Tropical and Subtropical Agroecosystems, 19 (2016): 167 - 179

EFFECTS OF TILLAGE AND CROPPING SYSTEMS ON MAIZE AND BEANS YIELD AND SELECTED YIELD COMPONENTS IN A SEMI-ARID AREA OF KENYA

[EFECTO DE LA LABRANZA Y SISTEMA DE CULTIVO EN LA PRODUCCIÓN DE MAÍZ Y FRÍJOL EN UNA REGIÓN SEMI ÁRIDA DE KENIA]

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SUMMARY

Conservation of soil moisture through tillage practices is an important management objective for crop production in semi-arid areas. A study to evaluate the effects of tillage practices on maize and bean yields was conducted in Mwala Sub County, Eastern Kenya, in the long (LR) and short rains (SR) of 2012/13. The tillage treatments were: Disc Ploughing (DP), Disc Ploughing and Harrowing (DPH), Ox-ploughing (OX), Subsoiling – Ripping (SSR), Hand hoeing with Tied Ridges (HTR) and Hand hoeing (H) only. There were three cropping systems of Sole Maize (SM), Sole Bean (SB) and Maize - Bean intercrop (M + B), which were investigated in a Split-Plot Design field experiment with four replications. Data on maize and bean yield and yield components were monitored throughout the four cropping seasons. Maize plant height, leaf area and leaf area index, maize and beans grain and biomass yields were significantly affected by tillage ($P < 0.05$). No significant effect of cropping systems on the maize height was observed. Higher maize grain yields ($P < 0.05$) were obtained in the sole maize plots in LR 2012 (5.01 Mg ha^{-1}), SR 2012 (4.19 Mg ha^{-1}) and in the SR 2013 season (2.82 Mg ha^{-1}). A three - season bean grain yield average by tillage shows that DPH > SSR > DP > OX > HTR > H, with values ranging from 0.75 Mg ha^{-1} to 1.46 Mg ha^{-1} ($P < 0.05$). Intercropping reduced the seasonal means of bean grain yields ($P < 0.05$) with a 54 % decrease by intercropping (0.73 Mg ha^{-1}) compared to the sole bean (1.6 Mg ha^{-1}). Thus, the DP and DPH improved crop yield and yield components and can be recommended as tillage practices in the semi-arid region.

Key words: tillage; cropping systems;maize and bean yields; semi-arid areas

RESUMEN

La conservación de la humedad del suelo a través de las prácticas de labranza es un objetivo importante para la gestión de la producción agrícola en zonas semiáridas. Un estudio para evaluar los efectos de las prácticas de labranza sobre los rendimientos de maíz y frijol se llevó a cabo en Mwala Sub Condado, en el Este de Kenia, en el período de lluvias largo (LR) y corto (SR) de 2012/13. Los tratamientos de labranza fueron: disco de arado (DP), discos de arado y desgarradora (DPH), arado con buey (OX), Subsolado - quebrado (SSR), manual con la azada de atada (HTR) y manual con azada (H) solamente. Había tres sistemas de cultivo de maíz sólo (SM), fríjol sólo (SB) y el maíz - frijol intercalado (M + B), que fueron investigados en un experimento de campo de diseño de parcela dividida con cuatro repeticiones. Los datos sobre el rendimiento y sus componentes del maíz y frijol y fueron evaluados durante las cuatro estaciones de cultivo. Los rendimientos, altura de la planta de maíz, el área foliar y el índice de área foliar, producción de granos de maíz y frijol y biomasa se vieron afectados por la labranza (P <0.05). No se observó ningún efecto de los sistemas de cultivo en la altura de maíz. Los mayores rendimientos de grano de maíz (P <0.5) fueron obtenidos en las parcelas de maíz en LR 2012 (5.01 Mg ha-1), SR 2012 (4.19 Mg ha-1) y en la temporada SR 2013 (2.82 Mg ha-1). El rendimiento medio de las tres estaciones ajustado por el tipo de labranza muestra que DPH> RSS> DP> OX> HTR> H, con valores que van de 0.75 Mg ha^{-1} hasta 1.46 Mg ha^{-1} ($P < 0.05$). El cultivo intercalado redujo la medias estacionales de los rendimientos de grano de frijol ($P < 0.05$), con una reducción del 54% en el cultivo intercalado (0.73 Mg ha^{-1}) en comparación con el grano de frijol sólo (1.6 Mg ha-1). Por lo tanto, la DP y DPH mejoraron los componentes del rendimiento y rendimiento de los cultivos y pueden ser recomendados como las prácticas de labranza en la región semi-árida.

Palabras clave: labranza; sistemas de cultivo; los rendimientos de maíz y frijol; zonas semiáridas

INTRODUCTION

In Sub-Saharan Africa (SSA), rainfed agriculture plays a critical role in food security at the national and household levels, but is characterized by low crop yields (Cooper *et al.*, 2008). Much of the population in SSA cultivate maize (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.), which rank first and second in importance as staple food (CIMMYT, 2003). Intercropping of maize and beans is a common practice in East Africa and Kenya in particular. The importance of intercrops arises from the stabilizing effect of the crops on food security, enhanced efficiency of the use of land, water and labour. Intercropping also helps in risk aversion in case of crop failure, soil conservation and improvement of soil fertility, weed control and provide balanced human nutrition (Lithourgidis *et al.*, 2011; Odendo *et al.*, 2011; Belel *et al.*, 2014).

