

Intermediate Maturing Soybean Produce Multiple Benefits at 1:2 Maize:Soybean Planting Density

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Abstract

A study was conducted to identify the most suitable intercropping arrangement in smallholder farms in Western Kenya. Biomass and N (nitrogen)-accumulation, N₂ fixation and grain yield of maize and soybeans grown as intercrops at three planting densities were assessed. The study was conducted in four seasons. Three soybean varieties, Namsoy 4m, SC Squire and TGx1987-18F, were used in the experiment. Maize: soybean planting densities 1:1 (D1), 1:2 (D2), 1:3 (D3) as well as sole soybean (SS) and sole maize (SM) were tested. Higher biomass, N-accumulation, and N-fixed in the order 3.8 Mg ha⁻¹, 260 kg ha⁻¹ and 161 kg ha⁻¹ respectively, were recorded in D3 with long maturing variety TGx1987-18F. Conversely, higher soybean grain yield < 2.4 Mg ha⁻¹ was achieved by intermediate maturing SC Squire in D3. The highest maize yield in the intercrop was obtained in D1. N balance calculations indicated that planting TGx1987-18F resulted in an addition of 6 to 67 kg N ha⁻¹, while SC Squire and Namsoy 4 m removed 3 to 89 kg N ha⁻¹ when soybean grain was removed from the field. The differences in N balances between the intercrops depended on the N-fixed and the amount of N in harvested soybean and maize grain. Greater land equivalent ratio < 1.75 were obtained with SC Squire and Namsoy 4m in D2. We concluded that intermediate maturing soybean have multiple benefits for farmers in Western Kenya at 1:2 maize: soybean planting density provided that the practice is accompanied with good soil and crop management practices.

Keywords: soybean-maize intercropping, agricultural intensification, smallholder farmers, soybean varieties, ¹⁵N natural abundance

1. Introduction

Intercropping is regarded as an important practice to stabilize yield, improve crop production and environmental quality in regions with risk in production (Juma, Tabo, Wilson, & Conway, 2013; Vanlauwe et al., 2015). The stability in yield of intercrops is obtained in several ways, most frequently by compensation of yields of individual components (B. Rerkasem, K. Rerkasem, Peoples, Herridge, & Bergersen, 1988; Waddington, Mekuria, Siziba, & Karigwindi, 2007). The reasons for increased production of intercrops are different length of vegetation period, various need for resources and different time of using those resources, suitable vertical arrangement of crops leading to better use of light and less intense competition for nutrients and water (Belel, Halim, Ruffi, & Saud, 2014). However, in the highly populated areas in SSA, majority of farmers practice intercropping because of unavailability of land for cropland expansion. Intercropping of legumes and cereals also conserves natural resources and increase economic returns (Juma et al., 2013).

The most reported best combination for intercropping is intercrop of one crop from the cereal family and the one from the legume family, for example, maize and soybean. Cereals have often been found to have better growth and yields when intercropped with N₂ fixing legumes (Egbe, 2010; Fukai & Trenbath, 1993; Layek et al., 2014; Zhang et al., 2015). This trend is attributed to the transfer of symbiotically fixed N₂ from legumes to cereals, which can be (i) an indirect transfer, through the decomposition of litter, roots and nodules (Fujita, Ofosu-Budu,

& Ogata, 1992); or (ii) through mycorrhizal uptake and translocation (Ofosu-Budu, Fujita, & Ogata, 1990); or (iii) a direct transfer through the common mycorrhizal networks, which enable linkages to form between the root systems of both mixes of crop species (He, Xu, Qiu, & Zhou, 2009) as well as (iv) through the rhizodeposition and subsequent uptake of released root exudates (Fujita et al., 1992; Høgh-Jensen & Schjoerring, 2001; Mahieu et al., 2014). Despite claims for substantial N transfer from legumes crops to the associated cereal crops, benefits are insufficient to meet the requirement of intercropped cereal (Giller, 2001). According to Ledgard, Giller, and Bacon (1995), the benefits from N contribution by legumes are more likely to occur to subsequent crops as the main transfer pathway is due to root and nodule senescence and fallen leaves.

Another advantage of intercropping cereals and legumes is the more efficient utilization of resources such as light, water and nutrients over time and space, leading to increased productivity compared with each sole crop of the mixture (Agegnehu, Ghizaw, & Sinebo, 2008; Mucheru-Muna et al., 2010; Willey, 1979; Zhang & Li, 2003). Increased productivity is attributed to factors such as (i) maintained light absorption rate over a longer period (Stern, 1993); (ii) reduced evapotranspiration rate due to higher leaf area per ground area provided by the legume (Anglade, Billen, & Garnier, 2015); (iii) increased availability of water in the root zones because of deeper penetrating roots of legumes (Giller, 2001) and (iv) promoted N uptake, utilization and photosynthetic efficiency of cereals (Tsubo, Walker, & Mukhala, 2001; Zhang et al., 2015).

