and tillage practice ($P<0.05$).

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.

Table 3. Inorganic soil NO_3^--N and total inorganic-N (mg N kg^{-1}), at 0 – 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: $LSD_{(0.05\ level)}$: CS = NS, Tillage = NS, CS x Tillage = NS				
		Total-N: $LSD_{(0.05\ level)}$: CS = NS, Tillage = NS, CS x Tillage = NS				

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

3.3 Cumulative Water Intake

Significant difference ($P<0.05$) was found in all cropping systems and tillage practices in both October 1999 and October 2000 seasons (Table 4). Cumulative water intake by the cropping system 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 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 cropping systems in cumulative water intake in the second post fallow season (October 2001) than the first post fallow season (October 2000). This decline could be attributed to break down of soil physical properties. The benefits accrued during fallowing are easily lost by cultivation (Wilkinson & 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.

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
	$LSD_{(0.05\ level)}$: 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
	$LSD_{(0.05\ level)}$: CS = 17.5, Tillage = 12.6, CS x Tillage = 25.0		

LSD = least significant difference; CS = Cropping system.

3.4 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, for Msekera site). 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. Generally, soils with a bulk density higher than 1.6 g cm^{-3} are considered to restrict root growth (Cresswell and Hamilton (2002). 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 (October 2000) was lowest in maize planted after natural fallow (1.27 gcm^{-3}) and highest under maize monoculture with fertilizer (1.62 gcm^{-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 cropping treatments. 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 impended 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.

3.5 Maize Grain Yields

At Chadiza site, there was no interaction between cropping 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 cropping system 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 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 & Sharma, 1994).

At Msekera, in both 2000/2001 and 2001/2002 seasons, maize yields were significantly different ($P<0.05$) among the cropping and tillage practices. No interaction between cropping 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 et al. (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/disease outbreaks (Sileshi, personal communication, Chitedze Research Station, Zambia).

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.

3.6 Dry Weed Biomass

Significant differences ($P<0.05$) were observed in weed infestation among the cropping systems and the tillage practices at fallow clearance and at the two weeding times (Table 7). 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 2001/2002 season. The low weed infestation under Sesbania cropping system at fallow clearance could be attributed to its ability to suppress weeds in relation to other fallow systems. These results conform to Sileshi and Mafongoya (2003) findings under similar conditions. Significant difference in weed biomass was recorded for cropping system and tillage practice at 2 and 7 WAP (Table 7). Higher weed infestation occurred under natural fallow for zero tillage practice, compared to other cropping systems during the first and second weedings. Similarly, total weed biomass was also significantly affected by cropping system 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 (Rao, 1983). Böhringer (1991) reported that mulch morphology plays an important role in controlling weeds and facilitating hand hoe weeding.

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 2WAP			
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		
Weeds at 7WAP			
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.

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.

3.7 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 cropping systems 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, planting and two weeding in one season under different cropping systems 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.

4. Conclusions

This study illustrates the various tillage practices and their implication on labour in relation to maize production under different fallowing systems in smallholder farms. 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 cropping systems. 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.

References

Acharya, C. L., & Sharma, P. D. (1994). Tillage and mulch effects on soil physical environment, root growth, nutrient uptake and yield of maize and wheat on an Alfisol in north-west India. *Soil and Tillage Research, 32*(4), 291-302. http://dx.doi.org/10.1016/0167-1987(94)00425-E

ACT, C., & FAO, R. GTZ (2003) Conservation Agriculture, The future for Africa.

Addati, L., & Cassirer, N. (2008). *Equal sharing of responsibilities between women and men, including care giving in the context of HIV/AIDS*. Paper prepared for the Expert Group meeting on the equal sharing of responsibilities between women and men, including care giving in the context of HIV/AIDS, organized by the United Nations Division for the Advancement of Women, Geneva.

Anderson, J. M., & Ingram, J. S. I. (1993). *Tropical Soil Biology and Fertility: A Handbook of Methods* (2nd ed., p. 221). CAB International, Wallingford, UK.

Arora, V. K., Gajri, P. R., & Prihar, S. S. (1991). Tillage effects on corn in sandy soils in relation to water retentivity, nutrient and water management, and seasonal evaporativity. *Soil and Tillage Research, 21*(1), 1-21. http://dx.doi.org/10.1016/0167-1987(91)90002-F

Bilalis, D., Papastylianou, P., Konstantas, A., Patsiali, S., Karkanis, A., & Efthimiadou, A. (2010). Weed-suppressive effects of maize–legume intercropping in organic farming. *International Journal of Pest Management, 56*(2), 173-181. http://dx.doi.org/10.1080/09670870903304471

Böhringer, A. (1991). The potential of alleycropping as a labor efficient management option to control weeds: A hypothetical case. *Der Tropenlandwirt-Journal of Agriculture in the Tropics and Subtropics, 92*(1), 3-12.