A yield advantage in species mixture may occur when intercropped crops differ in use of growth resources when they are grown together and are able to complement each other than when grown separately (Mucheru - Muna *et al.*, 2011; Lithourgidis *et al.*, 2011). Other advantages of intercropping as cited by Matusso *et al.* (2012) and Belel *et al.* (2014) include higher total yields than sole crop yields, greater yield stability, more efficient use of nutrients and better weed control. Cereal as a sole crop requires a larger area to produce the overall yields achieved in an intercropping system. However, the efficient use of basic resources in a given intercropping system depends partly on the inherent efficiency of the individual crops that make up the system and partly on complementary effect between the crops (Ijoyah, 2012).

Despite the importance of maize and beans in Kenya, their yields have remained low in the arid and semi-arid areas. The low yields have been attributed to low and poorly distributed rainfall, high evapotranspiration rates, low and declining soil fertility, mismatching of varieties and agro-climatic zones and poor, ineffective and unsustainable land-use and crop management practices (Mburu *et al.*, 2011; Kutu, 2012). The average maize yield is about 2 Mg ha^{-1} and beans less than 1 Mg ha^{-1}; with potential yields of over 6 Mg ha^{-1} and 2 Mg ha^{-1}, respectively. These potential yields can be achieved through the use of improved seed, optimal fertilizer rates and recommended crop husbandry practices (Government of Kenya [GoK], 2010; Mburu *et al.*, 2011).

Maize and bean in Eastern Kenya is produced under rainfed conditions where the rainfall is usually inadequate, short in duration, poorly distributed and highly variable between and within seasons (Wamari *et al.*, 2012). Although there has been an increase in their production due to expansion of cultivated land into marginal areas, productivity per unit area of land has continued to decline. These low yields have been attributed to low soil fertility, periodic water stress, diseases and pests (Katungi *et al.*, 2010). Therefore, intercropping may help improve productivity of low external input farming, a characteristic of smallholder farmers, who depend largely on natural resources such as rainfall and soil fertility. Thus, the choice of crop cultivars and hence agronomic manipulations to certify the most effective use of limiting resources is critical for high crop yields.

Conservation of soil moisture through tillage practices is an important management objective for crop production in semi-arid areas. Identification of the best tillage methods that not only improve rainwater infiltration but also conserve adequate soil moisture for plant growth is imperative (Cornelis *et al.*, 2013). Tillage in the predominately maize-based cropping systems on small farms in Mwala Sub County Kenya is mostly manual, using ox ploughs and the handhoe. Tillage – based conventional agriculture is assumed to have led to soil organic matter decline, water runoff, soil erosion and other manifestations of physical, chemical and biological soil degradation (Thierfelder and Wall, 2009). On the other hand, conservation tillage practices such as tied ridging, subsoiling and ripping have the potential of soil moisture retention and mitigation of intra-seasonal dry spells (Manyatsi *et al.*, 2011).

Conservation tillage also conserves available rainwater which is otherwise lost in the magnitude of 70 to 85 % of rainfall in Sub Saharan Africa, through soil evaporation and through deep percolation and surface run-off hence makes it beneficial to the crops (Cornelis *et al.,* 2013).

Although conservation tillage is highly encouraged, there is strong evidence that this kind of tillage may not be good for soils prone to surface crusting and sealing, a characteristic for most of the soils in the semi-arid areas of Kenya (Gitau *et al.,* 2006; Mujdeci *et al.,* 2010; Giller *et al.,* 2011). Therefore, the local biophysical conditions in the smallholder farming systems in these semi-arid areas need to be considered and deliberate adaptation efforts made. With this background, this study was conducted in semi-arid Mbiuni Location, Mwala Sub County, Eastern Kenya, to evaluate the effects of tillage and cropping systems on maize and bean yields and yield components.

MATERIALS AND METHODS

Study site description

This study was conducted in Mbiuni Location, Mwala Sub County, Kenya (1˚15'S, 37˚ 22'E). The area is characterized by low, erratic and poorly distributed bimodal rainfall that makes crop production difficult under rain fed conditions. The long rains commence in mid-March and end in May while short rains start in mid-October and end in late November. Mid-season drought spells commonly occur in both seasons and pose a risk to crop production. The mean annual rainfall for Mwala Sub County is 596 mm (Ngugi *et al.,* 2011). Soil chemical and physical properties at the experimental site are shown by Table 1. The composite soils were analysed using standard methods as outlined in Okalebo *et al.* (2002). Some chemical properties at the site indicate that initial soil N (0.12 %) and P (< 15 mg/kg) were very low. The soils had low organic carbon content (< 2 %). The CEC was low (< 12 cmol/kg) indicating low nutrient retention capacity (Gachene and Kimaru, 2002).

Experimental design and layout

A field experiment was established in 2012 and ran for four cropping seasons during the long (LR) (March - May) and short rains (SR) (October – December) (i.e. LR 2012, SR 2012, LR 2013, SR 2013). The treatments consisted of six tillage practices: Disc Ploughing (DP), Disc Ploughing and Harrowing (DPH), Ox-ploughing (OX), Hand hoeing with Tied Ridges (HTR), Hand hoeing (H) only and Subsoiling – Ripping (SSR). The cropping systems treatments were Sole Maize (SM), Sole Bean (SB) and Maize - Bean intercrop (M + B). The treatments were arranged in a Split-Plot Design with tillage practices as the main plots and the cropping system as the sub plots, with four replications.