Despite the many benefits, intercropping of cereal-legume may lead to reduction in yield of the legume component because of the adverse competitive effects (Willey et al., 1983). The cereal component has often a fast growth rate in the intercrop, height advantage, and a more widespread rooting system which gives it upper hand in competition with associated legume crop (Belel et al., 2014). Greater yield loss of the legume crop may therefore occur due to reduced intensity and quality of solar radiation intercepted by the legume crop canopy during the reproductive period which is an important environmental factor determining yield and yield components of the legume (Biabani, Hashemi, & Herbert, 2012; Jin, Liu, Wang, & Herbert, 2003).

Indices such as land equivalent ratio (LER) (Keating & Carberry, 1993; Smith & Francis, 1986; Willey, 1979), competition ratio (Rao & Willey, 1980), intercropping advantage (Banik, Sasmal, Ghosal, & Bagchi, 2000), and monetary advantage index (Dwivedi et al., 2015), are used to describe competition and economic advantage of intercropping compared to monocropping. In East Asia and West Africa savannah, higher LER (> 1.0), and yield advantage (of 2-63%), indicating advantage in intercropping, has been reported in maize-soybean intercropping in comparison to monocropping (Layek et al., 2014; Muoneke, Ogwuche, & Kalu, 2007; Zhang et al., 2015).

Although intercropping of cereals and legumes is widespread among smallholder farmers in SSA (Odendo, Bationo, & Kimani, 2011), there is limited knowledge on how soybean can best be intercropped with maize to achieve higher nitrogen fixation and yield of both maize and soybean. This is because, in the past, many countries in SSA, including Kenya, gave low priority to soybean research as it was considered a minor crop (J. N. Chianu, Nkonya, Mairura, J. N. Chianu, & Akinnifesi, 2010). In the meantime, soybean is gaining a changing strategic importance, firstly as a key protein source in the booming animal feed industry and secondly as a commodity for human nutrition and income (Chianu et al., 2010), demanding for innovations to increase its productivity. This paper reports results of the study conducted in Western Kenya with the objectives to (i) assess biomass accumulation and nitrogen fixation of soybean varieties intercropped with maize at different planting densities, (ii) determine yields of maize and soybean intercropped at different planting densities; and (iii) assess the benefits of intercropping soybean and maize at different planting densities under smallholder farmers' conditions.

2. Materials and Methods

2.1 Description of Study Sites

The study was carried out in Western Kenya, at Lubino and Manyala villages and was maintained on the same sites for 4 seasons namely the short rainy seasons of 2012 and 2013 and the long rainy seasons of 2013 and 2014. The two sites are separated by a distance of about 50 km. Manyala is found in Butere District located at 0.971°N and 34.274°E, 1363 m altitude. Lubino is found in Mumias District located at 0.312°N and 34.565°E, 1372 m altitude. The rainfall pattern in Western Kenya is bimodal with two distinct rainy seasons; the long rainy season starting in March ending June and short rainy season starting in October ending December. Annual average rainfall in Western Kenya ranges from 900 mm to 2200 mm. Temperatures range from a minimum of 14 °C to a maximum of 36 °C throughout the year (Jaetzold & Schmidt, 2005). According to the same authors the soils at Lubino and Manyala are classified, respectively, as Humic nitisols and Orthic ferralsols.

2.1.1 Weather Conditions During the Study Period

During the study period, the rainfall was recorded daily at all sites using portable rain gauges. The four seasons of the study experienced very different growing conditions (Figure 1). The 2012 short rainy season was excellent for the experiment, but dry spell followed through mid- November and January 2013 when soybean was setting pods (Figure 1a). The 2013 long rainy season was exceptional. The first half of March was dry, resulting in later than normal planting in April (Figure 1b). The planting conditions in 2013 short rainy season were excellent for establishing the experiments, but prolonged dry spell occurred throughout December, which affected the crop at Lubino site (Figure 1c). The 2014 long rainy season was unique with much rain than normal (Figure 1d). The season was cool, and the overall performance of the crop was good. The cumulative rainfall during the study period was 933 and 853 mm during the short rainy season of 2012 and 1368 and 1199 mm during the 2013 long rainy season in Manyala and Lubino, respectively. During the short rainy season of 2013, 892 and 1256 mm was recorded while in the long rainy season of 2014, 1801 and 3295 mm was recorded in Manyala and Lubino respectively (Figures 1a-1d).

