

Full Length Research

# 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 N<sub>03</sub>-N content (8.24 mg kg<sup>-1</sup> and 9.15 mg kg<sup>-1</sup>, respectively); whereas at Kamujine, the sole soybean treatment recorded statistically the highest N<sub>03</sub>-N content (8.24 mg kg<sup>-1</sup>). At Kamujine the sole soybean treatment recorded statistically the highest (12.84 mg kg<sup>-1</sup>) 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, the SOC 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<sup>-1</sup>, 75 kg P ha<sup>-1</sup>, and 450 kg K ha<sup>-1</sup> 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 ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ) 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 lack 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 *et 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 Woome, 2009). Cereal – grain legume intercropping has potential to address the soil nutrient depletion on smallholder farms (Sanginga and Woome, 2009). Improved intercropping systems are part of ISFM technologies (Mucheru-Muna *et al.*, 2010; Sanginga and Woome, 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<sup>2</sup> and the experimental site lies at N 0°31' 4.2" E 37° 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<sup>2</sup>. 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  $\text{Mg}^{2+}$  were determined colourimetrically in a spectrophotometer and  $\text{Ca}^{2+}$ , and  $\text{K}^+$  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<sup>-1</sup>, applied two weeks before planting; 94.5 grams of Calcium Ammonium Nitrate as source of N, equivalent to 30 kg N ha<sup>-1</sup>, 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<sup>-1</sup>, 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 23<sup>rd</sup> of March

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

Soil parameter	Embu – ATC Site	Kamujine Site
pH in water <sub>(1:2.5)</sub>	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 <sup>-1</sup> )	0.22	0.21
Exchangeable Mg (C mol kg <sup>-1</sup> )	0.53	0.53
Exchangeable K (C mol kg <sup>-1</sup> )	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 12<sup>th</sup> of October 2012 for the 1<sup>st</sup> and 2<sup>nd</sup> seasons, respectively. At Kamujine, planting was done on the 26<sup>th</sup> of March and 15<sup>th</sup> of October 2012 for the 1<sup>st</sup> and 2<sup>nd</sup> 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<sub>3</sub><sup>-</sup>) 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<sup>-1</sup>) 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 <sub>3</sub> <sup>-</sup> - N) mg kg <sup>-1</sup> .....						
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
	<i>p-value</i>		0.4638	0.1780	0.9224	0.7915	0.0285*	0.7444
LSD <sub>(0.05)</sub>		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
	<i>p-value</i>		0.6283	0.7124	0.2385	0.0567	0.0728	0.4762
LSD <sub>(0.05)</sub>		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<sub>3</sub><sup>-</sup> - 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<sub>3</sub><sup>-</sup> - N content (9.01 mg kg<sup>-1</sup>) 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<sub>3</sub><sup>-</sup> - N content (8.24 mg kg<sup>-1</sup> and 9.15 mg kg<sup>-1</sup>, respectively) than

the sole soybean and conventional treatments, with 14.95 mg kg<sup>-1</sup> and 14.62 mg kg<sup>-1</sup>, 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<sub>3</sub><sup>-</sup> - 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<sub>3</sub><sup>-</sup> - N content (8.24 mg kg<sup>-1</sup>) 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 <sub>4</sub> <sup>+</sup> - N) mg kg <sup>-1</sup> .....						
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
<i>p-value</i>		0.8610	0.7855	0.2338	0.0930	0.4800	0.7602	0.4771
LSD <sub>(0.05)</sub>		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	6.86	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
<i>p-value</i>		0.6406	0.7239	0.5532	0.1578	0.5169	0.3174	0.6718
LSD <sub>(0.05)</sub>		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).