Bouwer H. (1986). Intake rate: cylinder infiltrometer. In *Methods of soil analysis, part I. Physical and mineralogical methods. Agronomy Monograph no. 9* (2nd ed.). American Society of Agronomy, Soil Science Society of America.

Capinera, J. L. (2005). Symposium: Relationships between insect pests and weeds: an evolutionary perspective. *Weed Science, 53*, 892-901. http://dx.doi.org/10.1614/WS-04-049R.1

Chauhan, B. S., Singh, R. G., & Mahajan, G. (2012). Ecology and management of weeds under conservation agriculture: a review. *Crop Protection, 38*, 57-65. http://dx.doi.org/10.1016/j.cropro.2012.03.010

Chintu, R. (2004). Subsoil nitrogen dynamics as affected by planted coppicing tree legume fallows. *Experimental Agriculture, 40*, 327-340. http://dx.doi.org/10.1017/S0014479704001826

Cresswell, H. P., & Hamilton. (2002). Particle Size Analysis. In N. J. McKenzie, H. P. Cresswell, & K. J. Coughlan (Eds.), *Soil Physical Measurement and Interpretation for Land Evaluation* (pp. 224-239). CSIRO Publishing: Collingwood, Victoria.

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communication in Soil Science and Analysis, 32*, 1221-1250. http://dx.doi.org/10.1081/CSS-100104110

Diana, G., Beni, C., & Marconi, S. (2008). Organic and mineral fertilization: Effects on physical characteristics and boron dynamic in an agricultural soil. *Communications in Soil Science and Plant Analysis, 39*, 1332-1351. http://dx.doi.org/10.1080/00103620802004037

Dorich, R. A., & Nelson, D. W. (1984). Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soil. *Soil Science Society of America Journal, 48*, 72-75. http://dx.doi.org/10.2136/sssaj1984.03615995004800010013x

Fageria, N. K., Baligar, V. C., & Bailey, A. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in Soil Science and Plant Analysis, 36*, 2733-2757. http://dx.doi.org/10.1080/00103620500303939

FAO. (1988). Soil Map of the World-Revised Legend. *World Soil Resources Report* 60 FAO/UNESCO, Rome.

Good, A. G., & Beatty, P. H. (2001). Fertilizing Nature: A Tragedy of Excess in the Commons. *PLoS Biology, 9*, 8.

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley and Sons Inc., New York.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research, 114*, 23-34. http://dx.doi.org/10.1016/j.fcr.2009.06.017

Hamza, M. A., & Anderson, W. K. (2005). Soil compaction in cropping systems a review of the nature, causes and possible solutions. *Soil Tillage Research, 82*, 121-145. http://dx.doi.org/10.1016/j.still.2004.08.009

Juo, A. S. R., Franzluebberrs, K., Dabiri, A., & Ikhile, B. (1996). Soil properties and crop performance on a kaolinitic Alfisol after 15 years of fallow and continuous cultivation. *Plant and Soil, 180*, 209-217. http://dx.doi.org/10.1007/BF00015304

Karki, T. B., & Shrestha, T. (2014). Maize production under no-tillage system in Nepal. *World Journal of Agricultural Research, 2*, 13-17. http://dx.doi.org/10.12691/wjar-2-6A-3

Khant, G. (1971). Changes in N, P, K and C in three soil types after 5 year minimum cultivation. *Landwirtsch Forsch Sonderh, 26*, 273-280.

Klingman, D. L. (1971). Measuring weed density in crops. In L. Chiarappa (Ed.), *Crop Loss Assessment Methods*. 3.1.5/1-3.1.5/6. FAO, Rome.

Kostiakov, A. N. (1932). On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. *Transactions of the sixth committee International Society of Soil Science*, Russian Part A: 17-21.

Kwesiga, F., Franzel, S., Mafongoya, P., Ajayi, O., Phiri, D., Katanga, R., ... Chirwa, T. (2005). Improved Fallows in Eastern Zambia: History, Farmer Practice and Impacts. A paper prepared for the IFPRI Workshop on "Successes in African Agriculture," Lusaka, Zambia, June 10-12, 2002

Kwesiga, F., Phiri, D., Mwanza, S., & Simwanza, P. C. (1995). Zambia/ICRAF Agroforestry Research Project. Annual Report. Chipata, Zambia. 80

Landers, J. N., Saturnino, H. M., & de Freitas, P. L. (2002). Organizational and Policy Considerations in Zero Tillage, in Saturnino H M and Landers J N (eds) *The Environment and Zero Tillage*, Brazil: Associacao de Plantio no Cerrado, Brasilia

Liu, X., Herbert, S. J., Hashemi, A. M., Zhang, X., & Ding, G. (2006). Effects of agricultural management on soil organic matter and carbon transformation – a review. *Plant Soil and Environment, 52*, 531-543.

