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Changes of Soil Inorganic N, Soil Organic C and N Uptake by Maize and Soybean under Different Intercropping Patterns in Embu West and Tigania East Counties of Central Kenya

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In the central highlands of Kenya, low soil fertility is one of the major constraints causing decreased maize production and other staple food and income generating crops. The purpose of this study was therefore to determine the effects of maize-soybean intercropping patterns on soil inorganic N, soil organic C and N uptake by maize and soybean. The effects of conventional=1M:1S,MBILI-MBILI=2Maize:2Soybean; 2Maize:4Soybean, 2Maize:6Soybean and two sole crops of maize and soybean were investigated during two seasons (2012 Long Rains and 2012 Short Rains) at Embu and Meru Counties, using a randomized complete block design (RCBD) with four replications. At Embu, during 2012 LR, the MBILI and 2M:4S treatments observed significantly the lowest N03- - N content (8.24 mg kg-1 and 9.15 mg kg-1, respectively); whereas at Kamujine, the sole soybean treatment recorded statistically the highest N03- - N content (8.24 mg kg-1). At Kamujine the sole soybean treatment recorded statistically the highest (12.84 mg kg-1) soil Inorganic N. The N uptake by maize and soybean was significantly affected by the intercropping patterns and it was positively correlated with soil mineral N, at both sites during the sampling period. At Kamujine, theSOC was significantly affected by the intercropping and the conventional treatment recorded the highest value of 2.46%.

Key words: maize-soybean, intercropping patterns, soil mineral-N, N-uptake, chemical soil properties, central highlands, Kenya.

INTRODUCTION

Soil-fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in sub-Saharan Africa (Sanchez*et al*., 1997). An average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} has been lost during the last 30 years from about 200 million ha of cultivated land in 37 African countries (Smaling *et al*., 1997). The necessity to improve soil fertility management has therefore become a very important issue in the development policy agenda due to the strong linkage between soil fertility and food security on the one hand and the implications on the economic well-being of the population on the other (Mugwe *et al*., 2011). In the central highlands of Kenya, the intensive cultivation without adequate soil nutrient replenishment, the declining soil fertility as has resulted in low returns to agricultural investment, decreased food security and general high food prices (Odera *et al*., 2000).

However, the area has high potential for food production because of favorable seasonal precipitation; many of the soils are deficient in nutrients, particularly of nitrogen (Mugwe *et al*., 2011).Nitrogen is one of the major plant nutrients and in the soil is broadly subdivided into organic and inorganic forms. Inorganic N is available for plant uptake while organic forms slowly become available for plant uptake through microbial decomposition and mineralization. The principal forms of inorganic N in soils are ammonium (NH_4^+) and nitrate (NO_3^-) and any nitrogen in the soil that is available to the crop is almost always in one of the two forms (Barrios *et al*., 1998).In the central high lands of Kenya, farmers luck financial resources to replenish nitrogen through inorganic fertilization (Mugwe *et al*., 2004), and the use of organic materials alone and/or their combination with inorganic have been recommended by several studies (Bekunda *et al.,* 1997; Mugendi *et al.,* 1999; Gruhn *at al.*, 2000; Jama *et al*., 2000; Mugwe *et al*., 2007), and major concern has been the low availability of the needed amount of organic material to replenish the soil fertility. For instance, despite its low availability, manure is the most widely used organic materials by approximately 80% of the smallholder farmers in the central high lands of Kenya (Makokha*et al*., 2001).

Therefore, it is necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security (Landers, 2007; Gruhn *et al.,* 2000). Such technologies include the use of integrated soil fertility management practices (ISFM) such as intercropping cereals with grain legumes as one of its main components (Mucheru-Muna *et al*., 2010; Sanginga and Woomer, 2009). Cereal – grain legume intercropping has potential to address the soil nutrient depletion on smallholder farms (Sanginga and Woomer, 2009). Improved intercropping systems are part of ISFM technologies (Mucheru-Muna *et al*., 2010; Sanginga and Woomer, 2009) and in central highlands of Kenya the information is scarce regarding to optimum cropping pattern of maize-soybean intercropping system, and regarding to its effect on soil inorganic N, soil organic C and N uptake by maize and soybean.