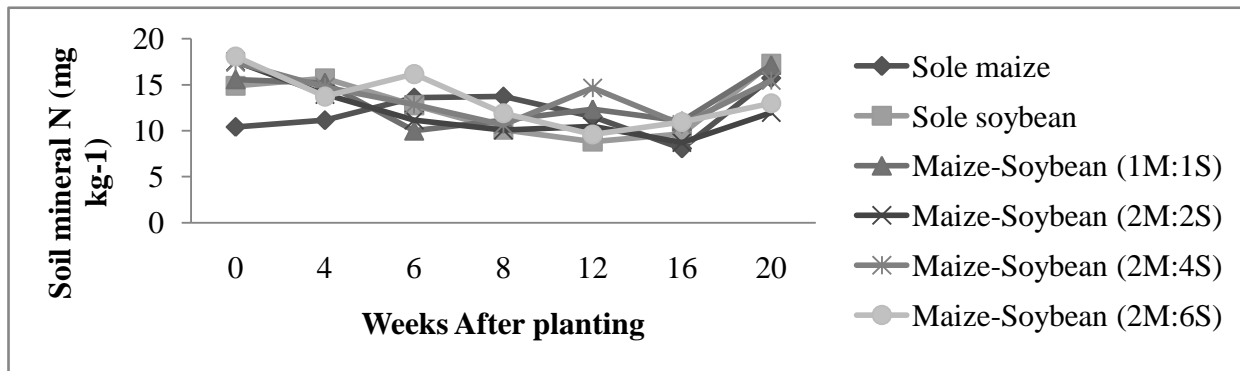
At Embu during 2012 LR, no significant differences were observed in soil ammonium – N content (NH<sub>4</sub><sup>+</sup> - N) among the intercropping patterns during all the sampling periods. Similar results were also observed at Kamujine, where the treatments had no significant effect of soil ammonium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

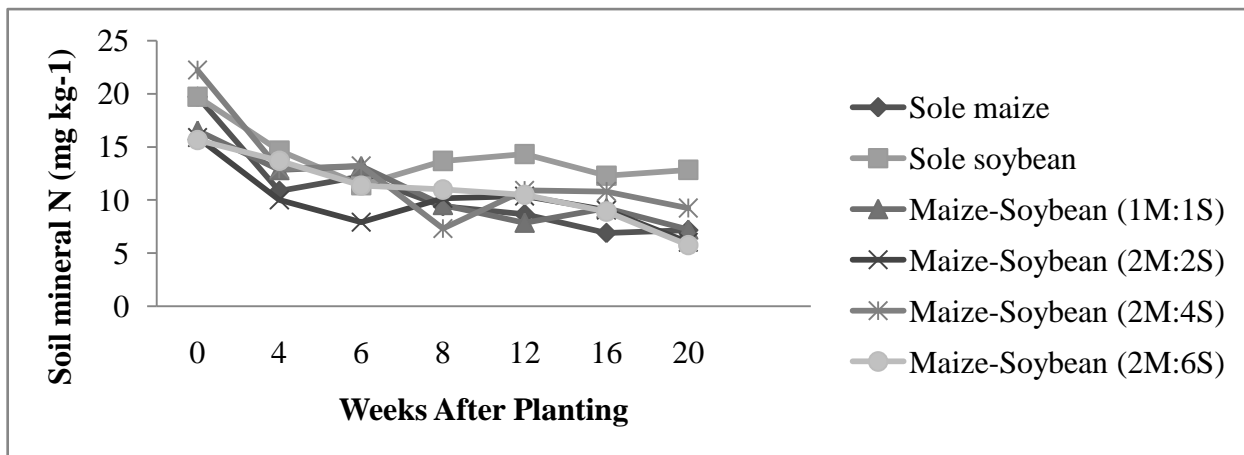
also reported by Anggria, Kasno and Rochayati (2012) who found that under dry conditions with aerobic conditions the ammonification of organic residues was faster than the oxidation of ammonium to nitrate, and resulted in a higher ammonium accumulation.

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 <sup>-1</sup> )
						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	
<i>p</i> – value			0.0026**	0.4320	0.1942	0.6001	<0.0001***	<0.0001***	0.0041**
LSD <sub>(0.05)</sub>			0.86	0.74	0.80	0.94	0.73	3.54	3.70
Kamujine	Sole maize	Maize	1.60	1.66	1.97	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	
<i>p</i> – value			<0.0001****	<0.0001*	0.0102**	0.0031**	0.0053**	<0.0001***	<0.0001***
LSD <sub>(0.05)</sub>			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  $14.88 \text{ kg ha}^{-1}$  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 ( $0.13 \text{ kg ha}^{-1}$ ), though not statistically different from other soybean treatments. Also, maize under MBILI treatment observed significantly the highest N uptake to the grain ( $9.41 \text{ kg ha}^{-1}$ ) 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 ( $4.85 \text{ kg N ha}^{-1}$ ,  $p<0.0001$ ) 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 ( $4.30 \text{ kg ha}^{-1}$ ,  $p<0.0001$ ) 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 ( $\text{pH}=5.33$  and  $\text{pH}=5.46$ , 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  $\text{N}_2$  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
	<i>p-value</i>	0.0530*	0.2460
<i>LSD</i> <sub>(0.05)</sub>		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
	<i>p-value</i>	0.0800	0.0020**
<i>LSD</i> <sub>(0.05)</sub>		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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## REFERENCES

