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# Effects of different maize (*Zea mays* L.) – soybean (*Glycine max* (L.) Merrill) intercropping patterns on soil mineral-N, N-uptake and soil properties

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**The adoption of ISFM technologies such as maize-soybean intercropping system is being promoted as one of the options to address low soil fertility and crop productivity among the farmers of the central highland of Kenya. The purpose of this study was therefore to determine the effects of maize-soybean intercropping patterns on soil inorganic N, N uptake and soil chemical properties. The experiment conducted during 2012 LR and 2012 SR and it was arranged in a randomized complete block design (RCBD) with four replications. The treatments were four maize (M) – soybean (S) intercropping patterns (conventional=1M:1S; MBILI-MBILI=2M:2S; 2M:4S; 2M:6S) and two sole crops of maize and soybean, respectively. The results showed that at Embu during 2012 LR, at harvest the MBILI and 2M:4S treatments observed significantly (*p*=0.0525) the lowest $N0_3^-$ - N content (8.24 mg $kg^{-1}$ and 9.15 mg $kg^{-1}$, respectively); and at Kamujine during the same 2012 LR, at harvest the sole soybean treatment recorded statistically (*p* = 0.0301) the highest $N0_3^-$ - N content (8.24 mg $kg^{-1}$). At Kamujine the sole soybean treatment recorded statistically (*p*=0.0131) the highest (12.84 mg $kg^{-1}$) soil mineral 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. During 2012 SR at Embu site, the MBILI treatment observed significantly the highest soil total N value of 0.05% (*p*=0.0530). The soil SOC was not significantly affected by the intercropping patterns at this location. The SOC was significantly affected by the intercropping and the conventional treatment recorded the highest value of 2.46%, *p*=0.0020.**

**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 SSA (Mugwe et al., 2007). 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 major reasons for the nutrient depletion process are (i) the breakdown of traditional

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**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 |

practices and (ii) the low priority given to the rural sector (Sanchez et al., 1997). Increasing pressures on agricultural land have resulted in much higher nutrient outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies, such as fallowing land, intercropping cereals with legume crops, mixed crop-livestock farming, and opening new lands (Sanchez et al., 1997). Thus, continued population pressure has reduced farm sizes to the point where farms can only provide adequate living for their families if the land is farmed very intensively and if there is off-farm income (Sanchez et al., 1997). Luck of an effective fertilizer supply and distribution system has resulted in reduced crop productivity and food insecurity as the main consequences of the soil fertility depletion in Africa (Palm et al., 1997). 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). The legumes play an important role in nitrogen fixation (Peoples and Craswell, 1992), and are important source of nutrition for both humans and livestock (Nandwa et al., 2011). In the central highlands of Kenya, cereal – legume intercropping is already being widely practiced by the smallholder famers. According to Sanginga and Woomer (2009) intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as cowpea, mung bean, soybean and groundnuts accumulate from 80 to 350 kg nitrogen (N) ha$^{-1}$ (Peoples and Craswell, 1992). For instance, soybean can positively contribute to soil health, human nutrition and health, livestock nutrition, household income, poverty reduction and overall improvements in livelihoods and ecosystem services, than many others leguminous grain crops (Rakasi, 2011; Raji, 2007). 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 chemical properties.

## 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 sub county*

Embu West District is located in Embu County, in the central highlands of Kenya, and occupies an area of 708 km$^2$ and is bordered by Mbeere district to the East and South East, Kirinyaga to the West and Meru South to the North. The experimental site lies within N 0° 31´ 4.2´´ E 37° 27´ 20´´ and at the altitude of 1468 m above the sea level (ASL), at Embu Agricultural Staff Training College (Jaetzold et al., 2006). Diagnosis study carried out in the central highlands of Kenya have reported soil fertility constraints, particularly N and P deficiencies, low carbon content and low soil pH (Gachimbi et al., 2002). The major agro-ecological zone (AEZ) is Upper Midland 2 (UM 2), the soils are humic nitisols and the total arable land area is 478 km$^2$ with total available agricultural land area covering 371 km$^2$. Table 1 shows the soil characteristics of the soils in Kamujine. The average annual rainfall varies from 1230 to 909 mm with long rainy season between March and June and short rainy season between October and December, respectively. Rainfall for the two seasons in which the experiment was conducted is presented Figure 1.

### *Tigania East sub county*

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 within N 0° 6´ 19.5´´ E 037° 64´ 39.6´´ and at the altitude of 935 m above the sea level (ASL), at Kamujine Dispensary in