Crop management

A dryland maize variety (DH 02) and beans (rose coco - GLP 2) were used as the test crops. These crops were planted in rows in 25 m^2 plots. Maize was planted at a spacing of 90 × 30 cm in pure stands with the sole bean plants planted at a spacing of 45 × 15 cm. In the intercropping plots, the beans were at a spacing of 90 × 15 cm, grown between the maize rows. In the tied ridging plots, maize and beans were planted in the same row spacing but in alternating hills. Thinning to a single plant per hill for maize and two plants for the legume was done four weeks after germination. In each cropping system, nitrogen and phosphorus were applied to maize at 60 kg N ha^{-1} and 65 kg P_20_5 ha^{-1} (DAP 18:46:0) at planting and additional 60 kg N ha^{-1} (CAN 26:0:0) was top dressed at 4 weeks after planting (WAP). The bean seeds were inoculated with Bio-Fix© biofertilizer before sowing. All plots were hand-weeded using a handhoe as is usually practised by the farmers.

Crop measurements

In order to assess crop growth, the following maize growth parameters were collected: maize plant height, maize stover yield and maize grain yield. Maize plant height was measured periodically (different weeks after planting) throughout the growing season from the ground level to the uppermost full extended leaf and to the tip of the tassel after tasselling, using measuring tape. Maize leaf area was estimated by length multiplied by maximum width and multiplied by 0.75, which is the maize calibration factor (Elings, 2000). Five measurements of each of the parameters was taken and then averaged and the corresponding leaf area index (LAI) computed. The LAI was computed by dividing the total leaf area of a maize plant stand by the total land area occupied by the single stand (Mauro *et al.,* 2001). Final crop biomass and grain yields were determined from plants harvested in a sample area of 2 × 2 m at the centre of the plot. Harvesting of maize was done after the crops were dry in the field and fresh biomass was measured on site. The yields were calculated based on the mean experimental plot area and later adjusted to metric tons per hectare (tonnes/ha = Mg ha^{-1}).

Table 1. Baseline chemical and physical properties of the experimental site (0 - 30 cm) in Mbiuni Location, Mwala Sub County

Soil property	Value	Soil property	Value
pH (H_2O)	6.50	Sand (%)	22.00
pH (0.01M $CaCl_2$)	5.61	Silt (%)	39.00
Organic Carbon %	1.10	Clay (%)	39.00
Total Nitrogen %	0.09	Textural Class	Clay loam
Potasium (K) (cmol/kg)	2.35	Bulk density (Mg m^{-3})	1.27
Sodium (Na) (cmol/kg)	0.46	Saturated hydraulic conductivity (Ksat) (cm/h)	0.27
Calcium (Ca) (cmol/kg)	2.31	Saturation (cm/cm^3)	0.664
Magnesium (Mg) (cmol/kg)	0.39	Field capacity (cm/cm^3)	0.508
CEC (cmol/kg)	6.70	Wilting point (cm/cm^3)	0.480
Phosphorus (P) (mg/kg)	13.50	Plant available water (cm/cm^3)	0.028

CEC = Cation Exchange Capacity

Statistical analysis

Yield and yield components data were subjected to analysis of variance (ANOVA) using Genstat 14th Edition statistical software (Genstat, 2011). Mean separation was done using LSD at 5 % level of probability where the *F*-values were significant.

RESULTS

Crop yields and yield components

Maize height

The average plant height increased ($P < 0.05$) with time within the different treatments (Table 2). When the maize height at different weeks after planting was averaged for four seasons, there were differences ($P < 0.05$) observed of time, tillage and season. Other interactions observed were time × tillage, time × cropping system and time and season ($P < 0.05$).

Plant height increased progressively and was influenced by the tillage treatment and the cropping system in each season. The sole maize maintained taller plants at the various WAP within the seasons, with a 2.6 % height decrease due to intercropping noted. No differences in maize height due to cropping systems ($P = 0.853$) were observed for the four seasons. The average trend of plant height observed across tillage practices was DPH > DP > H > OX > SSR > HTR.

Maize leaf area and leaf area index (LAI)

Time series data show that maize leaf area and LAI were influenced by season and tillage ($P < 0.05$) (Table 3 and 4). There was also a tillage and time effect observed ($P < 0.05$). A three - season average (SR 2012, LR 2013 and SR 2013) shows a mean trend of leaf area and LAI in different tillage at DPH > DP > SSR > H > OX > HTR. Cropping systems also affected the leaf area and LAI ($P < 0.05$), with sole maize having higher values of LAI and leaf area values at 1.55 and 0.46 m^2 compared to 1.48 and 0.45 m^2 for the intercrop, respectively.

Maize grain and biomass yields

Maize grain yield was affected ($P < 0.05$) by season, tillage and cropping system (Figures 1 and 2). A significant cropping system and season interaction ($P < 0.05$) was also observed. This interaction shows that the average maize grain yields obtained were differentially influenced by the cropping system within a season. Higher grain yields were obtained in the sole maize plots in LR 2012 (5.01 Mg ha^{-1}), SR 2012 (4.19 Mg ha^{-1}) and in the SR 2013 season (2.82 Mg ha^{-1}). There was a 3.6 % increase in yields in the intercropping systems as compared to the sole maize in the LR 2013 season.