MATERIALS AND METHODS

Study area

The experiment was carried out in two sub counties of central highlands of Kenya, namely Embu West and Tigania East sub counties. Embu West District is located in Embu County, in the central highlands of Kenya, and occupies an area of 708 Km^2 and the experimental site lies at N 0°31´ 4.2´´ E 37^0 27´ 20´´ with the altitude of 1468 m above the sea level (ASL), at Embu Agricultural Staff Training College (Jaetzold *et al*., 2006).The soils are humic nitisols. The average annual rainfall varies from 909 to 1230 mm with long rainy season between March and June and short rainy season between October and December, respectively. Tigania East Sub County is located in Meru County, in the central highlands of Kenya and it occupies 108.6 km^2. The experimental site lies at N 0° 6´ 19.5´´ E 037°64´ 39.6´´ with the altitude of 935 m above the sea level (ASL), at Kamujine Dispensary in Mikinduri Division. The soils are mainly eutric Nitisols and humic Cambisols. The average annual rainfall varies from 1000 to 2200 mm with long rainy season between March and June and short rainy season between October and December, respectively (Jaetzold *et al*., 2006).

Before planting, soil samples from the experimental sites were collected at 0 – 15 cm depth for analysis for organic carbon, total nitrogen using standard methods (Okalebo *et al.,* 2002), extractable P, Ca, Mg, K, Na using Mehlich-1 (M1) extraction method, where P and Mg^{2+} were determined colourimetrically in a spectrophotometer and Ca^{2+}, and K^+ were determined using flame photometer (Table 1).

In general (Table 1), the soils in the two contrasting sites were different. For instance, at Embu site they were relatively acidic compared to Kamujine site. The total N (%) was slightly higher at Embu site compared to Kamujine. The soil organic carbon was 40 percent higher at Embu site than at Kamujine, and at this site the soil texture was relatively lighter (45 percent clay) than at Embu site (65 percent clay).

Experiment establishment and management

The fields were ploughed using hand hoe and left as such for two weeks. Plots measuring 7.0 by 4.5 m were marked just before planting. Pathways measuring 3.0 m and 2.0 m were left between the blocks and plots, respectively. The following external nutrient replenishment inputs were applied per plot: 6kg of manure equivalent to 30 kg N ha^{-1}, applied two weeks before planting; 94.5 grams of Calcium Ammonium Nitrate as source of N, equivalent to 30 kg N ha^{-1}, for soybean the Nitrogen (starter N) was applied at sowing while for maize it was applied when the crop has six leaves, as topdressing; 189 grams of Tripe Super Phosphate as source of P, equivalent to 60 kg P ha^{-1}, which was applied at sowing.

Experimental design and treatments

The cropping system was of sole maize (*Zea mays* L.), sole soybean (*Glycine max* (L.) Merrill) and maize (M) – soybean (S) intercropping with cropping patterns (Table 2). At Embu-ATC, planting was done on the 23rd of March

Table 1: Soil Characteristics at Embu – ATC and Kamujine sites, Kenya.

Soil parameter	Embu – ATC Site	Kamujine Site
pH in water $_{(1:2.5)}$	5.30	5.50
Total N (%)	0.03	0.01
Total soil organic carbon (%)	2.64	1.88
Extractable P (ppm)	13.40	9.54
Exchangeable Ca (C mol kg-1)	0.22	0.21
Exchangeable Mg (C mol kg-1)	0.53	0.53
Exchangeable K (C mol kg-1)	0.12	0.08
Clay (%)	65	45
Sand (%)	17	20
Silt (%)	18	35

Table 2: Treatments in the two sites (ATC-Embu and Kamujine)

Treatment	Cropping system	Treatment	Cropping system
T1	Sole maize	T4	Maize-Soybean (2:2)
T2	Sole soybean	T5	Maize-Soybean (2:4)
T3	Maize-Soybean (1:1)	T6	Maize-Soybean (2:6)

and 12th of October 2012 for the 1st and 2nd seasons, respectively. At Kamujine, planting was done on the 26th of March and 15th of October 2012 for the 1st and 2nd seasons, respectively.

Soil sampling and determination of soil mineral nitrogen

Soil samples for determination of mineral N were taken from 0-15 cm depth at 0, 2, 4, 6, 8, 12, 16 and 20 weeks after planting (WAP) , in all plots, during the Long Rains season (March-August/2012). The soil samples was taken at 10 different spots per plot then bulked to give one composite sample, this aimed to eliminate the variability of inorganic N. After sampling the soil samples were packed in cooler boxes and delivered to the laboratory within 24 hours. To avoid any further mineralization before extraction, the samples were stored in the fridge at 5 °C. The soil extraction was done using 2M KCl, then the analysis of extractable nitrate (NO_3^-) though a flow injection system, using cadmium reduction column method, followed by determination of extractable ammonium using colorimetric method through a flow injection system (Okalebo *et al.,* 2002).