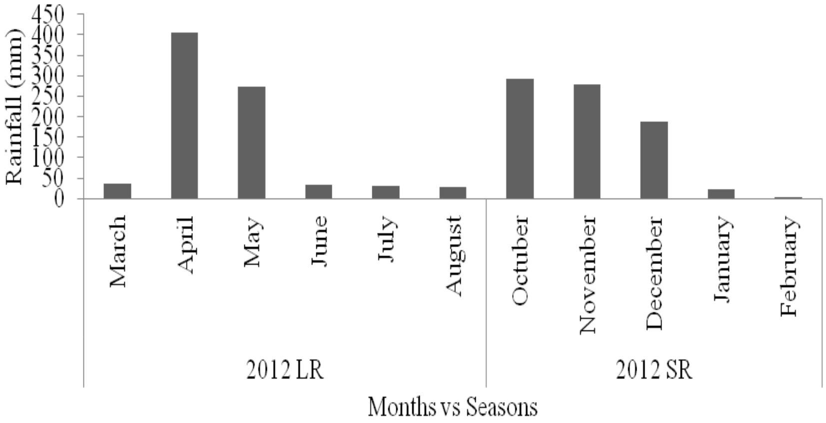

**Figure 1.** Rainfall amount during 2012 LR and 2012 SR at Embu-ATC, Embu west sub county, Kenya.

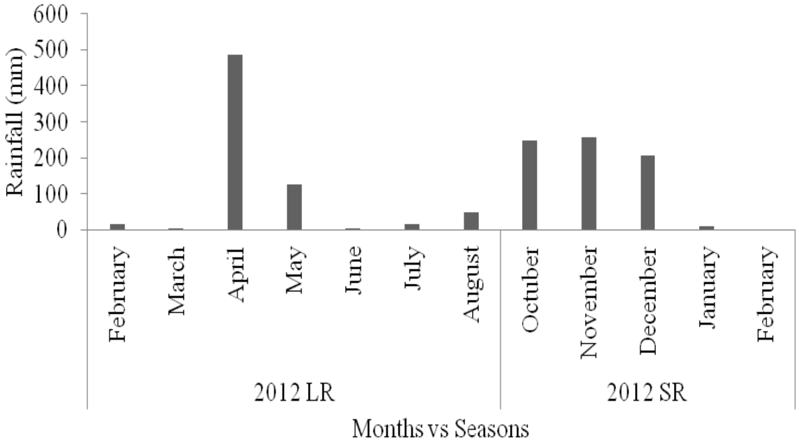

**Figure 2.** Rainfall amount during 2012 LR and 2012 SR at Kamujine site, Tigania East Sub county, Kenya.

Mikinduri Division. The major agro-ecological zones are Lower Midlands 3 and Upper Midland 3 (LM 3 and UM 3), the soils are mainly eutric Nitisols and humic Cambisols. The annual average temperature varies from 19.2 to 22.9°C (Jaetzold et al., 2006). Table 1 shows the soil characteristics of the soils in Kamujine.

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). Rainfall for the two seasons in which the experiment was conducted and presented in Figure 2.

### Management of the experiment

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. At Embu-ATC, planting was done on the 23rd of March 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. The sole maize (*Zea mays* L.) var. DK 8031 was planted at a spacing of 0.75 m 0.50 m inter and intra-row, respectively. The number of hills per row was 10 with three seeds per hill in order to ensure maximum plant population and to account for germination failure; and two weeks after germination the excess plants were thinned out to remain with two plants per hill. The sole soybean (*Glycine max* (L.) Merrill) var. Gazelle was hand drilled at a spacing of 0.45 m × 0.10 m in inter and intra – row spacing resulting to 62 plants per row to ensure maximum germination/population and the excess plants were thinned out to remain with the recommended population of 31 plants per row after 2 weeks of emergence. The following external nutrient replenishment inputs were applied per plot: 6 kg of manure equivalent to 30 kg N ha$^{-1}$, applied two weeks before planting; 94.5 g of CAN 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 g of TSP as source of P, equivalent to 60 kg P ha$^{-1}$, which was applied at sowing. The fertilizers were applied accordingly to the recommendation from FURP (1987). Management practices were the same for both the monocrop and the maize – soybean intercrop.

**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) |

### Experimental design and management

First, soil samples from the experimental sites were collected at 0 to 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. The experiment was established in Embu-ATC (Embu West district) and in Kamujine (Tigania East district) and it was laid out as a randomized complete block design (RCBD) with four replicate blocks and plot sizes measuring 7 m × 4.5 m. 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).

### Soil sampling and determination of soil mineral nitrogen

Soil sampling was done during two seasons, in March long rain (LR) and in October short rain (SR) of 2012, at the beginning of the season before planting, at 0 to 15 cm depth ($t_0$). Subsequent samples was taken at 2, 4, 6, 8, 12, 16 and 20 weeks after planting (WAP) at the same depth, in all plots, during the LR 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. Then, the soil samples was packed in cooler boxes and delivered to the laboratory within 24 h. To avoid any further mineralization before extraction, the samples were stored in the fridge at 5°C. The soil extraction was done using 2 M 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. This sampling was done outside the net plots. The samples were then oven-dry at 60°C for 48 h, milled and sieved through a 1.0 mm sieve and then analyzed separately for nitrogen concentration using Kjeldahl acid digestion method, followed by colorimetry 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 chemical properties

The soil samples that were taken for mineral N determination was also measured on 2.5:1 water to soil suspension for pH using pH meter model AD1000. The same samples were used to determine the extractable phosphorous (P) and the exchangeable cations ($Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$) though Mehlich-1 (M1) extraction method, where P and $Mg^{2+}$ were determined colourimetrically in a spectrophotometer and $Ca^{2+}$, $K^+$ and $Na^+$ were determined using a flame photometer. Total N was determined though Kjeldahl acid digestion method, using an automatic CN elemental analyzer 2000, while organic carbon was determined by the sulphuric acid and aqueous potassium dichromate mixture, also using an automatic CN elemental analyzer 2000.