Mandal, B. K., Saha, A., Dhara, M. C., & Bhunia, S. R. (1994). Effects of zero and conventional tillage on winter oilseed crop in West Bengal. *Soil Tillage Research, 29*, 49-57. http://dx.doi.org/10.1016/0167-1987(94)90101-5

Mader, P., & Berner, A. (2011). Development of reduced tillage systems in organic farming in Europe. *Renewable Agriculture and Food Systems, 27*, 7-11. http://dx.doi.org/10.1017/S1742170511000470

Mafongoya, P. L., & Bationo, A. (2006). Appropriate available technologies to replenish soil fertility in southern Africa. *Nutrient Cycling in Agroecosystems, 76*, 137-151. http://dx.doi.org/10.1007/s10705-006-9049-3

Mafongoya, P. L., Katanga, R., Mkonda, A., Chirwa, T. S., Chintu, R., & Matibini, J. (1999). Zambia/ICRAF Agroforestry Research Project, Annual Report. Chipata, Zambia, pp 55 -65

Mariki, W. (2003). The Impact of Conservation Tillage and Cover Crops on Soil Fertility and Crop Production in Karatu and Hanag Districts of Northern Tanzania, TFSC/GTZ Technical Report for 1999 – 2003, Arusha: TFSC

Matusso, J. M. M., Mugwe, J. N., & Mucheru-muna, M. (2014). Potential role of cereal-legume intercropping systems in integrated soil fertility management in smallholder farming systems of Sub-Saharan Africa. *Journal of Agriculture and Environmental Management, 3*, 162-174.

Murungu, F. S. (2012). Conservation Agriculture for smallholder farmers in the Eastern Cape Province of South Africa: recent developments and future prospects. *African Journal of Agricultural Research, 7*, 5278-5284.

Murungu, F. S., Chiduza, C., & Muchaonyerwa, P. (2010). Biomass accumulation, weed dynamics and nitrogen uptake by winter cover crops in a warm-temperate region of South Africa. *African Journal of Agricultural Research, 5*, 1632-1642.

Okonkwo, C. I., Mbagwu, J. S. C., & Egwu, S. O. (2008). Nitrogen Mineralization from Prunings of Three Multipurpose Legume and Maize Uptake in Alley Cropping System. *Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension, 7*, 143-148. http://dx.doi.org/10.4314/as.v7i2.1596

Rao, V. S. (1983). *Principles of Weed Science* (p. 540). Oxford University Press and IBH, Oxford.

Rasaily, G., & Xiaodong, Q. (2012). Development Strategies of small scale conservation farming practices on two wheeled tractor in Bangladesh. *African Journal of Agricultural Research, 7*, 3747-3756.

SAS Institute. (1996). *SAS/STAT*, Release 6.12 SAS Institute Inc., Cary, NC.

Sileshi, G., & Mafongoya, P. L. (2003). Effect of rotational fallows on abundance of soil insects and weeds in maize crops in eastern Zambia. *Applied Soil Ecology, 23*, 211-222. http://dx.doi.org/10.1016/S0929-1393(03)00049-0

Sileshi, G., Kuntashula, E., & Mafongoya, P. L. (2006). Effects of improved fallows on weed infestation in maize in eastern Zambia. *Zambian Journal of Agricultural Science, 8*, 6-12.

Singh, H. P., Batish, D. R., & Kohli, R. K. (2003). Allelopathic Interactions and allelochemicals: new possibilities for sustainable weed management. *Critical Reviews in Plant Sciences, 22*, 239-311. http://dx.doi.org/10.1080/713610858

Sjogren, S., Keith, D., & Karlesson, A. (2010). Effect of Improved fallows with *Sesbania sesban* on maize productivity and *Striga hermonthica* in western Kenya. *Journal of Forestry Research, 21*, 379-386. http://dx.doi.org/10.1007/s11676-010-0085-0

USDA. (1975). *Soil Taxonomy, agricultural handbook number* 436, Soil Conservation Service, USA.

Vencill, W. K., Nichols, R. L., Webster, T. M., Soteres, J. K., Mallory-Smith, C., Burgos, N. R., ... McClelland, M. R. (2012). Herbicide resistance: toward an understanding of resistance development and the impact of herbicide resistant crops. *Weed Science (Special Issue), 60*, 2-30. http://dx.doi.org/10.1614/ws-d-11-00206.1

Vogel, H. (1994). Weeds in single-crop conservation farming in Zimbabwe. *Soil Tillage Research, 31*, 169-185. http://dx.doi.org/10.1016/0167-1987(94)90078-7

Wilkinson, G. E., & Aina, P. O. (1976). Infiltration of water into two Nigerian soils under secondary forest and subsequent arable cropping. *Geoderma, 50*, 51-59. http://dx.doi.org/10.1016/0016-7061(76)90070-7

Zaviehmavadat, L., Mazaheri, D., Majnon, H. N., & Rezaei, M. (2013). The effect of Maize and Cowpea Intercropping on weed control condition. *International Journal of Agronomy and Plant Production, 4*, 2885-2889.