Determination of maize and soybean N uptake

Destructive random sampling of maize and soybean plants was carried out at 4, 6, 8, 12, 16 and 20 WAP (harvest) for determination of N concentration in the plant tissue. The samples were then analyzed separately for nitrogen concentration using Kjeldahl acid digestion method, followed by colorimetric method (Okalebo *et al.,* 2002). Nitrogen uptake by maize and soybean crops was determined by multiplying the dry matter yields (kg ha^{-1}) with nitrogen concentration (%).

Determination of the soil total N and soil organic carbon

Total N was determined using Kjeldahl acid digestion method, using an automatic CN elemental analyzer 2000 (Okalebo *et al.*, 2002), while organic carbon was determined by combustion using an elemental analyzer CNS-2000 analyzer using an automatic CN 2000.

Data analysis

Data of soil mineral N, N uptake by maize and soybean,

Table 3: Soil nitrate-N at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting						
		0	4	6	8	12	16	20
		……….. Nitrate – N (NO_3^- - N) mg kg^{-1}………....						
Embu	Sole maize	5.19	9.18	6.55	6.65	6.72	4.59	8.24
	Sole soybean	7.42	9.81	8.62	7.83	5.78	5.76	14.95
	Maize-Soybean (1:1)	6.95	11.36	6.06	8.17	4.71	5.01	14.62
	Maize-Soybean (2:2)	10.22	6.08	7.80	8.77	5.66	5.10	12.20
	Maize-Soybean (2:4)	8.77	10.07	6.50	8.07	9.01	5.56	9.15
	Maize-Soybean (2:6)	8.76	8.50	7.49	5.53	4.69	7.16	10.38
p-value		0.4638	0.1780	0.9224	0.7915	0.0285*	0.7444	0.0525*
$LSD_{(0.05)}$		5.36	4.04	5.52	5.23	2.62	3.69	5.01
Kamujine	Sole maize	13.31	5.75	7.38	5.47	5.12	5.17	3.73
	Sole soybean	12.87	9.37	9.00	8.79	8.06	6.67	8.24
	Maize-Soybean (1:1)	10.71	8.51	6.25	4.12	4.38	4.08	3.78
	Maize-Soybean (2:2)	11.94	6.31	4.14	5.57	3.40	4.30	3.14
	Maize-Soybean (2:4)	14.72	6.40	6.38	6.06	5.76	5.32	6.14
	Maize-Soybean (2:6)	9.53	8.04	6.62	6.51	4.01	4.93	1.66
p-value		0.6283	0.7124	0.2385	0.0567	0.0728	0.4762	0.0301*
$LSD_{(0.05)}$		6.70	5.71	3.86	2.80	3.13	2.84	3.90

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$.

and soil chemical properties were subjected to analysis of variance using SAS version 9.0. To test the differences between different cropping pattern and conventional intercropping systems, the means were subjected to *t-student* test at 95% of significance level ($p<0.05$). The correlations between soil inorganic N and N uptake were done using Pearson Correlation Coefficient (*r*).

RESULTS AND DISCUSSION

Soil mineral N

At Embu during 2012 LR, no significant differences were observed in soil nitrate – N content (NO_3^- - N) among the intercropping patterns during all the sampling periods, except at 12 WAP where the 2Maize:4Soybean treatment observed significantly (p=0.0285) higher NO_3^- - N content (9.01 mg kg^{-1}) than all other treatments, excluding sole maize treatment. At harvest (20 WAP) the 2Maize:2Soybean and 2Maize:4Soybean treatments observed significantly (p=0.0525) the lowest NO_3^- - N content (8.24 mg kg^{-1} and 9.15 mg kg^{-1}, respectively) than the sole soybean and conventional treatments, with 14.95 mg kg^{-}1 and 14.62 mg kg^{-1}, respectively. This is an indication that intercropping may have reduced the soil nitrate that moved to region where it could not be easily absorbed by plant roots. Similarly, at Kamujine during the same season (2012 LR), no significant differences were also observed in soil nitrate – N content (NO_3^- - N) among the intercropping patterns during all the sampling periods, except at 20 WAP where sole soybean treatment recorded statistically (p = 0.0301) the higher NO_3^- - N content (8.24 mg kg^{-1}) than all other treatments, except the 2M:4S treatment (Table 3).