- Anggria L, Kasno A, Rochayati S (2012). Effect of Organic Matter on Nitrogen Mineralization in Flooded and Dry Soil. *J. Agric. Biolo. Sci.* 7(8): 586-590.
- Bambrick A (2009). Soil Organic Carbon in Tree-Based Intercropping Systems of Quebec and Ontario, Canada. MSc. Thesis. McGill University, Montréal, Canada. 93pp.
- Barrios E, Kwesiga F, Buresh RJ, Sprent JI, Coe R (1998). Relating Preseason Soil Nitrogen to Maize Yield in Tree Legume-Maize Rotation. *Soil Sci. Soc. Am. J.* 62:164–169.
- Bayer C, Dieckow J, Amado TJC, Eltz FLF, Vieira FCB (2009). Cover Crop Effects Increasing Carbon Storage in a Subtropical no-till Sandy Acrisol. *Communications in Soil Science and Plant Analysis*, Vol.40: 1499-1511.
- Bekunda MA, Bationo A, Ssali H (1997). Soil Fertility Management in Africa: A Review of Selected Research Trials, p. 63-79. In R.J. Buresh et al. (ed.) *Replenishing soil fertility in Africa*. SSSA Spec. Publ. 51. SSSA, Madison, WI.
- Bichel A (2013). Applied Soybean and Maize Residue Contributions to Soil Organic Matter in a Temperate Soybean/Maize Intercropping System. MSc. Thesis. University of Waterloo, Canada. 149pp.
- Brophy LS, Heichel GH, Russelle MP (1987). Nitrogen Transfer from Forage Legumes to Grass in a Systematic Planting Design. *Crop Sci.* 27:753-758.
- Dyer L (2010). Evaluation of Soil chemical and Physical Characteristics in a Complex Agroecosystem in the Argentine Pampa. MSc. Thesis. University of Waterloo, Canada. 135pp.
- Francis CA (1986). *Multiple Cropping Systems*. Macmillan, New York.
- Gruhn P, Goletti F, Yudelman M (2000). Integrated Nutrient Management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges. International Food Policy Research Institute, 2033 K Street, N.W. Washington, D.C. 20006 U.S.A. September, 2000.
- Hauggaard-Nielsen H, Ambus P, Jensen ES (2001a). Interspecific Competition, N use and Interference with Weeds in Pea-Barley Intercropping. *Field Crops Research*. 70, 101-109.
- Hauggaard-Nielsen H, Ambus P, Jensen ES (2001b). Temporal and Spatial Distribution of Roots and Competition for Nitrogen in Pea-Barley Intercrops – a Field Study Employing <sup>32</sup>P Methodology. In: *Competitive Interactions, Resource Use and Nitrogen Dynamics in Annual Intercrops in Low-Input Cropping Systems*. Ph.D.-thesis by Hauggaard-Nielsen, H. Plant Biology and Biogeochemistry Department. Risø National Laboratory. [www.risoe.dk/pbk](http://www.risoe.dk/pbk).
- Hauggaard-Nielsen H, Ambus P, Jensen ES (2001c). Nitrate Leaching and N Balance in Cropping Systems with Sole or Intercropped Pea and Barley. In: *Competitive Interactions, Resource Use and Nitrogen Dynamics in Annual Intercrops in Low-Input Cropping Systems*. Ph.D.-thesis by Hauggaard-Nielsen, H. Plant Biology and Biogeochemistry Department. Risø National Laboratory. [www.risoe.dk/pbk](http://www.risoe.dk/pbk).
- Huang JX, Sui P, Nie SW, Wang BB, Nie ZJ, Gao WS, Yuan-quan Chen YQ (2011). Effect of Maize-Legume Intercropping on Soil Nitrate and Ammonium Accumulation. *Journal of Food, Agriculture & Environment* Vol.9 (3&4): 416 - 419.
- Ibeawuchi II (2007). Soil-Chemical Properties as Affected by Yam/Cassava/Landrace Legumes Intercropping Systems in Owerri Ultisols Southeastern Nigeria. *International Journal of Soil Science*, 2: 62 – 68.
- Jaetzold R, Schmidt H, Hornetz B, Shisanya CA (2006). *Farm Management Handbook of Kenya*. Natural Conditions and Farm Information, 2<sup>nd</sup> edition, vol. 11/C. Ministry of Agriculture/GTZ, Nairobi, Kenya (Eastern Province).