The seasonal means of maize grain yields were 4.78 Mg ha^{-1} (LR 2013), 3.77 Mg ha^{-1} (SR 2012), 2.16 Mg ha^{-1} (LR 2013) and 2.78 Mg ha^{-1} in the SR 2013 season (Figure 1). The four - season mean maize grain yields were also reduced by 10.1 % (from 3.48 - 3.13 Mg ha^{-1}) by the intercropping system. In the SR 2012 season, the OX and SSR plots maintained high moisture levels throughout the season but gave the lowest maize grain yields (3.3 Mg ha^{-1} and 3.37 Mg ha^{-1}, respectively). Low yields in the HTR plots (1.81 Mg ha^{-1}) were obtained in LR 2013. A four - season average grain yield show a tillage trend of DPH > DP > H > OX > HTR > SSR, with values ranging from 2.9 Mg ha^{-1} to 3.8 Mg ha^{-1} ($P < 0.05$). This shows that conventional tillage favored maize grain yields in Mwala Sub County.

Table 2. Maize plant height (cm) as affected by tillage practices, cropping systems, time of measurement and seasons in Mbiuni Location, Mwala Sub County

Tillage (T)	Long rains 2012			Short rains 2012		Long rains 2013		Short rains 2013
	4 WAP	6 WAP	9 WAP	5 WAP	7 WAP	4 WAP	6 WAP	4 WAP
H	72.90ab	140.80b	173.90b	60.96bc	129.10abc	48.44bc	84.10bc	34.14a
HTR	67.80a	126.00a	157.70a	56.29a	119.00a	41.49a	71.10a	36.14ab
MB	74.70b	147.20bc	176.20bc	60.50abc	132.60bc	48.12bc	88.90c	35.88ab
MBH	78.90b	152.10c	182.20c	62.58bc	126.90abc	48.88bc	90.60c	34.12a
OX	75.60b	146.10bc	171.30b	59.33ab	124.10ab	45.32ab	75.60ab	38.14b
SSR	-	-	-	64.16c	135.80c	50.20c	86.80c	37.09ab
Mean	74.00	142.40	172.30	25.02	127.90	47.08	82.08	35.92
Cropping systems (C)								
SM	72.40	144.20	174.70	61.88	134.10	47.91	83.40	36.16
M+B	75.60	149.20	169.80	59.39	121.70	46.24	82.20	35.67
LSD (5%)	5.31	8.65	8.17	3.23	6.70	2.19	5.12	2.56
Significance levels								
T	0.04	<.001	<.001	0.03	0.045	0.01	0.01	0.07
C	0.23	0.39	0.22	0.12	0.001	0.13	0.64	0.69
T × C	0.23	0.11	0.92	0.49	0.512	0.15	0.34	0.54
CV %	4.0	2.5	1.4	4.5	0.5	9.9	11.1	7.5

Tillage: H = Hand hoeing, HTR = Hand hoeing with Tied Ridges, DP = Disc Ploughing, DPH = Disc Ploughing + Harrowing, OX = Ox-ploughing, SSR = Subsoiling - Ripping, (-) = not measured in that season, WAP = Weeks after Planting, Different letters within the columns indicate significant difference at 5 % probability level.

Table 3: Maize leaf area (m^2) as affected by tillage practices, cropping systems and seasons in Mbiuni Location, Mwala Sub County

Tillage (T)	Maize leaf area (m^2)								
	Short rains 2012			Long rains 2013			Short rains 2013		
	3 WAP	5 WAP	7 WAP	4 WAP	6 WAP	10 WAP	2 WAP	8 WAP	12 WAP
H	0.076	0.051	0.764	0.2564bc	0.5432b	0.661ab	0.1279	0.529	0.592
HTR	0.068	0.431	0.668	0.2011a	0.4453a	0.512a	0.1464	0.552	0.605
DP	0.071	0.465	0.735	0.2944c	0.5626b	0.613a	0.1684	0.638	0.725
DPH	0.067	0.439	0.698	0.2989c	0.6629b	0.775b	0.1366	0.608	0.691
OX	0.073	0.458	0.713	0.2386bc	0.4869ab	0.542a	0.1561	0.615	0.708
SSR	0.077	0.521	0.730	0.279bc	0.5503b	0.628a	0.1467	0.620	0.678
LSD (5%)	0.0098	0.0591	0.0652	0.0465	0.0866	0.1360	0.0327	0.1086	0.1078
Cropping systems (C)									
SM	0.074	0.500	0.747	0.265	0.547	0.638	0.145	0.592	0.672
M+B	0.070	0.441	0.689	0.258	0.534	0.605	0.149	0.595	0.661
LSD (5%)	0.0053	0.0413	0.0427	0.0263	0.0343	0.0534	0.0126	0.0452	0.0493
Significance levels									
T	0.238	0.027	0.092	0.003	0.003	0.013	0.190	0.274	0.087
C	0.078	0.008	0.011	0.597	0.435	0.205	0.454	0.886	0.635
T × C	0.054	0.440	0.326	0.101	0.100	0.388	0.861	0.356	0.107
CV %	7.3	3.1	3.4	11.3	8.6	7.4	11.8	10.5	7.6

Tillage: H = Hand hoeing, HTR = Hand hoeing with Tied Ridges, DP = Disc Ploughing, DPH = Disc Ploughing + Harrowing, OX = Ox-ploughing, SSR = Subsoiling - Ripping, **Cropping systems**: SM = Sole Maize, M + B = Maize - Bean intercrop, Different letters within the columns indicate significant difference at 5 % probability level.