The low soil nitrate content observed at harvest (20 WAP) in maize – soybean intercrop agrees with results of Ye, Li and Sun (2008) who reported that the soil nitrate N was lower under faba bean – pea intercrop than under their monocrops. Li *et al.* (2005) and, Zhang and Li (2003) also reported that intercropping maize with faba beans decreased the soil nitrate – N content at harvest. Intercropping faba beans with wheat reduced the nitrate concentration in soil profile (Stuelpnagel, 1993). This might be due to the complimentary root distribution of cereal/legume intercrop or the increased time of plant

Table 4: Soil ammonium-N at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting						
		0	4	6	8	12	16	20
		……… Ammonium – N (NH_4^+ - N) mg kg^{-1}………...						
Embu	Sole maize	5.24	5.07	5.82	4.96	5.87	2.99	3.54
	Sole soybean	7.45	5.89	4.14	2.28	3.03	3.90	2.32
	Maize-Soybean (1:1)	7.64	3.86	3.96	2.99	7.63	6.06	2.52
	Maize-Soybean (2:2)	7.31	4.78	4.61	3.41	3.77	4.14	3.75
	Maize-Soybean (2:4)	8.67	4.69	6.26	2.56	5.64	5.16	6.32
	Maize-Soybean (2:6)	9.31	5.23	8.67	6.36	4.91	3.80	2.59
p-value		0.8610	0.7855	0.2338	0.0930	0.4800	0.7602	0.4771
LSD$_{(0.05)}$		6.92	2.91	4.29	3.12	5.06	4.57	4.63
Kamujine	Sole maize	6.42	5.11	4.84	3.25	3.53	1.72	3.78
	Sole soybean	686	5.29	2.39	5.59	6.28	5.62	4.60
	Maize-Soybean (1:1)	5.84	4.33	6.95	5.42	3.49	5.17	3.45
	Maize-Soybean (2:2)	3.96	3.71	3.79	4.62	6.99	4.77	2.89
	Maize-Soybean (2:4)	7.51	6.53	6.85	1.27	5.16	5.49	3.12
	Maize-Soybean (2:6)	6.11	5.66	4.73	4.47	6.48	3.98	4.10
p-value		0.6406	0.7239	0.5532	0.1578	0.5169	0.3174	0.6718
LSD$_{(0.05)}$		4.41	3.97	5.87	3.56	4.91	3.88	2.38

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$.

uptake of N by maize in intercropping systems (Li *et al.*, 2005). For instance, Li *et al.* (2005) found that in the maize – faba beans system, maize roots were distributed in both the profiles of maize and faba beans. Thus, maize could utilize the nitrate in the strip of intercropping faba beans (Li, 1999).

At Embu during 2012 LR, no significant differences were observed in soil ammonium – N content (NH_4^+ - N) among the intercropping patterns during all the sampling periods. Similar results were also observed at Kamujine, where the treatments had no significant effect of soil ammonium – N (Table 4).

The findings above indicate that intercropping patterns had little effect on soil ammonium nitrogen. Similar results were also observed by Huang *et al.* (2011) who did not find significant differences on soil ammonium N under maize-legume intercropping systems. However, there was a general increase in general increase in ammonium – N at the end of the season. This increase could be due to dry soil conditions that helped the microorganisms to mineralize organic – N from residues into ammonium – N, making it available in the soil solution at that particular period. Similar findings were also reported by Anggria, Kasno and Rochayati (2012) who found that under dry conditions with aerobic conditions the ammonification of organic residues was faster than the oxidation of ammonium to nitrate, and resulted in a higher ammonium accumulation.

At Embu during 2012 LR, no significant differences were observed in soil mineral – N content among the intercropping patterns during all the sampling periods. However, during the season there was general increase of soil mineral N for the MBILI, sole soybean and conventional treatments, where the MBILI treatment observed the highest value (51.06 per cent) followed by the sole soybean with 16.21 per cent (Figure 1). On the other hand, there was general decrease of soil mineral N for the sole maize, 2M:4S, and 2M:6S treatments, where the sole maize recorded the highest decrease of 31.60 per cent (Figure 1).