- Jama B, Palm CA, Buresh RJ, Niang A, Gachengo C, Nziguheba G, Amadalo B (2000). *Tithonia Diversifolia* as a Green Manure for Soil Fertility Improvement in Western Kenya: a Review. *AgroforSyst* 49: 201–221. doi:10.1023/A:1006339025728.
- Jensen ES (1996). Grain Yield, Symbiotic N<sub>2</sub> Fixation and Interspecific Competition for Inorganic N in Pea-Barley Intercrops. *Plant Soil* 182, 25-38.
- Jones RA, Giddens JE (1985). Tolerance of Soybean Rhizobia to Soil Acidity. *Petanika*. Vol. 8(3): 311-315.
- Landers JN (2007). Tropical Crop–livestock Systems in Conservation Agriculture: The Brazilian Experience. *Integrated Crop Management*. Vol. 5–2007.FAO.Rome, 2007.
- Li L (1999). Interspecific Facilitative and Competitive Interactions Between Intercropped Species in Intercropping Systems. Ph.D. Dissertation. China Agricultural University, Beijing.
- Li L, Sun J, Zhang F, Li X, Yang S, Rengel Z (2001). Wheat/Maize or Wheat/Soybean Strip Intercropping I. Yield Advantage and Interspecific Interactions on Nutrients. *Field Crop Res.* 71:123-137.
- Li WX, Li L, Sun JH, Zhang FS, Christic P (2003a). Effects of Nitrogen and Phosphorus Fertilizers and Intercropping on Uptake of Nitrogen and Phosphorus by Wheat, Maize and Faba bean. *J. Plant Nutr.* Vol. 26(3): 629-642.
- Li W, Li L, Sun J, Guo T, Zhang F, Bao X., An P, Tang C (2005). Effects of Intercropping and Nitrogen Application on Nitrate Present in the Profile of an OrthicAnthrosol in Northwest China.
- Li XJ, Wang JC, Lu SH, Zhang FS, Zeng XZ, Ai YW (2003b). Effects of Non-Flooded Mulching Cultivation and Nutrition Management on Crop Growth, Nutrient Uptake and Balances in Rice/Wheat cropping systems. *Field Crop Res.* Vol. 83(3):297-311.
- Makokha S, Kimani S, Mwangi W, Verkuijl H, Musembi F (2001). Determinants of fertilizer and manure use in Kiambu district, Kenya. International Maize and Wheat Improvement Center (CIMMYT) and Kenya Agricultural Research Institute (KARI), Mexico DF. 32pp
- Mazzoncini M, Sapkota TB, Bárberi P, Antichi D, Risaliti R (2011). Long-term Effect of Tillage, Nitrogen Fertilization and Cover Crops on Soil Organic Carbon and Total Nitrogen Content. *Soil & Tillage Research.* 114:165-174.
- Mucheru-Muna M, Pypers P, Mugendi D, Kung'u J, Mugwe J, Merckx R, Vanlauwe B (2010). Staggered Maize–Legume Intercrop Arrangement Robustly Increases Crop Yields and Economic Returns in the Highlands of Central Kenya. *Field Crops Research* 115 (2010) 132–139. 2009 Elsevier B.V. All rights reserved. Journal homepage: [www.elsevier.com/locate/fcr](http://www.elsevier.com/locate/fcr).
- Mugendi DN, Nair PKR, Mugwe JN, O'Neill MK, Woome P (1999) Alley Cropping of Maize with Calliandra and *Leucaena* in the Subhumid Highlands of Kenya. Part 1. Soil fertility changes and maize yield. *AgroforestSyst* 46: 39–50
- Mugendi D, Mucheru-Muna M, Pypers P, Mugwe J, Kung'u J, Vanlauwe B, Roel M (2010). Maize Productivity as Influenced by Organic Inputs and Mineral Fertilizer in a Nitisol Soil in Meru South District. 19<sup>th</sup> World Congress of Soil Science, Soil Solutions for a Changing World.1 – 6 August 2010, Brisbane, Australia.
- Mugwe J, Mugendi DN, Okoba BO, Tuwei P, O'Neill M (2004) Soil Conservation and fertility improvement using leguminous shrubs in central highlands in central highlands of Kenya. In: Bationo A (ed) *Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa*. Academy Science, Nairobi, pp 277–297.
- Mugwe J, Mugendi DN, Mucheru-Muna M, Kung'u J (2011). Soil Inorganic N and N Uptake by Maize Following Application of Legume Biomass, Tithonia, Manure and Mineral Fertilizer in Central Kenya. In: A. Bationo et al. (eds.), *Innovations as Key to the Green Revolution in Africa*, pp 605-612. DOI 10.1007/978-90-481-2543-2\_62, © Springer Science+Business Media B.V. 2011.
- Mugwe J, Mugendi D, Kung'u J, Mucheru-Muna M (2007). Effect of Plant Biomass, Manure and Inorganic Fertilizer on Maize Yield in the Central Highlands of Kenya. *African Crop Science Journal*, Vol. 15, No. 3, pp. 111 - 126 ISSN 1021-9730/2007. Printed in Uganda. All rights reserved 2007, African Crop Science Society.
- Ning T, Zheng Y, Han H, Jiang G, Li Z (2012). Nitrogen Uptake, Biomass Yield and Quality of Intercropped Spring- and Summer-Sown Maize at Different Nitrogen Levels in the North China Plain. *Biomass and Bioenergy*. Vol. 47:91-98.
- Nzabi AW, Makini F, Onyango M, Kidula N, Muyonga CK, Miruka M, Mutai E, Gesare M (2000). Effect of Intercropping Legume with Maize on Soil Fertility and Maize Yield. Kenya Agricultural Research Institute, Kisii Regional Research Centre, P.O. Box 523, Kisii.
- Odera MM, Kimani SK, Musembi F (2000) Factors Influencing Adoption of Integrated use of Manure and Inorganic Fertilizer in Central Highlands of Kenya. In: MukisiraEA, KiriroFH, WamuongoJW, WamaeLW, Muriithi FM, Wasike W (eds) *Collaborative and participatory research for sustainably improved livelihoods*. Proceedings of the 7th Biennial Scientific conference. Kenya Agricultural Research Institute (KARI), Nairobi, pp 58–64.
- Okalebo JR, Gathua KW, Woome PL (2002). *Laboratory Methods of Soil and Plant Analysis: A Working Manual*. 2<sup>nd</sup> Ed. TSBF-CIAT and SACRED Africa, Nairobi, Kenya.
- Rerkasem B, Rerkasem K, Peoples MB, Herridge DF, Bergersen FJ (1988). Measurement of N<sub>2</sub> Fixation in