### Data analysis

Data of soil mineral N, N uptake by maize and soybean, and soil chemical properties were subjected to analysis of variance using SAS version 8. To test the differences between different cropping pattern and conventional intercropping systems, the means were subjected to *t-student* test at 95 per cent 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 ($N0_3^-$ - N) as affected by the intercropping patterns during all the sampling periods, except at 12 WAP where the 2M:4S treatment observed significantly ($p$=0.0285) the highest $N0_3^-$ - N content (9.01 mg $kg^{-1}$) than all other treatments, excluding sole maize treatment; and at harvest (20 WAP) where the MBILI and 2M:4S treatments observed significantly ($p$=0.0525) the lowest $N0_3^-$ - N content (8.24 mg $kg^{-1}$ and 9.15 mg $kg^{-1}$, respectively) than the sole soybean and conventional treatments, with 14.95 and 14.62 mg $kg^{-1}$, respectively. This indicated that intercropping reduced the soil nitrate that moved to region where it couldn't be easily absorbed by plant roots. At Kamujine during the same 2012 LR, no significant differences were also observed in soil nitrate – N content ($N0_3^-$ - N) as affected by the intercropping patterns during all the sampling periods, except at 20 WAP where sole soybean treatment recorded statistically ($p$=0.0301) the highest $N0_3^-$ - N content (8.24 mg $kg^{-1}$) than all other treatments, excluding the 2M:4S treatment (Table 3).

The lower soil nitrate content observed at harvest (20 WAP) in maize – soybean intercrop was also reported by Ye et al. (2008). Li et al. (2005) and Zhang and Li (2003)

**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 $p < 0.001$.

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 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) as affected by 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). This signified that the 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.

At Embu during 2012 LR, no significant differences were observed in soil mineral – N content as affected by the intercropping patterns during all the sampling periods (Table 5). 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%) followed by the sole soybean with 16.21% (Figure 3a). 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% (Figure 3b). Similarly, Hauggaard-Nielsen et al. (2001a) did not find significant differences on soil mineral N at harvest in the 0 to 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) 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 affected by the treatments during all the sampling periods, except at 20 WAP where sole soybean recorded statistically ($p$=0.0131) the highest (12.84 mg kg$^{-1}$) soil mineral N than all other treatments, excluding 2M:4S treatment (Table 5). 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%) and the lowest (34.92%) values, respectively (Figure 4). Similarly, Hauggaard-Nielsen et al. (2001b) observed higher soil mineral N at harvest in the 0 to 25 cm soil layer under pea sole crop compared to the other treatments independent of cropping strategy. Hauggaard-Nielsen et al. (2001c) reported that the lowest soil inorganic N deficit was observed in pea sole crop and the greatest in barley

**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 $p < 0.001$.

**Table 5.** Soil mineral – 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 |
| | | Soil mineral N (mg kg$^{-1}$) | | | | | | |
| Embu | Sole maize | 10.42 | 11.15 | 13.61 | 13.73 | 11.53 | 8.08 | 15.74 |
| | Sole soybean | 14.87 | 15.70 | 12.76 | 10.10 | 8.81 | 9.66 | 17.28 |
| | Maize-Soybean (1M:1S) | 15.59 | 15.22 | 10.01 | 11.16 | 12.34 | 11.07 | 17.14 |
| | Maize-Soybean (2M:2S) | 17.53 | 13.96 | 11.16 | 10.07 | 10.48 | 8.73 | 11.99 |
| | Maize-Soybean (2M:4S) | 17.44 | 14.76 | 12.86 | 10.64 | 14.64 | 10.68 | 15.47 |
| | Maize-Soybean (2M:6S) | 18.07 | 13.72 | 16.16 | 11.89 | 9.60 | 10.96 | 12.98 |
| *p-value* | | 0.2846 | 0.5250 | 0.5306 | 0.8432 | 0.2235 | 0.7907 | 0.5689 |
| LSD$_{(0.05)}$ | | 7.38 | 5.23 | 6.89 | 6.64 | 5.02 | 5.48 | 7.34 |
| Kamujine | Sole maize | 19.73 | 10.86 | 12.22 | 9.42 | 8.66 | 6.89 | 7.15 |
| | Sole soybean | 19.73 | 14.66 | 11.39 | 13.68 | 14.34 | 12.29 | 12.84 |
| | Maize-Soybean (1M:1S) | 16.55 | 12.83 | 13.20 | 9.54 | 7.87 | 9.25 | 7.23 |
| | Maize-Soybean (2M:2S) | 15.90 | 10.03 | 7.93 | 10.19 | 10.39 | 9.07 | 6.04 |
| | Maize-Soybean (2M:4S) | 22.23 | 12.93 | 13.23 | 7.33 | 10.92 | 10.81 | 9.26 |
| | Maize-Soybean (2M:6S) | 15.64 | 13.70 | 11.35 | 10.98 | 10.49 | 8.91 | 5.75 |
| *p-value* | | 0.4582 | 0.7342 | 0.6385 | 0.1880 | 0.3351 | 0.2669 | 0.0131* |
| LSD$_{(0.05)}$ | | 8.08 | 7.07 | 7.11 | 4.81 | 6.06 | 4.62 | 3.88 |

ns, Not significant; *, significant at $p \leq 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