Similarly, Hauggaard-Nielsen, Ambus and Jensen (2001a) did not find significant differences on soil mineral N at harvest in the 0-25 cm soil layer under pea sole crop compared to the other treatments. The increase on soil mineral N for sole soybean and some of the intercropping treatments was also reported by Rusinamhodzi (2006)

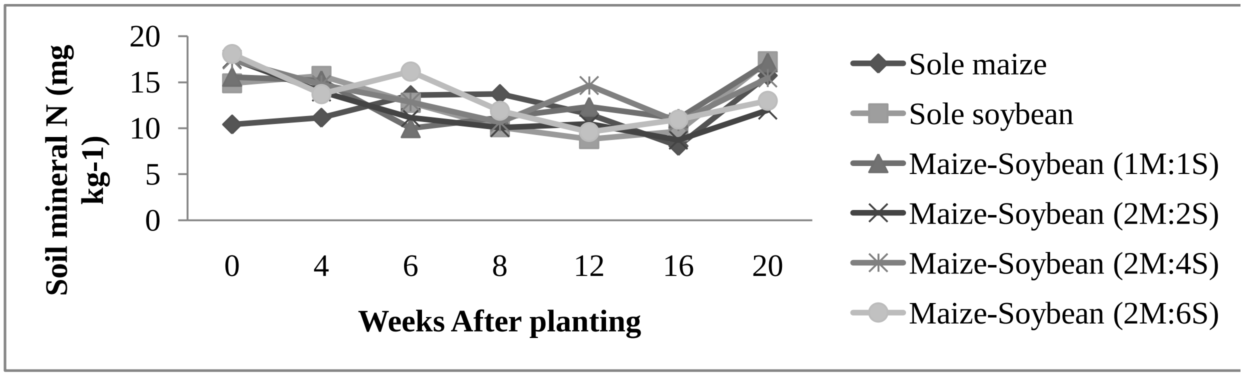

Figure 1. Soil mineral – N trend at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu

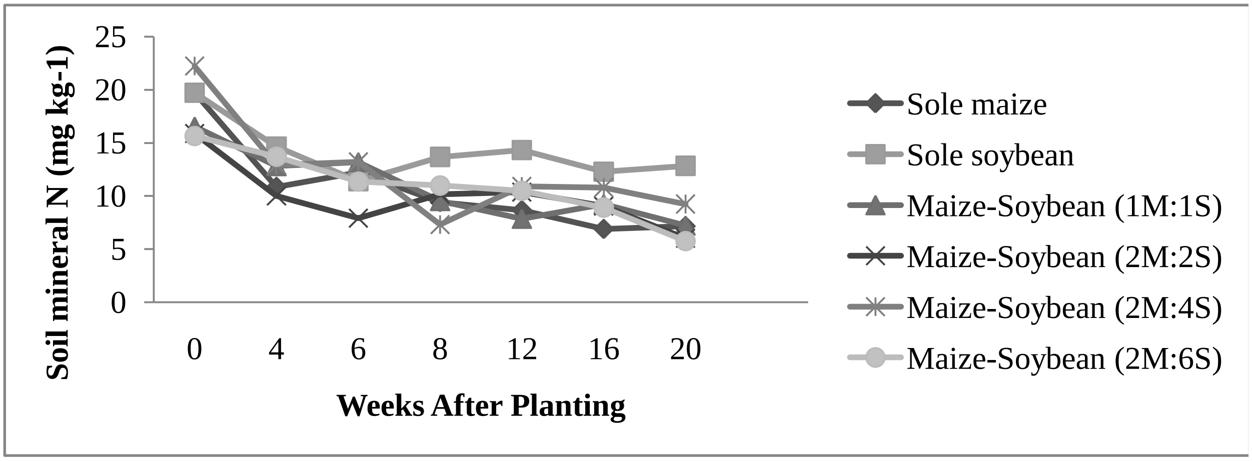

Figure 2. Soil mineral – N trend at 0–15 cm soil depth sampled at different periods during 2012 LR at Kamujine

who found that soil mineral N had increased in sole cowpea and cowpea-cotton treatments but not sole cotton cropping system.

At Kamujine during 2012 LR, no significant differences were also observed in soil mineral – N content as result of the treatments during all the sampling periods. Despite that, during the season there was general decrease of soil mineral N in all the treatment, where the sole maize and sole soybean treatments recorded the highest (63.76 per cent) and the lowest (34.92 per cent) values, respectively (Figure 2).