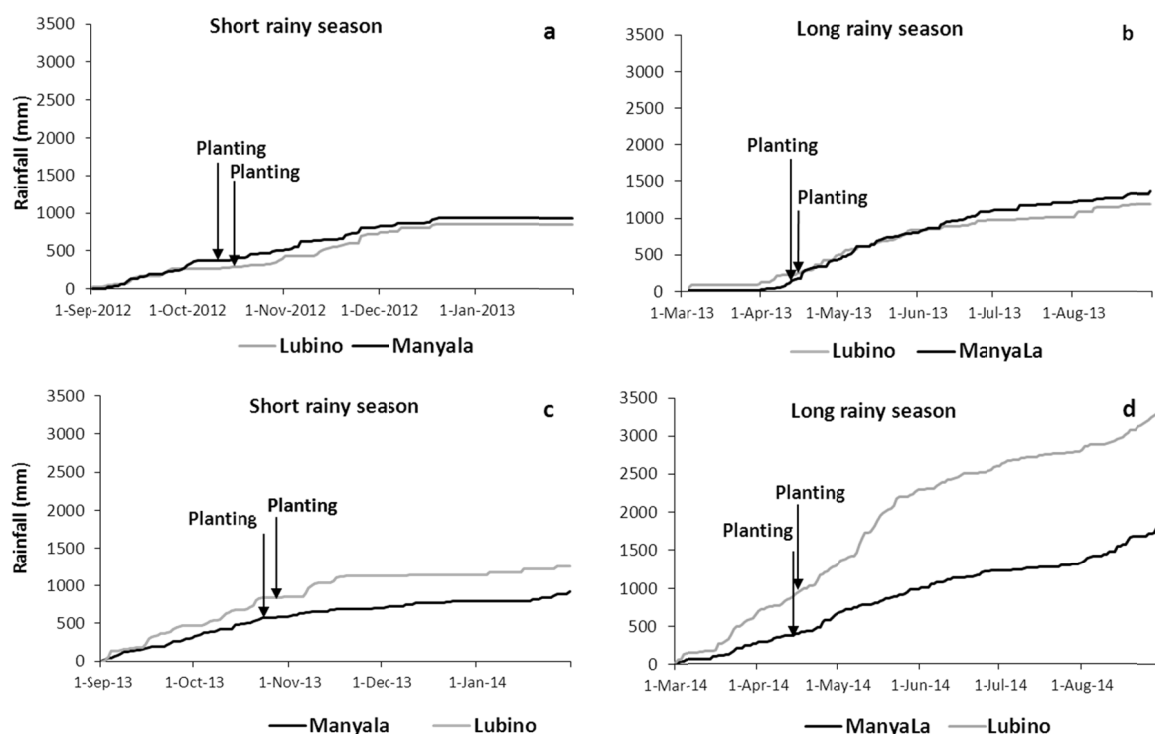


Figure 1. Cumulative daily rainfall during the experimental periods as recorded in 2012 short rainy season (a), 2013 long rainy season (b), 2013 short rainy season (c) and 2014 long rainy season (d) as recorded at Manyala and Lubino sites

2.1.2 Soil Characterization

At the beginning of the experiment in 2012, composite top-soil of nine to twelve samples were collected from each site from 0-20 cm layer in a zigzag manner using a 5 cm diameter soil auger. Samples were air-dried and ground to pass a 2 mm sieve. The soils were analyzed for physical and chemical properties at the International Centre for Tropical Agriculture (CIAT) soil laboratory in Nairobi, Kenya, following procedures described in Okalebo, Gathua, and Woome (1993). Soil pH was determined in a soil:water (1:2.5) suspension. The Bray 2 method was used to determine available P and the Kjeldahl method for total N. Walkley Black method was used to determine organic C and the ammonium acetate method for CEC and exchangeable cations (K, Ca and Mg). Exchangeable Al, B, Zn, Cu and Fe and available molybdenum (Mo) were analyzed based on Mehlich 3 extraction procedure (Mehlich, 1984). Particle size distribution was determined using the hydrometer method and the textural class of the soil was determined using the USDA textural triangle.

Soil data from experimental fields showed wide variability in major properties with soil at Lubino being strongly acidic, low in total N and exchangeable Mg (Table 1). The soil at Manyala was slightly acidic with moderate levels of exchangeable Mg. Both soils had moderate levels of organic C (2.4-2.5 g kg⁻¹), but were low in total N, exchangeable K and Ca. Available P in both soils was far below the critical value for maize and soybean of < 15 mg kg⁻¹ (Nandwa & Bekunda, 1998), but micronutrients Zn, Cu, B and Mo were in sufficient range (Landon, 1991). The sandy clay loam soil at Lubino site had high levels of exchangeable Al and Fe, when compared to a clayey textured soil at Manyala site.