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 (Hauggaard-Nielsen et al., 2001c). As an average of four years experimentation,

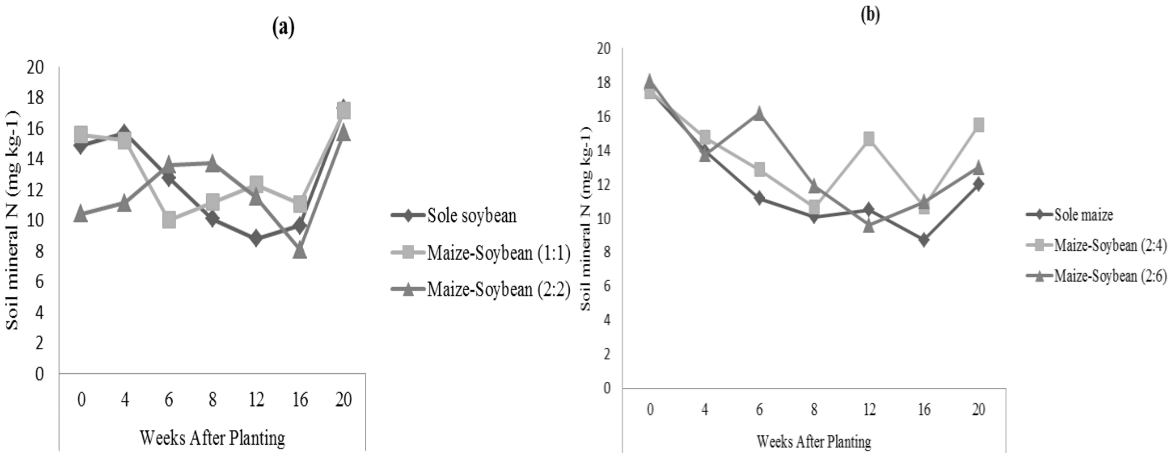

**Figure 3.** Soil mineral – N trend at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu.

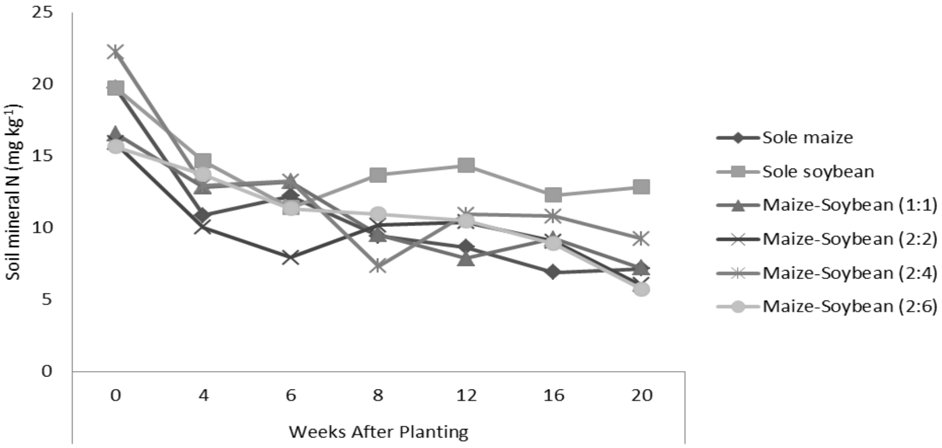

**Figure 4.** Soil mineral – N trend at 0–15 cm soil depth sampled at different periods during 2012 LR at Kamujine.

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 6). For instance, at 4 WAP the sole soybean yielded significantly the highest N amount (2.75% N, *p*=0.0026) than all 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 and harvest the sole soybean had accumulated significantly the lowest N (0.35% N, *p*<0.0001 and 0.33% N, *p*<0.0001, respectively) than all 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. For the grain, monocropped soybean had accumulated significantly the highest amount of N (5.59% N, *p*<0.0001) than all other treatments, excluding soybean under conventional and MBILI 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 that for sole cropping, particularly up to 12 WAP (Table 6).

During 2012 LR at Kamujine site, intercropping systems affected significantly the N acquisition by maize and soybean (Table 6). For instance, at 4 WAP the