Similarly, Hauggaard-Nielsen, Ambus and Jensen (2001b) observed higher soil mineral N at harvest in the 0-25cm soil layer under pea sole crop compared to the other treatments independent of cropping strategy. Hauggaard-Nielsen, Ambus and Jensen (2001c) reported that the lowest soil inorganic N deficit was observed in pea sole crop and the greatest in barley sole crop. This suggests that legume and non-legume intercrops are not likely to increase soil N in the long term, but rather deplete it (Nielsen, Ambus and Jensen, 2001c). As an average of four years experimentation Jensen (1996) equivalently concluded that the N balance was positive for sole cropped pea, whereas it was negative for barley and pea-barley in all years.

Nitrogen uptake by maize and soybean

At Embu during 2012 LR, the N uptake of maize and soybean was significantly affected by the intercropping patterns (Table 5). For instance, at 4 WAP the sole

Table 5: Effects of intercropping patterns on N uptake by maize and soybean during 2012 LR at Embu and Kamujine sites

Location	Treatment	Crop	Weeks After Planting						
			4	6	8	12	16	20	
			Plant N concentration (%)					N uptake (kg ha^{-1})	
								Stover	Grain
Embu	Sole maize	Maize	1.69	1.73	2.79	2.52	1.78	9.32	6.12
	Sole soybean	Soybean	2.75	1.96	2.88	1.48	0.35	0.13	2.67
	Maize-Soybean (1M:1S)	Maize	1.30	1.69	2.67	2.18	1.95	9.21	7.02
		Soybean	2.59	2.02	2.98	2.19	1.21	1.19	5.75
	Maize-Soybean (2M:2S)	Maize	1.38	1.39	2.80	2.02	2.16	14.88	9.41
		Soybean	2.43	2.02	3.34	2.08	0.53	0.44	3.78
	Maize-Soybean (2M:4S)	Maize	1.82	1.87	2.72	2.45	1.88	7.52	7.25
		Soybean	2.25	2.07	3.53	2.07	0.60	0.33	1.56
	Maize-Soybean (2M:6S)	Maize	1.02	1.34	2.33	2.39	1.90	10.00	6.58
		Soybean	2.20	1.90	2.93	1.99	0.45	0.31	3.15
p – value			0.0026**	0.4320	0.1942	0.6001	<0.0001***	<0.0001***	0.0041**
LSD$_{(0.05)}$			0.86	0.74	0.80	0.94	0.73	3.54	3.70
Kamujine	Sole maize	Maize	1.60	1.66	197	1.43	1.07	3.95	3.30
	Sole soybean	Soybean	3.00	2.60	3.16	3.31	0.69	1.27	2.92
	Maize-Soybean (1M:1S)	Maize	1.24	1.61	1.78	1.43	1.04	3.50	4.30
		Soybean	2.87	4.28	2.97	2.22	0.26	0.06	0.25
	Maize-Soybean (2M:2S)	Maize	1.31	1.33	2.05	1.77	1.75	4.85	3.47
		Soybean	3.26	2.79	2.68	1.72	0.38	0.07	0.21
	Maize-Soybean (2M:4S)	Maize	1.73	1.79	2.43	1.79	0.61	1.44	2.13
		Soybean	2.79	2.12	2.98	2.84	0.71	0.35	0.86
	Maize-Soybean (2M:6S)	Maize	0.97	1.28	2.27	1.09	0.86	1.52	2.84
		Soybean	3.20	3.19	2.72	1.78	0.99	0.56	1.09
p – value			<0.0001****	<0.0001*	0.0102**	0.0031**	0.0053**	<0.0001***	<0.0001***
LSD$_{(0.05)}$			0.87	0.99	0.78	1.00	0.65	1.78	1.47

ns – not significant; *significant at $p \leq 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$.

soybean yielded significantly the highest N amount (2.75 per cent N, p=0.0026) than all the other treatments, excluding intercropped soybean. This was strongly correlated (r=0.81; p=0.0988) with soil mineral at the same sampling period (4 WAP); however the correlation was not significant at p=0.05. At 16 WAP the sole soybean had accumulated significantly the lowest N (0.35 per cent N, p<0.0001) than all the other treatments, except soybean under 2M:2S, 2M:4S and 2M:6S treatments. Also, the N uptake by soybean during this period was positively correlated (r=0.48; p=0.4125) with soil mineral N at the same sampling period. The maize under MBILI treatment observed significantly (p<0.0001) the highest N uptake of 14.88 kg ha^{-1} than all other treatments, followed by maize under 2M:6S, which was not significantly different to soybean component under all the treatments; and sole soybean observed significantly the lowest N uptake (0.13kg ha^{-1}), though not statistically different from other soybean treatments. Also, maize under MBILI treatment observed significantly the highest N uptake to the grain (9.41 kg ha^{-1}) than sole soybean, soybean under MBILI, soybean under 2M:4S and soybean under 2M:6S treatments. The N accumulated in maize grain was positively correlated with soil mineral N at 4 and 16 WAP, with r=0.87 (p=0.0543) and r=0.81 (p=0.0995), respectively. In general, the N accumulation by maize under intercropping treatments was generally lower than for sole cropping, particularly up to 12 WAP (Table 5).