Table 4. Maize leaf area index (LAI) as affected by tillage practices, cropping systems and seasons in Mbiuni Location, Mwala Sub County

	Maize leaf area index (LAI)								
Tillage (T)	Short rains 2012			Long rains 2013			Short rains 2013		
	3 WAP	5 WAP	7 WAP	4 WAP	6 WAP	10 WAP	2 WAP	8 WAP	12 WAP
H	0.252	1.693	2.548	0.855bc	1.811b	2.202ab	0.426	1.765	1.972
HTR	0.228	1.437	2.227	0.670a	1.484a	1.707a	0.488	1.841	2.017
DP	0.235	1.549	2.448	0.981c	1.875b	2.044a	0.561	2.127	2.417
DPH	0.220	1.463	2.325	0.996c	2.176b	2.584b	0.455	2.028	2.304
OX	0.243	1.526	2.377	0.795bc	1.623ab	1.806a	0.520	2.051	2.361
SSR	0.256	1.738	2.433	0.93bc	1.834b	2.093a	0.489	2.067	2.262
LSD (5%)	0.0328	0.1970	0.2174	0.1550	0.2888	0.4532	0.1091	0.3619	0.3592
Cropping systems (C)									
SM	0.247	1.665	2.489	0.883	1.822	2.128	0.482	1.974	2.241
M+B	0.232	1.470	2.297	0.860	1.779	2.017	0.498	1.985	2.203
LSD (5%)	0.0177	0.1376	0.1422	0.0877	0.1124	0.1780	0.0420	0.1507	0.1643
Significance levels									
T	0.238	0.027	0.092	0.003	0.003	0.013	0.190	0.274	0.087
C	0.078	0.008	0.011	0.597	0.435	0.205	0.454	0.886	0.635
T × C	0.054	0.440	0.326	0.101	0.100	0.388	0.861	0.356	0.107
CV %	7.3	3.1	3.4	11.3	8.6	7.4	11.8	10.5	7.6

Tillage: H = Hand hoeing, HTR = Hand hoeing with Tied Ridges, DP = Disc Ploughing, DPH = Disc Ploughing + Harrowing, OX = Ox-ploughing, SSR = Subsoiling - Ripping, **Cropping systems**: SM = Sole Maize, M + B = Maize - Bean intercrop, Different letters within the columns indicate significant difference at 5 % probability level.

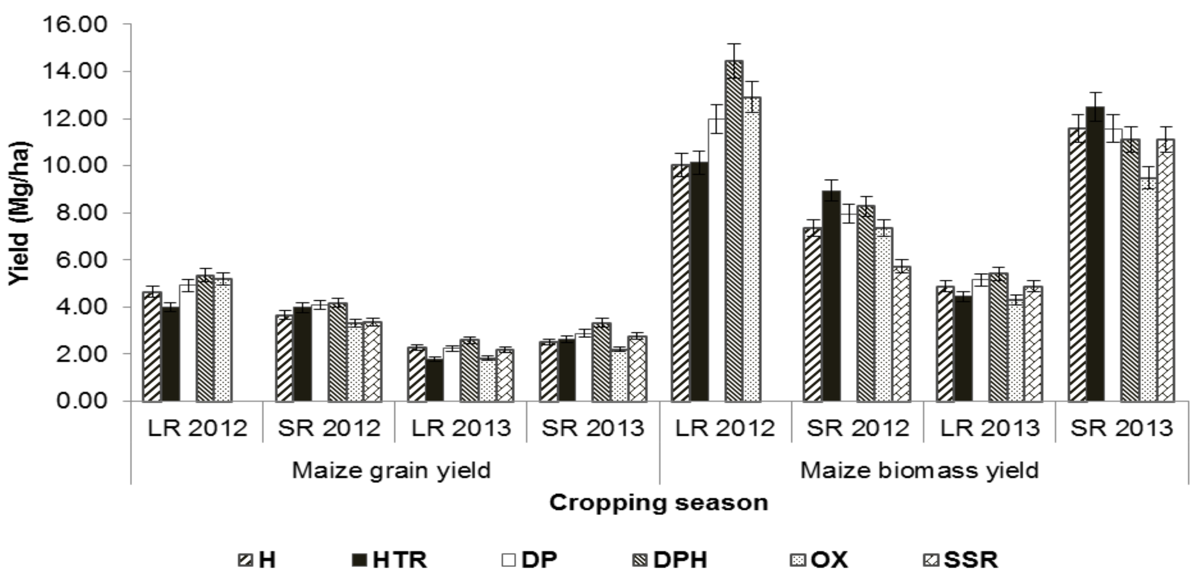

Figure 1. Maize grain and biomass yield as influenced by cropping season and tillage practices in Mbiuni Location, Mwala Sub County