Table 1. Physico-chemical properties of the surface soil (0-20 cm) at the experimental sites

Characteristic	Site	
	Lubino	Manyala
pH (1:2.5 Water)	5.2	5.7
Available P (mg kg ⁻¹)	2.4	7.9
Total N (g kg ⁻¹)	0.1	0.2
Organic C (g kg ⁻¹)	2.5	2.4
C.E.C (meq/100 g)	6.8	9.3
Exchangeable K (cmol _c kg ⁻¹)	0.1	0.1
Exchangeable Ca (cmol _c kg ⁻¹)	1.3	1.1
Exchangeable Mg (cmol _c kg ⁻¹)	0.1	0.2
Al (mg kg ⁻¹)	980.2	660.4
Zn (mg kg ⁻¹)	69.7	57.1
Cu (mg kg ⁻¹)	8.4	11.2
Fe (mg kg ⁻¹)	389.2	189.6
B (mg kg ⁻¹)	4.0	6.8
Mo (mg kg ⁻¹)	1.2	3.6
Sand (%)	55.8	27.9
Clay (%)	25.4	47.4
Silt (%)	18.8	24.7
Textural Class	Sand Clay Loam	Clay

2.2 Treatment and Experimental Design

To estimate maize and soybean populations that give higher biomass and grain yield in maize-soybean intercrops, three maize: soybean planting densities, coded as 1:1 (D1); 1:2 (D2) and 1:3 (D3) (in which the first number represents lines of maize and second number represents lines of soybean) were considered. Treatments with sole soybean (SS) and sole maize (SM) were also included as controls. The planting densities were evaluated using three soybean varieties namely; Namsoy 4m (supplied by Makerere University, Uganda), SC Squire (Supplied by Seed Co. Zimbabwe) and TGx1987-18F (supplied by International Institute of Tropical Agriculture (IITA), Malawi). The tested soybean varieties are well adapted to Western Kenya conditions but differ in growth habit. SC Squire and Namsoy 4m are determinate in growth (finish most of their vegetative growth when flowering begins) and have intermediate growth duration (90-95 days). The soybean variety Namsoy 4m tends to keep more leaves towards maturity when compared to SC Squire. The variety TGx1987-18F is indeterminate (continues with vegetative growth after flowering begins) and takes longer to mature (> 110 days).

To avoid the impact of Striga (a witch weed that is endemic in Western Kenya) on the experiments, an open pollinated (OP) Imidazolinone herbicide resistant maize (IR-maize) variety WS 003 was used. The experimental plots measured 6.5 × 3 m. The experiment comprised 13 treatments with different populations of maize and soybean (Table 2).

Table 2. Treatments and their corresponding equivalent plant population on one ha. The treatments arrangement is as it was in one replication

Treatment no.	Treatment Abbreviation*	Planting density	Soybean varieties	Maize plants in 1 ha	Soybean plants in 1 ha	Maize spacing (between and within row)	Net plot (harvested area)
1	D1	1:1	Namsoy 4m	53.330	266.660	0.75×0.25	4.5×2.0 m
2	D1	1:1	SC Squire	53.330	266.660	0.75×0.25	4.5×2.0 m
3	D1	1:1	TGx1987-18F	53.330	266.660	0.75×0.25	4.5×2.0 m
4	D2	1:2	Namsoy 4m	33.330	333.330	1.2×0.25	4.5×2.5 m
5	D2	1:2	SC Squire	33.330	333.330	1.2×0.25	4.5×2.5 m
6	D2	1:2	TGx1987-18F	33.330	333.330	1.2×0.25	4.5×2.5 m
7	D3	1:3	Namsoy 4m	24.240	363.630	1.65×0.25	3.3×2.0 m
8	D3	1:3	SC Squire	24.240	363.630	1.65×0.25	3.3×2.0 m
9	D3	1:3	TGx1987-18F	24.240	363.630	1.65×0.25	3.3×2.0 m
10	SS	Sole soybean	Namsoy 4m	-	444.440	-	4.5×2.5 m
11	SS	Sole soybean	SC Squire	-	444.440	-	4.5×2.5 m
12	SS	Sole soybean	TGx1987-18F	-	444.440	-	4.5×2.5 m
13	SM	Sole maize	-	53.330	-	0.75×0.25	4.5×2.0 m

Note. * 1:1 (D1) = One row of maize alternated with one row of soybean; 1:2 (D2) = One row of maize alternated with two rows of soybean; 1:3 (D3) = One row of maize alternated with three rows of soybean; The planted plot size was 6.5×3 m.

The experimental design was a factorial, arranged in a randomized complete block design (RCBD) with three replicates, where maize: soybean planting densities and the soybean varieties were the factors.