**Table 6.** 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 | |
| | | | Stover | | | | | | Grain |
| Embu | Sole maize | Maize | 1.69 | 1.73 | 2.79 | 2.52 | 1.78 | 1.67 | 1.13 |
| | Sole soybean | Soybean | 2.75 | 1.96 | 2.88 | 1.48 | 0.35 | 0.33 | 5.59 |
| | Maize-Soybean (1M:1S) | Maize | 1.30 | 1.69 | 2.67 | 2.18 | 1.95 | 1.83 | 1.66 |
| | | Soybean | 2.59 | 2.02 | 2.98 | 2.19 | 1.21 | 1.17 | 5.44 |
| | Maize-Soybean (2M:2S) | Maize | 1.38 | 1.39 | 2.80 | 2.02 | 2.16 | 2.03 | 1.62 |
| | | Soybean | 2.43 | 2.02 | 3.34 | 2.08 | 0.53 | 0.50 | 5.17 |
| | Maize-Soybean (2M:4S) | Maize | 1.82 | 1.87 | 2.72 | 2.45 | 1.88 | 1.77 | 1.90 |
| | | Soybean | 2.25 | 2.07 | 3.53 | 2.07 | 0.60 | 0.57 | 4.21 |
| | Maize-Soybean (2M:6S) | Maize | 1.02 | 1.34 | 2.33 | 2.39 | 1.90 | 1.71 | 1.77 |
| | | Soybean | 2.20 | 1.90 | 2.93 | 1.99 | 0.45 | 0.44 | 4.66 |
| *p – value* | | | 0.0026** | 0.4320 | 0.1942 | 0.6001 | <0.0001*** | <0.0001*** | <0.0001*** |
| $LSD_{(0.05)}$ | | | 0.86 | 0.74 | 0.80 | 0.94 | 0.73 | 0.68 | 0.71 |
| Kamujine | Sole maize | Maize | 1.60 | 1.66 | 197 | 1.43 | 1.07 | 1.03 | 0.98 |
| | Sole soybean | Soybean | 3.00 | 2.60 | 3.16 | 3.31 | 0.69 | 1.10 | 5.07 |
| | Maize-Soybean (1M:1S) | Maize | 1.24 | 1.61 | 1.78 | 1.43 | 1.04 | 1.00 | 1.40 |
| | | Soybean | 2.87 | 4.28 | 2.97 | 2.22 | 0.26 | 0.26 | 5.39 |
| | Maize-Soybean (2M:2S) | Maize | 1.31 | 1.33 | 2.05 | 1.77 | 1.75 | 1.68 | 1.10 |
| | | Soybean | 3.26 | 2.79 | 2.68 | 1.72 | 0.38 | 0.37 | 4.88 |
| | Maize-Soybean (2M:4S) | Maize | 1.73 | 1.79 | 2.43 | 1.79 | 0.61 | 0.59 | 0.89 |
| | | Soybean | 2.79 | 2.12 | 2.98 | 2.84 | 0.71 | 0.71 | 4.91 |
| | Maize-Soybean (2M:6S) | Maize | 0.97 | 1.28 | 2.27 | 1.09 | 0.86 | 0.83 | 1.47 |
| | | Soybean | 3.20 | 3.19 | 2.72 | 1.78 | 0.99 | 0.70 | 4.65 |
| *p – value* | | | <0.0001**** | <0.0001* | 0.0102** | 0.0031** | 0.0053** | 0.0176* | <0.0001*** |
| $LSD_{(0.05)}$ | | | 0.87 | 0.99 | 0.78 | 1.00 | 0.65 | 0.70 | 0.78 |

ns, Not significant; *, significant at $p \leq 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

soybean under MBILI treatment had accumulated significantly the highest N (3.26% 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% N, *p*<0.0001) than all other treatments. At 8 WAP the soybean sole acquired significantly the highest N (3.16% 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 of the same period. At 12 WAP still the sole soybean observed significantly the highest N (3.31% N, *p*=0.0031) than all 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% N, *p*=0.0053) than all other intercropping patterns. At harvest, still the maize under MBILI treatment accumulated significantly the highest N (1.68% N, *p*=0.0176) than all other treatments, except sole maize, sole soybean 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 various treatments had accumulated significantly (*p*<0.0001) the lowest N level than the entire soybean, sole and intercropped (Table 6).

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 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 et al., 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, b). 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.

## Effects of maize – soybean intercropping patterns on chemical soil properties

At Embu site, before planting the pH values were not significantly different (*p*=0.6585) from one treatment to another, and were ranging between 5.30 (for conventional and MBILI treatments) and 5.37 (for sole soybean treatment). After harvesting the first (2012 LR) and second (2012 SR) seasons they were not significantly (*p*=0.5581 and *p*=0.7956, respectively) affected by the treatments. However, they experienced a general decrease from the preseason to post second season; the highest and lowest reduction was observed in the sole maize (2.49%) and the conventional (0.57%) treatments, respectively. This situation was not expected because manure that was applied as blank was supposed to have increased the soil pH in all the treatments due to its buffer capacity; but, probably the exchangeable cations were leached from the topsoil (0-15 cm) because of the heavy rains that were registered during the seasons. At Kamujine site, although there were also no significant differences in the three sampling periods (*p*=0.3046, *p*=0.1946 and *p*=0.0835, respectively), the situation was slightly different from Embu site because the pH values increased from the preseason to post second season, where the sole maize recorded the highest increase (8.31%) and 2M:6S treatment with the lowest value of 4.03% (Table 7).

At Embu site, the available phosphorus values did not show any significant differences (*p*=0.2373, *p*=0.6963, *p*=0.3224, respectively) among the treatments, during all the sampling periods. However, the P values were generally decreased from the preseason to the post second season, varying from 66.83 in the 2M:6S treatment to 35.82% (in the conventional treatment). Similar situation was observed at Kamujine site, where P values were also not significantly different in the three sampling periods (*p*=0.7243, *p*=0.6508 and *p*=0.6775, respectively). However, they also decreased from the preseason to post second season, with values varying from 57.56% (conventional treatment) to 37.74% in the MBILI treatment (Table 7).