- Maize (*Zea mays* L.)- Rice-bean (*Vigna umbellata* [Thumb.] Ohwi and Ohashi) Intercrops. *Plant and Soil*. 108:125-135.
- Rusinamhodzi L (2006). Effects of Cotton – Cowpea Intercropping on Crop Yields and Soil Nutrient Status under Zimbabwean Rain – Fed Conditions. M.Ph. Thesis. University of Zimbabwe.
- Sainju UM, Senwo ZN, Nyakatawa EZ, Tazisong IA, Reddy KC (2009). Tillage, Cropping Systems, and Nitrogen Fertilizer Source Effects on Soil Carbon Sequestration and Fractions. *Journal of Environmental Quality*, Vol.37: 880-888.
- Sanginga N, Woomer PL (2009). Integrated Soil Fertility Management in Africa: Principles, Practices and Development Process. (eds.). *Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture*. Nairobi. 263 pp.
- Shata SM, Safaa A, Mahmoud A, Hanan S, Siam (2007). Improving Calcareous Productivity by Integrated Effect of Intercropping and Fertilizer. *Res. J. Agric. & Biol. Sci.* 3(6):733-739.
- Simpson JR (1965). The Transfer of N from Pasture Legumes to an Associated Grass under Several Systems of Management in Pot Culture. *Aust. J. Agric. Res.* 16:915-926.
- Stern WR (1993). Nitrogen Fixation and Transfer in an Intercropping Systems. *Field Crop Res.* 34: 335-356.
- Stuelpnagel R (1993). Intercropping of Faba Beans (*Vicia faba* L.) with Oats or Spring Wheat. In *Proceedings of the International Crop Science Congress*, 14–44, July, 1992. Iowa State University, Ames, Iowa.
- Zhang F, Long L (2003). Using Competitive and Facilitative Interactions in Intercropping Systems Enhances Crop Productivity and Nutrient-Use Efficiency. *Plant and Soil* 248: 305–312.
- Zhang M, Ful XH, Feng WT, Zou X (2007). Soil Organic Carbon In Pure Rubber And Tea-Rubber Plantations in South-western China. *Tropical Ecology* 48(2): 201-207.