During 2012 LR at Kamujine site, intercropping systems affected significantly the N uptake by maize and soybean (Table 4.10). For instance, at 4 WAP the soybean under MBILI treatment had accumulated significantly higher N (3.26 per cent N, p<0.0001) than maize under different treatments. During this time the N uptake was highly positively correlated (r=0.79; p=0.1089) with soil mineral N of the same sampling period. At 6 WAP the soybean under conventional treatment yielded significantly the highest N (4.28 per cent N, p<0.0001) than all the other treatments. At 8 WAP the soybean sole acquired significantly the highest N (3.16 per cent N, p=0.0102) than sole maize and maize under conventional, MBILI, and 2M:6S treatments. At this time the N uptake by maize was significantly positively correlated (r=0.88; p=0.051) with soil mineral N during the same period. At 12 WAP the sole soybean also recorded significantly the highest N (3.31 per cent N, p=0.0031) than all the other treatments, excluding soybean under 2M:4S treatment. During this sampling period, the amount of N accumulated by soybean was highly significantly positively correlated (r=0.91; p=0.0301) with soil mineral N of the same period and soil mineral N at 16 WAP (r=0.89; p=0.0437), respectively. Whereas towards the end of season (at 16 WAP) the maize under MBILI treatment acquired statistically the highest N (1.75 per cent N, p=0.0053) than all the other intercropping patterns. At harvest, still the maize under MBILI treatment accumulated significantly the highest N (4.85 kg N ha^{-1}, p<0.0001) than all other treatments, except sole maize and maize under conventional treatments. At this moment the amount of N yielded by soybean was strongly correlated (r=0.78; p=0.1201) with the soil mineral N for the period. For the grain, the maize under conventional treatment observed significantly the highest N uptake (4.30 kg ha^{-1}, p<0.0001) than all other treatments, excluding sole maize, maize under MBILI, sole soybean and maize under 2M:6S treatments (Table 5).

The greater N acquisition by a non-legume crop intercropped with a legume is frequently reported in literature (Francis, 1986; Vandermeer, 1989; Stern, 1993; Li *et al*., 2001; Shata *et al*., 2007). In cereal-legume intercropping, an increase in N acquisition may be derived in two ways. First, the difference in competitive abilities of component species may increase N uptake by cereal, which in most cases has higher competitive ability relative to legume. This may conversely stimulate nodulation in legume, as noted by Rerkasem *et al.* (1988) for beans intercropped with maize. Second, an increase in N acquisition may also be attributed to N transfer to cereal from legume (Brophy, Heichel, and Russelle, 1987). The higher N facilitation may enable cereal to absorb more N in intercropping systems than in sole cropping systems, or it may increase the N fixation ability of legumes and may transfer from legume to cereal (Ning *et al*., 2012). However, in the experimental sites of this study the soils are moderately acidic (pH=5.33 and pH=5.46, at Embu and Kamujine sites, respectively), limiting phosphorus availability, which is harmful for BNF process and therefore lessen the N contribution of the legume component to system. Furthermore, according to Jones and Giddens (1985) there are a number of factors that affect N_2 fixation by legume in acid soil. The number of compactible rhizobia in the rhizosphere and the degree of infection of the root by the bacteria are important factors, which are controlled by environmental conditions such as soil pH. Thus, in cereal-legume intercropping, without N-fixing and transfer, the N demand of each intercrop may also increase N competition, particularly when relatively low amount of fertilizer-N and soil-N are used (Li *et al.,* 2003a; Li *et al.,* 2003b). Simpson (1965) stated that in some of the intercropping systems, competition by the legume for N is high and results in reduced N uptake by the cereal, and in this study it resulted in higher uptake by soybean as compared to the maize component. On the other hand, the higher N uptake by maize observed under MBILI treatment at Kamujine site could be due to the fact that during that time the legume component had accomplished its N requirements and about to be harvested. Therefore, the competition for N could be reduced to its minimum.