At Embu site, at preseason the $N0_3^-$ - N values were not significantly different (*p*=0.4638) from one treatment to another; however, the highest value was in the MBILI treatment (10.22 mg $kg^{-1}$) and the sole maize had the lowest value of 5.19 mg $kg^{-1}$ $N0_3^-$ - N. After the harvest of the second seasons (2012 SR), they still did not show any significant differences (*p*=0.4249) among the treatments, where the conventional treatment observed the lowest value of 5.50 mg $kg^{-1}$ $N0_3^-$ - N and the highest (9.05 mg $kg^{-1}$ $N0_3^-$ - N) was observed in the 2M:4S treatment. The situation was slightly different at Kamujine site, where during the preseason the $N0_3^-$ - N was not statistically different (*p*=0.6283) from one treatment to another at the preseason; but, after harvesting the second season (2012 SR), intercropping patterns affected significantly (*p*=0.0038) the $N0_3^-$ - N, and the sole soybean treatment had recorded statistically the highest $N0_3^-$ - N of 10.78 mg $kg^{-1}$ than all other treatments. This could be due to senescent nodules from the roots and decomposed organic matter of two seasons.

During the preseason at Embu site, the amount of $NH_4^+$ - N was not significantly different (*p*=0.8610) from one treatment to another; and, it remained not statistically different (*p*=0.9119) after harvesting the second season. However, the $NH_4^+$ - N values experienced a general decrease from the preseason to post second season; the lowest and highest reduction was observed in the sole

**Table 7.** Effect of intercropping patterns on soil chemical properties during 2012 LR and 2012 SR at Embu and Kamujine sites.

| Location | Treatment | pH (water, 1:2.5) | | | P (ppm) | | |
|---|---|---|---|---|---|---|---|
| | | Before | 2012LR | 2012SR | Before | 2012LR | 2012SR |
| Embu | Sole maize | 5.36 | 5.20 | 5.23 | 12.85 | 12.81 | 8.43 |
| | Sole soybean | 5.37 | 5.20 | 5.26 | 13.21 | 13.74 | 7.94 |
| | Maize-Soybean (1M:1S) | 5.30 | 5.32 | 5.27 | 12.21 | 15.03 | 8.99 |
| | Maize-Soybean (2M:2S) | 5.30 | 5.34 | 5.26 | 12.65 | 13.39 | 8.93 |
| | Maize-Soybean (2M:4S) | 5.36 | 5.32 | 5.30 | 15.78 | 13.62 | 9.31 |
| | Maize-Soybean (2M:6S) | 5.31 | 5.25 | 5.22 | 13.68 | 13.46 | 8.20 |
| *p-value* | | 0.6585 | 0.5581 | 0.7956 | 0.2373 | 0.6963 | 0.3224 |
| $LSD_{(0.05)}$ | | 0.12 | 0.21 | 0.13 | 3.09 | 2.86 | 1.40 |
| Kamujine | Sole maize | 5.41 | 5.62 | 5.90 | 9.50 | 10.84 | 6.21 |
| | Sole soybean | 5.43 | 5.51 | 5.71 | 9.50 | 12.15 | 6.64 |
| | Maize-Soybean (1M:1S) | 5.55 | 5.63 | 5.91 | 10.21 | 12.20 | 6.48 |
| | Maize-Soybean (2M:2S) | 5.41 | 5.55 | 5.73 | 8.76 | 13.01 | 6.36 |
| | Maize-Soybean (2M:4S) | 5.49 | 5.62 | 5.87 | 9.18 | 10.27 | 6.37 |
| | Maize-Soybean (2M:6S) | 5.48 | 5.49 | 5.71 | 10.02 | 12.56 | 7.20 |
| *p-value* | | 0.3046 | 0.1946 | 0.0835 | 0.7243 | 0.6508 | 0.6775 |
| $LSD_{(0.05)}$ | | 0.15 | 0.15 | 0.19 | 2.13 | 3.88 | 1.33 |

ns, Not significant; *, significant at $p \leq 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

maize (50.57%) and the 2M:4S (116.75%) treatments, respectively. At Kamujine site, there was also no significant differences during the two sampling periods (*p*=0.6406, and *p*=0.1446, respectively). However, the sole maize treatment showed the highest $NH_4^+$ - N reduction of 166.39% and the MBILI treatment observed the lowest reduction of about 30% (Table 8).

During the preseason and 2012 SR at Embu site, the mineral – N values did not show any significant differences (*p*=0.2846, *p*=0.3474, respectively) among the treatments, during the two the sampling periods. However, the mineral – N values were generally decreased from the preseason to the post second season, varying from 60.68 in the conventional treatment to 15.36% in the sole soybean, excluding for the sole maize treatment which observed unexpectedly increase in mineral – N values of 11.69%. The situation was slightly different at Kamujine site, where mineral - N values were only not significantly different (*p*=0.4582) during the preseason; but during 2012 SR, soil mineral – N was significantly (*p*=0.0112) affected by the intercropping patterns; and, sole soybean treatment had observed statistically the highest amount of soil mineral – N of 13.81 mg $kg^{-1}$ than all other treatments (Table 8).