2.3 Establishment of Experiments and Management

The experiments were established on flat beds prepared using a hand hoe. Before sowing, all plots received a basal application of legume fertilizer “SYMPAL” (NPK 0:25:15) + 10 CaO + 4 S + 1 Mg) at a rate of 200 kg ha^{-1} to provide P at a rate of 22 kg ha^{-1} , K at a rate of 25 kg ha^{-1} , Ca at a rate of 16 kg ha^{-1} , S at a rate of 6.4 kg ha^{-1} and Mg at a rate of 1.6 kg ha^{-1} . For soybean, SYMPAL fertilizer was applied in furrows dug 5 cm deep, slightly covered with soil to remain 2.5 cm deep for planting soybean. For maize, SYMPAL was applied in planting holes (approximately 10 g per planting hole). Plots with SM and D1 treatments received urea fertilizer at a rate of 130 kg ha^{-1} targeted to maize, to supply N at a rate of 60 kg N ha^{-1} where 20 kg was applied at planting and the remaining 40 kg top-dressed, four weeks after crop emergence. Since the population of maize in D2 and D3 was 38% and 55% of that of SM, respectively, the required N dose in D2 and D3 was adjusted to 33 and 23 kg N ha^{-1} , respectively. Soybean seeds were inoculated with rhizobia inoculant BIOFIX (supplied by MEA Kenya Ltd), containing *Bradyrhizobium japonicum* USDA 110 strain. The inoculant was applied at a rate of 10 g kg^{-1} seed, following a two-step method (Somasegaran & Hoben, 2012).

In plots receiving D1 treatment, one line of soybean was established between two lines of maize at a spacing of 0.37 m from the maize lines. In plots receiving D2 treatment, two soybean lines spaced at 0.45 m from each other were established in between two maize lines maintaining a distance of 0.37 m from maize lines. In plots receiving D3 treatment, three lines of soybean were established at same spacing as in D2. In plots receiving SS treatment, soybean was planted at a spacing of 0.45×0.05 m, in furrows opened at a depth of 2.5 cm, after application of SYMPAL fertilizer. Maize in SM plots was planted at a spacing of 0.75×0.25 m, by putting two seeds per planting hole, and subsequently thinned to remain one plant per hill two weeks after emergence. In the short rainy season, the sowing was carried out on 13 and 14 October 2012 and on 18 and 19 September 2013 at Manyala and Lubino site, respectively. Sowing in the long rainy season was done on 12 and 14 April 2013 and on 15 and 16 March 2014 at Manyala and Lubino site, respectively. The experimental fields were kept weed free by frequent weeding using a hand hoe.

2.4 Plant Harvesting, Sampling, Analysis and Calculations

Harvesting of soybeans to determine their biomass and N accumulation as well as N_2 fixation was done when the variety attained 50% flowering. Shoots of soybean plants were harvested in each plot from a randomly selected area of 0.5 m^2 , by cutting the plants at ground level. From each experimental site, additional samples of couch grass (*Digitaria scalarum*) that germinated and grew during the same period as soybeans, were collected around the experimental fields for use as reference plant to estimate the nitrogen fixation by soybean. The couch grass has slender wiry creeping rootstalks with the rooting depth (> 1 m) and a growth period of 100 days (Heuze, Tran,

& Delagarde, 2014), similar to that of soybean varieties tested. Samples of couch grass were collected from 10 positions around the experiment by cutting the grass at ground level then bulked to make a composite sample per location. The shoot samples (soybean and reference plants), were oven-dried at 65 °C to constant weight and the soybean shoot samples weighed.

Shoot biomass yield of soybeans were calculated using the weights of samples taken from each plot and were expressed in Mg ha⁻¹. The dry shoot samples, of soybean and couch grass, were ground to < 1 mm in cyclotech mill in preparation for N and ¹⁵N analysis at Catholic University at Leuven in Belgium. Analysis of δ¹⁵N of couch grass was done in the first two seasons and it was found to be consistent at each site. Hence, the average δ¹⁵N of the first two seasons was used to estimate N₂ fixation by soybeans in the third and fourth seasons, with the assumption that same signature was maintained. The measured values of shoot biomass and % N were used to estimate the total nitrogen in legume biomass (N-biomass), expressed in Mg ha⁻¹. The %N derived from N₂ fixation (Ndfa) was estimated using ¹⁵N natural abundance method (Unkovich et al., 2008).

$$\%Ndfa = (\delta^{15}N_{ref} - \delta^{15}N_{leg}) / (\delta^{15}N_{ref} - B \text{ value}) \times 100 \quad (1)$$

Where, δ¹⁵N ref is the ¹⁵N natural abundance of shoots of non-N-fixing reference plant, δ¹⁵N leg is the ¹⁵N natural abundance of legume (soybean) shoots, and the *B* value is the ¹⁵N natural abundance of a legume depending solely on N₂ fixation for its N nutrition. A *B* value of -1.83 was used in calculating %Ndfa. This value represents the mean *B* value for soybean based on experiments conducted by six different laboratories (Unkovich et al., 2008). The amount of N-fixed was calculated according to Maskey, Bhattarai, Peoples, and Herridge (2001):

$$N\text{-fixed} = (\%Ndfa/100) \times \text{legume N} \quad (2)$$

Where, %Ndfa is percentage of nitrogen derived from atmospheric fixation and legume N is the nitrogen content of soybean shoots.