Soil total N and soil organic carbon

During 2012 SR at Embu site, there were significant differences in soil total N as affected by intercropping patterns. For instance, the MBILI treatment observed the highest N value of 0.05 per cent (p=0.0530) than all other intercropping patterns, excluding the 2M:4S treatment.

Table 6: Effect of intercropping patterns on soil chemical properties (soil total N and SOC) during 2012 SR at Embu and Kamujine sites

Location	Treatment	Soil total N (%N)	Soil Organic C (%C)
Embu	Sole maize	0.01	2.48
	Sole soybean	0.02	2.48
	Maize-Soybean (1M:1S)	0.02	2.50
	Maize-Soybean (2M:2S)	0.05	2.53
	Maize-Soybean (2M:4S)	0.03	2.48
	Maize-Soybean (2M:6S)	0.02	2.56
p-value		0.0530*	0.2460
$LSD_{(0.05)}$		0.02	0.09
Kamujine	Sole maize	0.03	2.31
	Sole soybean	0.00	2.14
	Maize-Soybean (1M:1S)	0.02	2.46
	Maize-Soybean (2M:2S)	0.02	2.03
	Maize-Soybean (2M:4S)	0.02	2.30
	Maize-Soybean (2M:6S)	0.005	1.96
p-value		0.0800	0.0020**
$LSD_{(0.05)}$		0.02	0.22

ns – not significant; *significant at $p \leq 0.05$; **significant at $p<0.01$; ***significant at $p<0.001$.

Whereas, the soil organic carbon was not affected by the intercropping patterns ($p=0.2460$); however, the 2M:6S treatment observed numerically the highest SOC value of 2.56 per cent than all other treatments. In general, the SOC was higher under intercropping treatments than under sole cropping systems, probably due to higher crop residues produced under intercropping compared to sole cropping systems. However, the SOC has reduced about 5.11 percent at the end of the two seasons compared to the before planting time (Table 6).

Different situation was observed at Kamujine site, where the soil total N was not affected by the intercropping patterns ($p=0.0800$). This could be due to relatively slow turnover times for SOM, making the incorporation of residue into total N small. Whereas, the SOC was significantly affected by the intercropping and the conventional treatment recorded the highest value of 2.46 per cent, $p=0.0020$ (Table 6). In general, the SOC at this site was not expected to be relatively low under intercropping treatments than under sole crop treatments. The SOC has increased about 14.55 percent at the end of the season compared to before planting time. The higher SOC values observed at Embu site compared to Kamujine site could be due to relatively higher precipitation recorded at first location which resulted in lower mineralization rate and therefore higher SOC.

The higher SOC observed in this study under intercropping treatments compared to their sole crops was also reported by several other authors (Bichel, 2013; Dyer, 2010; Sainju *et al*., 2009; Nzabi *et al*., 2000). Bambrick (2009) reported that tree based intercropping systems had greater potential for carbon storage than conventional cropping systems due to the fact that carbon is stored in the biomass of growing trees and trees provide additional carbon inputs (leaves, roots) that contribute to the SOC pool. As reported at Embu site, Zhang *et al.* (2007) also did not find significant differences on SOC under intercropping treatments compared to their pure stands. On the other hand, the absence of differences in soil total N observed at Kamujine site was also reported by Dyer (2010) and Bichel (2013) in Argentina under maize-soybean intercropping systems. Mazzoncini *et al.* (2011) reported that soil total N stocks significantly changed after 15 years, and recommended long-term studies, especially when focusing on the SOM pool. The SOM have been used as indicators of the effects related to biomass source and amounts on soil organic matter dynamics in cropping systems (Bayer *et al.,* 2009). Soilchemical properties in terms of macro-, meso- and micro-nutrients after a cropping period depends on the type of crops planted and cropping systems used (Ibeawuchi, 2007).

CONCLUSIONS

The maize-soybean intercropping patterns affected significantly soil nitrate-N at both locations. The soil mineral-N was significantly affected by the maize-soybean intercropping patterns only at Kamujine site.

The N uptake of maize and soybean was significantly affected by the intercropping patterns, at both localities. The sole soybean treatment yielded the highest N amount.

At Embu site during 2012 SR, the soil total N was significantly affected by the intercropping patterns. The 2Maize:2Soybean treatment observed the highest soil total N. The soil organic carbon was significantly affected by the intercropping patterns at Kamujine site where the conventional treatment observed the highest SOC.

RECOMMENDATIONS

There is a research need to quantify the BNF activity of different intercropping patterns that could assist to explain some findings of this study.

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