At Embu site, before planting the $Ca^{2+}$ values were not significantly different (*p*=0.2670) from one treatment to another, and were ranging between 0.26 Cmol $kg^{-1}$ for 2M:4S treatment and 0.18 Cmol $kg^{-1}$ for MBILI treatment. After harvesting the first (2012 LR) and second (2012 SR) seasons they were not significantly (*p*=0.4209 and *p*=0.7795, respectively) affected by the treatments. However, they experienced a general decrease from the preseason to post second season; the highest and lowest reduction was observed in the sole maize (212.50%) and in the MBILI and 2M:6S treatments (100.0%), respectively. At Kamujine site, there were also no significant differences in the three sampling periods (*p*=0.6791, *p*=0.4224 and *p*=0.1715, respectively); and, similarly the $Ca^{2+}$ values observed reduction at the end of 2012 SR, where the highest reduction was recorded in the MBILI treatment (214.29%) and the lowest in the conventional treatment with 37.50% less $Ca^{2+}$ than its preseason (Table 9).

At Embu site, the $Mg^{2+}$ values did not show any significant differences (*p*=0.5922, *p*=0.5326, *p*=0.4484, respectively) among the treatments, during all the sampling periods. However, the values were slightly decreased from the preseason to the post second season, varying from 17.02% in the sole maize treatment to 1.89% in the sole soybean treatment. Slightly different situation was observed at Kamujine site, where $Mg^{2+}$ values were only significantly (*p*<0.0001) affected by the treatment during 2012 SR, having sole maize treatment observed statistically the highest $Mg^{2+}$ value of 0.37 Cmol $kg^{-1}$ than all other treatments (Table 9).

At Embu site, the $K^+$ values did not show any significant differences (*p*=0.6801, *p*=0.5579, *p*=0.3850, respectively) among the treatments, during all the sampling periods. However, the $K^+$ values were generally decreased from the preseason to the post second season, varying from 225% in the sole maize treatment to 50% in the sole soybean treatment. Similar situation was observed at

**Table 8.** Effect of intercropping patterns on soil chemical properties (mineral – N) during 2012 SR at Embu and Kamujine sites.

| Location | Treatment | N0$_3^-$ (mg kg$^{-1}$) | | NH$_4^+$ (mg kg$^{-1}$) | | Mineral N (mg kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|
| | | Before | 2012 SR | Before | 2012 SR | Before | 2012 SR |
| Embu | Sole maize | 5.19 | 8.32 | 5.24 | 3.48 | 10.42 | 11.80 |
| | Sole soybean | 7.42 | 8.73 | 7.45 | 4.16 | 14.87 | 12.89 |
| | Maize-Soybean (1M:1S) | 6.95 | 5.50 | 7.64 | 3.59 | 14.59 | 9.08 |
| | Maize-Soybean (2M:2S) | 10.22 | 7.17 | 7.31 | 4.47 | 17.53 | 11.64 |
| | Maize-Soybean (2M:4S) | 8.77 | 9.05 | 8.67 | 4.00 | 17.44 | 13.05 |
| | Maize-Soybean (2M:6S) | 8.76 | 8.25 | 9.31 | 4.45 | 18.07 | 12.70 |
| *p-value* | | 0.4638 | 0.4249 | 0.8610 | 0.9119 | 0.2846 | 0.3474 |
| LSD$_{(0.05)}$ | | 5.35 | 3.85 | 6.92 | 2.36 | 7.38 | 4.04 |
| Kamujine | Sole maize | 13.31 | 6.33 | 6.42 | 2.41 | 19.73 | 8.74 |
| | Sole soybean | 12.87 | 10.78 | 6.86 | 3.04 | 19.73 | 13.81 |
| | Maize-Soybean (1M:1S) | 10.71 | 5.55 | 5.84 | 2.73 | 16.55 | 8.27 |
| | Maize-Soybean (2M:2S) | 11.94 | 5.12 | 3.96 | 3.05 | 15.90 | 8.17 |
| | Maize-Soybean (2M:4S) | 14.72 | 7.47 | 7.51 | 3.14 | 22.23 | 10.62 |
| | Maize-Soybean (2M:6S) | 9.53 | 6.54 | 6.11 | 3.45 | 15.64 | 9.99 |
| *p-value* | | 0.6283 | 0.0038** | 0.6406 | 0.1446 | 0.4582 | 0.0112** |
| LSD$_{(0.05)}$ | | 6.70 | 2.57 | 4.41 | 0.78 | 8.08 | 3.06 |

ns, Not significant; *, significant at $p \leq 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

**Table 9.** Effect of intercropping patterns on soil chemical properties (exchangeable cations) during 2012 LR and 2012 SR at Embu and Kamujine sites.