In the present study, no attempt was made to estimate the N-fixed in soybean roots although studies have shown that roots of nodulating legumes contain substantial amount of fixed nitrogen (Unkovich et al., 2008).

At maturity, soybean and maize from respective treatments were harvested from the net area demarcated after leaving out two rows of maize/soybean on each side of the plot, the first two and the last two maize/soybean plants on each row to minimize possible edge effect. The cobs and pods were then, shelled, grains dried to 12% moisture content, and weighed. The weight of grains was used to calculate yields from each treatment and results extrapolated per hectare basis, expressed in Mg ha⁻¹. After harvest, soybean and maize residues in respective plots were ploughed into the soil to avoid removal by farmers or grazing by animals.

The N balance of intercrops was calculated for the entire one year by subtracting the total N contained in soybean grain and N contained in maize grain from the total N-fixed (averages of two short rainy seasons and 2 long rainy seasons). The nitrogen content of soybean was considered to be 6.08% (based on 38% protein) and maize 1.52% (based on 9.5% protein) (Giller, 2001). The N balance was then calculated as follows:

$$N_{balance} = \sum N_{fixed} - \sum N_{soybean \text{ grain}} + N_{maize \text{ grain}} \quad (3)$$

Where, N_{fixed} is N from N₂ fixation, N_{soybean grain} is N in harvested soybean grain and N_{maize grain} is N in harvested maize grain.

The efficiency of the different planting densities (D1, D2 and D3) for the three soybean varieties tested was determined by calculating the land equivalent ratios (LER) as described by (Willey, 1979). The LER of the intercrops or total LER (LER_{Total}) was obtained by summing the LERs for Maize (LER_{Maize}) and for soybean (LER_{Soybean}):

$$LER_{Total} = LER_{Maize} + LER_{Soybean} = YIM/YSM + YISB/YSSB \quad (4)$$

Where, YIM and YISB are grain yields per hectare of intercropped maize and soybean respectively, and YSM and YSSB are grain yields per hectare of sole cropped maize and soybean, respectively.

A LER value greater than 1.0 indicates an intercrop advantage relative to sole crop. LER values less than 1.0 indicate an intercrop disadvantage and LER values equal to 1.0 imply no difference between the intercrop and sole crop (Willey, 1979).

2.5 Statistical Analysis

Data on biomass accumulation, N-accumulation, N-fixed and grain yield of both maize and soybean were tested for normality and then subjected to analysis of variance (ANOVA) to determine if there were significant differences between planting densities at two locations in the different cropping seasons. The data was averaged

over 2 short rainy seasons (2012 and 2013) and 2 long rainy seasons (2013 and 2014) per location (as season was considered fixed factor) and the analyses were carried per location and season given the agroecological differences between the two locations (Manyala and Lubino) and weather conditions between the two rainy seasons. The statistical package GenStat version 13 was used. Where significant differences were obtained, the means were separated using Fisher's least significance difference (LSD) at $P \leq 0.05$.

3. Results

3.1 Biomass Yield, N-Accumulation and N_2 Fixation by Soybean

Shoot biomass varied across planting densities, sites and seasons (Tables 3 and 4). Higher shoot biomass was recorded on SS and tended to decrease with decreasing soybean plant population, but with a few exceptions. At Manyala site for example, in the short rainy season, biomass yield in D3 was 4% higher than in SS for soybean variety Namsoy 4m, but 13 and 4% lower for SC Squire and TGx1987-18F, respectively. In D2, a decrease in shoot biomass in the range of 19 to 22% was recorded while in D1 the reduction was in the range of 43 to 53% when compared to SS. The same trend was observed at Lubino site where shoot biomass was lower by 22 to 34% in D3, 31 to 45% in D2 and 50 to 61% in D1 relative to SS, across varieties.

In the long rainy season, shoot biomass at Manyala site was reduced by 7 to 26% in D3, 20 to 37.0% in D2 and 2 to 53% in D1 when compared to SS. At Lubino site the decrease ranged between 13 and 30 % in D2 and 28 to 35% in D1, but an increase in biomass yield of 8% was recorded in D3 with the varieties Namsoy 4m and SC Squire. Overall, the differences in shoot biomass between D2 and D1, D3 and D1, D3 and D2 and between D1, D2, and D3 relative to SS were small in the long rainy season when compared to the short rainy season. With the exception of Lubino site in the short rainy season, soybean shoot biomass recorded in D3 was not statically different ($P < 0.01$) from that recorded on SS. Soybean varieties exhibited differences in biomass accumulation under different maize-soybean planting densities with the variety TGx1987-18F accumulating more biomass across planting densities, location and seasons, followed by SC Squire and Namsoy 4m accumulating the least. In general, all soybean varieties accumulated more biomass in the short rainy season than in the long rainy season.