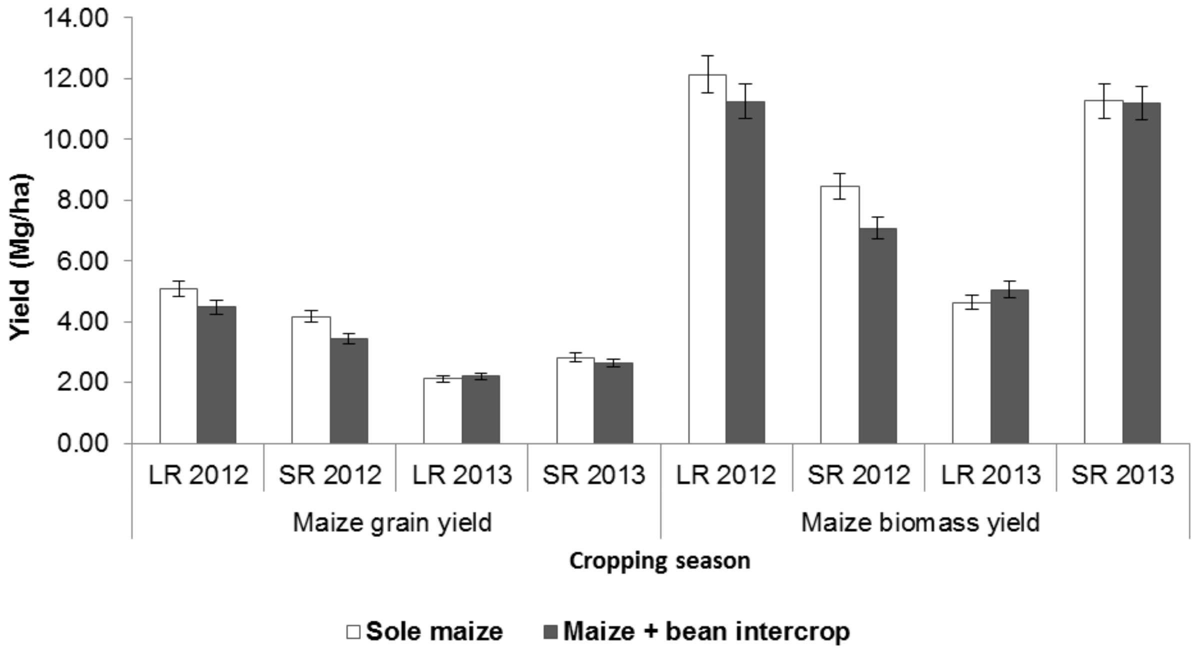

Figure 2. Maize grain and biomass yields as influenced by cropping season and cropping systems in Mbiuni Location, Mwala Sub County

Biomass yields were affected by season and tillage (Figure 1) and had a tillage × season interaction ($P < 0.05$). This interaction shows that the average biomass yields obtained were influenced by the tillage system within a season. The mean seasonal biomass yields were 11.7 Mg ha^{-1} (LR 2012), 7.8 Mg ha^{-1} (SR 2012), 4.9 Mg ha^{-1} (LR 2013) and 11.2 Mg ha^{-1}in SR 2013 (Figure 1). These yields differed significantly among the different tillage practices with a four-season biomass yield average of DPH > DP > HTR > OX > H > SSR.

Bean grain and biomass yields

Bean grain yields had ($P < 0.05$) differences by season and tillage (Figure 3). A season and tillage interaction and a cropping × season interaction ($P < 0.05$) were also observed. The interactions observed show that tillage and cropping systems differentially influenced the bean grain yields obtained within a cropping season. The mean seasonal grain yields were 0.74 Mg ha^{-1} in LR 2012, 1.28 Mg ha^{-1} in SR 2012 and 1.40 Mg ha^{-1} in SR 2013. No bean yield data were recorded in LR 2013 due to poor rainfall distribution and prolonged drier conditions in the growing season. The mean seasonal bean biomass yields were 1.53 Mg ha^{-1} in LR 2012, 3.81 Mg ha^{-1} in SR 2012 and 2.89 Mg ha^{-1} in SR 2013 (Figure 3). A three - season bean grain yield average by tillage shows that DPH > SSR > DP > OX > HTR > H with values ranging from 0.78 Mg ha^{-1} to 1.46 Mg ha^{-1} ($P < 0.05$). The bean biomass yields were also affected ($P < 0.05$) by intercropping (Figure 4) with sole bean producing a mean biomass yield of 3.70 Mg ha^{-1} as compared to 1.79 Mg ha^{-1} of the intercrop.

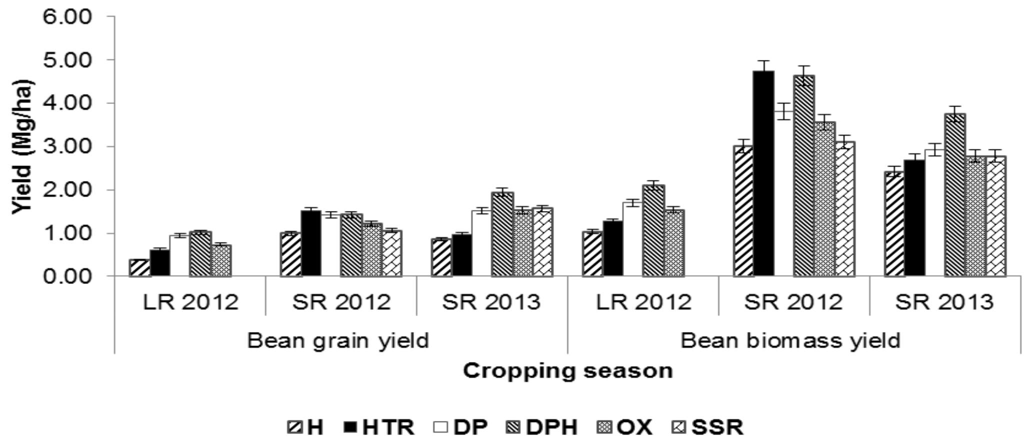

Figure 3. Bean grain and biomass yield as affected by cropping season and tillage practices in Mbiuni Location, Mwala Sub County