| Location | Treatment | Ca$^{2+}$ (Cmol kg$^{-1}$) | | | Mg$^{2+}$ (Cmol kg$^{-1}$) | | | K$^+$ (Cmol kg$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Before | 2012 LR | 2012 SR | Before | 2012 LR | 2012 SR | Before | 2012 LR | 2012 SR |
| Embu | Sole maize | 0.25 | 0.24 | 0.08 | 0.55 | 0.49 | 0.47 | 0.13 | 0.10 | 0.04 |
| | Sole soybean | 0.20 | 0.19 | 0.07 | 0.54 | 0.54 | 0.53 | 0.12 | 0.12 | 0.08 |
| | Maize-Soybean (1M:1S) | 0.25 | 0.24 | 0.09 | 0.53 | 0.49 | 0.48 | 0.11 | 0.11 | 0.05 |
| | Maize-Soybean (2M:2S) | 0.18 | 0.16 | 0.09 | 0.50 | 0.46 | 0.46 | 0.10 | 0.08 | 0.06 |
| | Maize-Soybean (2M:4S) | 0.26 | 0.20 | 0.10 | 0.55 | 0.53 | 0.52 | 0.12 | 0.11 | 0.07 |
| | Maize-Soybean (2M:6S) | 0.20 | 0.18 | 0.10 | 0.51 | 0.44 | 0.44 | 0.11 | 0.10 | 0.05 |
| *p-value* | | 0.2670 | 0.4209 | 0.7795 | 0.5922 | 0.5326 | 0.4484 | 0.6801 | 0.5579 | 0.3850 |
| LSD$_{(0.05)}$ | | 0.07 | 0.10 | 0.04 | 0.09 | 0.13 | 0.10 | 0.05 | 0.04 | 0.04 |
| Kamujine | Sole maize | 0.21 | 0.20 | 0.15 | 0.50 | 0.46 | 0.37a | 0.08 | 0.08 | 0.08 |
| | Sole soybean | 0.27 | 0.22 | 0.15 | 0.50 | 0.50 | 0.28cd | 0.06 | 0.08 | 0.07 |
| | Maize-Soybean (1M:1S) | 0.22 | 0.26 | 0.16 | 0.54 | 0.49 | 0.29c | 0.07 | 0.08 | 0.08 |
| | Maize-Soybean (2M:2S) | 0.22 | 0.22 | 0.07 | 0.53 | 0.52 | 0.26d | 0.09 | 0.08 | 0.07 |
| | Maize-Soybean (2M:4S) | 0.22 | 0.17 | 0.09 | 0.57 | 0.54 | 0.34b | 0.08 | 0.06 | 0.06 |
| | Maize-Soybean (2M:6S) | 0.18 | 0.22 | 0.10 | 0.49 | 0.58 | 0.33b | 0.07 | 0.08 | 0.07 |
| *p-value* | | 0.6791 | 0.4224 | 0.1715 | 0.4743 | 0.5672 | <0.0001*** | 0.4306 | 0.3612 | 0.4704 |
| LSD$_{(0.05)}$ | | 0.11 | 0.09 | 0.08 | 0.09 | 0.14 | 0.03 | 0.02 | 0.02 | 0.02 |

ns, Not significant; *, significant at $p \leq 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

Kamujine site, where K$^+$ values were also not significantly different in the three sampling periods (*p*=0.4306, *p*=0.3612 and *p*=0.4704, respectively). But differently from Embu site, at Kamujine site they showed three different trends, where in the sole maize and 2M:6S treatments the values remained constant; in the sole soybean and conventional treatments the values were slightly increased; and in the MBILI and 2M:4S

**Table 10.** 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 $p < 0.001$.

treatments the values decreased from the preseason to post second season (Table 9).

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% (*p*=0.0530) than all other intercropping patterns, excluding the 2M:4S treatment. 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% 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. 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%, *p*=0.0020 (Table 10). In general, the SOC at this site was not expected to be relatively low under intercropping treatments than under sole crop treatments. 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 increase in the soil pH values in intercropped systems compared with sole cropping systems as encountered at Kamujine site, demonstrates that intercropping lead to reduction in soil acidity compared to monocropping systems, probably due to higher organic material generation. Similarly, Esekhade and Idoko (2010) and Esekhade et al. (2003) observed higher soil pH in intercropping treatments compared with soil under monocropping. Yasin et al. (2010) argued that, decomposition product of organic matter (maize) in the soil can play a role as soil pH regulator. Contrarily to the findings in this study, Dahmardeh et al. (2010) found that intercropping of maize-cowpea had significantly increased the phosphorus and potassium in soil, and that the lowest P level was observed in the sole maize treatment. Although, not significantly different from other treatments, the lowest P level in sole maize was also observed in this study at Kamujine site. Similarly, Suwanarit et al. (1998) did not find significant effect of corn-groundnut intercropping system on available phosphorus. The soil mineral – N observed under sole legume treatment at Kamujine site was also reported by Dahmardeh et al. (2010), who found that soil mineral – N was significantly higher under sole cowpea treatment than in the other treatments.

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). Soil chemical 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 only at harvest (20 WAP) at both locations, and at 12 WAP at Embu site. But in general, the soil nitrate-N was reduced due to intercropping patterns. At both locations, the soil ammonium-N was not significantly affected by the maize-soybean intercropping patterns. The soil mineral-N was not significantly affected by the maize-soybean intercropping patterns at Embu site; and at Kamujine site it was only affected at harvest (20 WAP).

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. The N acquired by both crops was highly significantly positively correlated with soil mineral N. The maize-soybean intercropping patterns had no significant effect on soil pH, extractable phosphorus, exchangeable calcium and potassium, and extractable ammonium at both locations.

But, the nitrate-N and mineral-N that were significantly higher under sole soybean treatment at Kamujine site during 2012 SR; the exchangeable magnesium was significantly higher under maize sole crop at Kamujine site during 2012 SR.

At Embu site during 2012 SR, the soil total N was significantly affected by the intercropping patterns, whereas at Kamujine site was not affected. The MBILI 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, but it was not affected at Embu site.

## 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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