Shoot N-accumulation followed the same trend as shoot biomass across seasons and varieties. For example, in the short rainy season at Manyala site, a decrease in the order of 3% was recorded in D3 when compared to SS, except with the soybean variety Namsoy 4m, which recorded a 2% increase. N-accumulation in D2 and D1 decreased between 19 and 22% and 43 to 53%, respectively, when compared to SS across varieties. At Lubino site, a decrease in N-accumulation by 22 to 34% for D3, 30 to 45% for D2 and 50 to 63% for D1 relative to SS was recorded in the short rainy season. In the long rainy season, at Manyala site, for D3, a decrease in shoot N-accumulation was in the order of 8% with TGx1987-18F and 17% with SC Squire, but an increase of 32% with Namsoy 4m, for D3 was recorded. Furthermore, a decrease in shoot N-accumulation by 18 to 37% for D2 and D1, respectively was observed. At Lubino site, across varieties, N-accumulation decreased from 9 to 31% in D2 and 28 to 34% in D1 when compared to SS. In general, across varieties, seasons and sites, there were no significant differences between N accumulated in D3 and SS except for the short rainy season at Lubino site with the varieties Namsoy 4m and SC Squire. However, significant differences ($P < 0.001$) were found between N-accumulated in D1 and D2 when compared to SS. Across varieties and seasons, the highest N accumulation was recorded on SS, with the soybean variety TGx1987-18F accumulating more N.

The highest amount of N-fixed was recorded in SS with the soybean variety TGx1987-18F fixing 95 and 73 kg N ha⁻¹ in the short rainy season and 55 and 36 kg N ha⁻¹ in the long rainy season at Manyala and at Lubino site, respectively. No significant differences were found in N-fixed between SS and D3. In general, significant differences ($P < 0.001$) in N-fixed were detected between D1 and D2, D1 and D3, D1 and SS, D2 and SS and between D2 and D3 in the short and long rainy seasons, across sites and varieties. However, in the long rain season, these strong variations in N-fixed could not be detected between the planting densities across sites. In both seasons, at all sites, soybean varieties Namsoy 4m and SC Squire accumulated almost the same amount of biomass and nitrogen, and fixed almost the same amount of N when established at any of the planting densities, D1, D2, D3 or SS.

Table 3. Above ground biomass accumulation, N accumulation and N-fixed of tested soybean varieties under different maize-soybean planting densities as recorded at Manyala and Lubino experimental sites; data are means of yields of 2012 and 2013 short rainy seasons

Location	Planting Density	Soybean variety								
		Namsoy 4m			SC Squire			TGx1987-18F		
		AGBM (Mg ha ⁻¹)	N-acc. (kg ha ⁻¹)	N-fix. (kg ha ⁻¹)	AGBM (kg ha ⁻¹)	N-acc. (kg ha ⁻¹)	N-fix. (kg ha ⁻¹)	AGBM (Mg ha ⁻¹)	N-acc. (kg ha ⁻¹)	N-fix. (kg ha ⁻¹)
Manyala	D1	1.6	48	33	1.6	51	33	1.9	68	46
	D2	2.2	68	47	2.6	80	55	3.0	109	74
	D3	2.9	86	59	3.2	100	65	3.8	135	92
	SS	2.8	84	58	3.7	115	75	3.9	140	95
	SM	-	-	-	-	-	-	-	-	-
	LSD AGBM	0.5***								
	LSD N-acc.	16***								
	LSD N-fixed	11***								
Lubino	D1	1.0	31	21	1.3	42	28	1.2	42	29
	D2	1.6	50	34	1.8	58	39	1.8	61	42
	D3	2.1	64	44	2.0	64	43	2.2	73	50
	SS	2.7	82	57	2.7	83	56	3.3	111	76
	SM	-	-	-	-	-	-	-	-	-
	LSD AGBM	0.2***								
	LSD N-acc.	7***								
	LSD N-fixed	5***								

Note. AGBM: Above ground biomass accumulation; N-acc.: N accumulation; N-fix.: N-fixed; LSD = Least significant difference between means, *** $P < 0.001$.