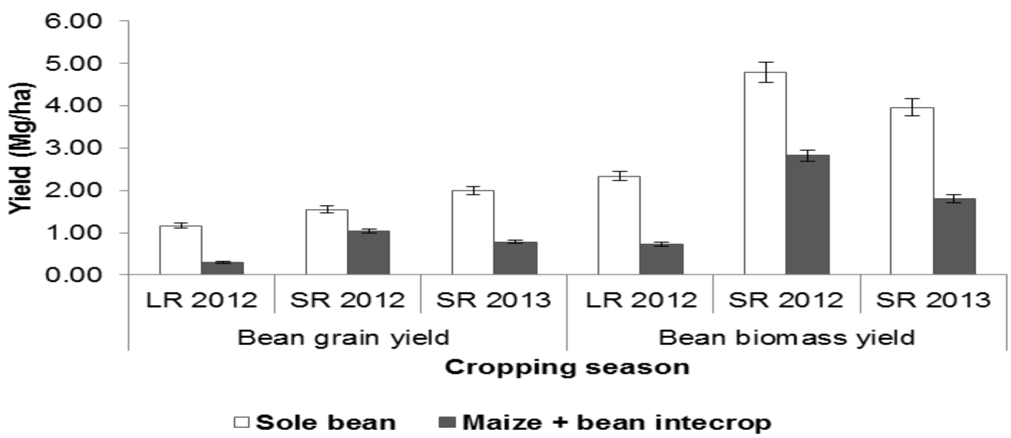

Figure 4: Bean grain and biomass yield as affected by cropping systems in Mbiuni Location, Mwala Sub County

DISCUSSION

Effect of tillage and cropping systems on crop performance

Maize height

The reduced pant height noted due to intercropping can be attributed to competition for soil moisture, nutrients and solar radiation in crop mixtures. Increasing soil loosening effects created by Disc Ploughing (DP/DPH) plots created an ideal seedbed condition which influenced the growth of the crop resulting in the tallest plants in all the seasons. Khurshid *et al.* (2006) in the semi-arid Faisalabad, Pakistan, found a mean increase in maize plant height of 11.28 % and 9.59 % in the case of conventional tillage (use of a rigger in ridge tillage) and deep tillage (use of a cultivator in deep tillage plots), respectively, over minimum tillage (dibbling) treatments. Plant height could be used as a measure of vegetative growth which sometimes is a reflection of the amount of moisture available to the crops.

Maize leaf area and leaf area index (LAI)

Conventional tillage practices favored the leaf area growth and LAI. These findings are similar to those observed by Carlesso *et al.* (2002) who reported higher LAI values in maize cultivated under conventional tillage and attributed that to improved access to soil moisture as compared to no-till. Thus, higher LAI results in better ground cover for lesser soil water evaporation and increased weed suppression (Sullivan, 2003). Therefore, the differences in maize LAI under the different tillage practices can also be attributed to the differences in exploration of the maize roots for soil moisture in the soil profile as was also observed by Javeed *et al.* (2014). On cropping systems, Bilalis *et al.* (2005) in Greece found that sole maize had the highest LAI (2.52) compared to maize intercropped with cowpea (2.12) and beans (2.44). They attributed it to the limiting effect to cereal-legume competition on leaf development in both species. On the other hand, higher LAI has also been reported with intercropping. Thobatsi (2009) working in Bethlehem, South Africa found a higher LAI of 2.23 under maize intercropped with a cowpea long duration cultivar. He attributed that to sufficient rainfall in that cropping season that stimulated leaf growth.

Maize grain and biomass yields

The decline in yields over the seasons was attributed to the rainfall distribution which varied in each growing season (Kenya Meteorological Department, [KMD], 2012 – 2014). Soil moisture content influences forms, solubility and accessibility of plant nutrients necessary for crop growth (Ampofo, 2006). According to Lobell and Asner (2003), management options are influenced by the prevailing weather conditions and explain about 30 % of year to year yield variability for major crops such as maize. These results are also supported by the findings of Vetsch and Randall (2004) in Minnesota, USA, who reported a significant effect of season on the grain yields of maize. Gwenzi *et al.* (2008) in a semi-arid region in Zimbabwe also observed that maize yields depended more on the maize genotype than on tillage systems, which they attributed to variations in seasonal rainfall distributions. Thus, a consideration of the effects of a given environmental situation e.g. rainfall variations on maize yields is crucial, in addition to the crop and soil management practices employed.

The yield reduction due to intercropping can be attributed to competition for moisture, nutrients and solar radiation associated with intercropping mixtures (Belel *et al.,* 2014). With the drier conditions experienced in LR 2013, intercropping thus offers an advantage in moisture-stressed environments. Intercropping increases canopy cover, thus reducing evaporation from soil surface (Belel *et al.,* 2014). Maize yield reduction in intercropped maize compared to the sole maize yields have been associated with interspecific competition in mixed stands and the absence of such competition in the monocrops (Vandermeer, 1989). Although yields of maize were lower in the maize-bean intercrop, the fact that two crops could be harvested in the same plot, compensated for the higher yields realized in the sole maize cropping system. The intercrop system may be better and preferable to the small scale farmers due to the dual purposes of ensuring food and nutritional security, as two crops are harvested in one season from the same land. The potential advantages of intercropping include over yielding by improved utilization of growth resources by the crop and improved reliability from season to season (Gitonga *et al.*, 2008; Lelei *et al.*, 2009; Odendo *et al.*, 2011).

The significant differences in the growth of maize among the different tillage practices show the sensitivity of maize to tillage treatments. High moisture levels maintained by OX and SSR in the SR 2012, did not translate to higher maize grain yields. Rockstrom *et al.* (2009) working in Kenya and Tanzania indicated higher maize yields with ripping compared to the conventional tillage, a contrast to this study. The increase in maize yields was attributed to the additional input of mulch which was not used in this study. Work done by Biamah and Nhlabathi (2003) in semi-arid Eastern Kenya, reported that subsoiling/ ridging increased maize grain yields by an average of 23 % and biomass yields by an average of 11 % as compared with yields under the conventional tillage. Although Pikul and Aase (2003) showed that infiltration was consistently greater under subsoiling compared to conventionally tilled plots with no subsoiling, the benefits of subsoiling in terms of maize growth and yield were not obvious in the present study.

On the low yields in the HTR plots obtained in LR 2013, Gicheru (1990) observed lower soil moisture and lower maize grain yields in tied ridges compared to the conventional tillage in western slopes of Mt Kenya during drier seasons. He attributed this to no runoff impounded and higher evaporation losses from soil due to increased soil surface area under tie-ridging. However, higher maize and bean yields in tied ridging have been reported by Gichangi *et al.* (2003) in the semi-arid highlands area of Central Kenya. Gebrekidan and Uloro (2002) in Alemaya, Eastern Ethiopia Highlands, found maize yield increments of 15 to 50 % due to tied ridges. Miriti (2010) working in Makueni Sub County, Kenya, found that maize yield was higher by 55 % in the tied ridging plots, a contrast to findings of this study. This concludes that crop response to tillage treatments differ with different soils and climatic characteristics among the sites.

From this study, conventional tillage favored maize grain yields in Mwala Sub County. These findings agree with Khan *et al.* (2001), Rashidi and Keshavarzpour (2007) and Awe and Abegunrin (2009), who concluded that annual disturbance and pulverization caused by tillage practices produce a finer and loose structure which in turn improved the seedling emergence, plant population density and consequently crop yields. The deep tillage in the tractor – ploughed plots (DP/DPH) favored better root growth and nutrient uptake by the crop and hence increased physiological and metabolic activities and reproductive development of crop which increased yields over those of other tillage practices (Alam *et al.,* 2013). Conventional tillage practices also had the highest biomass yields compared to the conservation tillage. Soil moisture average trend shows that SSR, OX and H had higher moisture across the seasons but yielded lower biomass yields. Lower moisture levels in DP, DPH and HTR yielded higher biomass yields, indicating their efficient soil water retention capacities.

Bean grain and biomass yields

These results show that the intensive tillage by DPH, SSR and DP favored better root growth hence water and nutrient uptake by the bean crop thus better yields. The reduction of bean yield under intercropping with maize could be attributed to the interspecific competition between the intercrop components for water, light, air and nutrients and also the aggressive effects of maize (C_4 species) on bean, a (C_3 species) (Matusso *et al.,* 2014). According to Matusso *et al.* (2014) crops with C_4 photosynthetic pathways have been known to be dominant when intercropped with C_3 species. The shading of the bean by the taller maize plants may also have contributed to the reduction of the yields of the intercropped bean (Belel *et al.,* 2014; Karanja *et al.,* 2014). Competition for water and nutrients could also have contributed to the low bean yields obtained in this study. The low competitive capacity of legumes compared to the cereals has been ascribed to its short root system, shallow root distribution, resulting to low competitive ability for mineral nitrogen (Mucheru – Muna *et al.,* 2011). A review by Ofori and Stern (1987) of 40 published papers showed that the yield of the legume component declined on average by about 52 % of the sole crop yield whereas the cereal yield was reduced by only 11 % in an intercropped system.

CONCLUSION

Though inconsistent per season, maize plant height, leaf area and LAI, maize and beans grain and biomass yields were significantly affected by tillage. No significant effect of cropping systems on the maize height. Crop response to tillage varied from season to season, which was attributed to rainfall differences that played a significant role toward the final crop yields. The apparent inconsistent tillage effects observed per season on maize and bean growth, yield and yield components, may be related to short term soil management effects and this further supports the need for long-term field studies (> 4 seasons) in the study area. Multi-locational studies are also necessary to assess the feasibility of tillage and cropping systems across diverse conditions that prevail in smallholder farms in semi-arid areas. This will provide site - specific recommendations of the appropriate tillage practices and cropping systems for adoption in these semi-arid areas.

Acknowledgements

This study was supported by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and International Development Research Centre (IDRC) through Sokoine University of Agriculture (SUA), Tanzania. We sincerely thank Mrs. Josephine Mutuku for providing her farm for conducting this study and Stanley Kisamuli for the technical support in the field.

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Submitted February 28, 2016 – Accepted July 26, 2016