Table 4. Above ground biomass accumulation, N accumulation and N-fixed of test soybean varieties under different maize-soybean planting densities as recorded at Manyala and Lubino experimental sites; data are means of yields of 2013 and 2014 long rainy seasons

Location	Planting Density	Soybean variety								
		Namsoy 4m			SC Squire			TGx1987-18F		
		AGBM (Mg ha ⁻¹)	N-acc. (kg ha ⁻¹)	N-fix. (kg ha ⁻¹)	AGBM (Mg ha ⁻¹)	N-acc. (kg ha ⁻¹)	N-fix. (kg ha ⁻¹)	AGBM (Mg ha ⁻¹)	N-acc. (kg ha ⁻¹)	N-fix. (kg ha ⁻¹)
Manyala	D1	1.5	48	32	1.3	43	29	1.9	61	41
	D2	1.3	44	30	1.6	53	35	2.4	78	53
	D3	1.9	62	57	2.7	87	57	3.1	100	68
	SS	2.5	82	43	3.2	104	69	3.3	109	73
	SM	-	-	-	-	-	-	-	-	-
	LSD AGBM	0.2***								
	LSD N-acc.	11***								
	LSD N-fixed	8***								
Lubino	D1	0.8	27	18	1.0	35	23	1.2	37	26
	D2	0.9	25	17	1.4	50	34	1.6	52	36
	D3	1.4	45	31	2.5	92	63	1.8	57	40
	SS	1.3	42	29	2.3	71	49	2.1	69	46
	SM	-	-	-	-	-	-	-	-	-
	LSD AGBM	0.3**								
	LSD N-acc.	10**								
	LSD N-fixed	7**								

Note. AGBM: Above ground biomass accumulation; N-acc.: N accumulation; N-fix.: N-fixed; LSD = Least significant difference between means, ** $P < 0.01$; *** $P < 0.001$.

3.2 Soybean and Maize Grain Yields

Across sites and seasons, higher yields of soybean were obtained under SS while for maize was obtained under D1 (Tables 5 and 6), with more yield of both crops achieved in the long rainy season. In the short rainy season, soybean grain yield was reduced by 50% in D1, but 15% in D2 and D3 across sites and soybean varieties. Clear differences in yield of soybean under different planting densities could be observed in the long rainy season. For example, at Manyala site, a yield reduction of 28, 45 and 58% was recorded in D3, D2 and D1, respectively. At Lubino site, a yield reduction of 16, 28 and 45% was recorded in D3, D2 and D1, respectively. Across sites and seasons the planting density D3 with soybean variety SC Squire gave the highest grain yield of 1.2 and 0.7 Mg ha⁻¹ in the short rainy season and 1.8 and 1.5 Mg ha⁻¹ in the long rainy season at Manyala and Lubino sites, respectively. Across sites, seasons and varieties, no significant differences in soybean grain yields could be observed between D3 and SS.

Maize grain yield was affected by planting densities (Tables 5 and 6). Compared to sole maize (SM), a general yield reduction by 40 to 50% and 20 to 40% was observed in D3, D2, for Lubino and Manyala site respectively, and similar trend was observed in both short and long rainy seasons. For D1, an increase in maize grain yield of up to 7% was recorded. No significant differences in maize grain yields could be observed between D1 and SM, except for Manyala site during the short rainy season and Lubino site in intercrop with Namsoy 4m in the same season. Higher yields of maize were recorded in the long rainy season across planting densities, where the intercrops of maize and soybean variety TGx1987-18F gave the highest yield (Table 6).

Table 5. Soybean grain yield and Maize grain yield under different maize-soybean planting densities as recorded at Manyala and Lubino experimental sites; data are means of 2012 and 2013 short rainy seasons

Location	Planting Density	Maize-Namsoy 4m		Maize-SC Squire		Maize-TGx1987-18F	
		SGY (Mg ha ⁻¹)	MGY (Mg ha ⁻¹)	SGY (Mg ha ⁻¹)	MGY (Mg ha ⁻¹)	SGY (Mg ha ⁻¹)	MGY (Mg ha ⁻¹)
Manyala	D1	0.2	1.4	0.7	1.4	0.2	1.5
	D2	0.4	1.1	1.1	1.1	0.2	1.2
	D3	0.4	1.0	1.2	1.0	0.2	0.9
	SS	0.4	-	1.4	-	0.3	-
	SM	-	1.8	-	1.8	-	1.8
	LSD SGY	0.2**					
	LSD MGY	0.2***					
Lubino	D1	0.1	1.2	0.3	1.9	0.4	1.9
	D2	0.2	1.5	0.7	1.4	0.5	1.5
	D3	0.2	1.1	0.7	1.0	0.6	1.1
	SS	0.4	-	0.9	-	1.2	-
	SM	-	1.9	-	1.9	-	1.9
	LSD SGY	0.1***					
	LSD MGY	0.3***					

Note. SGY: Soybean grain yield; MGY: Maize grain yield; LSD = Least significant difference between means, ** $P < 0.01$; *** $P < 0.001$.

Table 6. Soybean grain yield and Maize grain yield under different maize-soybean planting densities as recorded at Manyala and Lubino experimental sites; data are means of 2013 and 2014 long rainy seasons

Location	Planting Density	Maize-Namsoy 4m		Maize-SC Squire		Maize-TGx1987-18F	
		SGY (Mg ha ⁻¹)	MGY (Mg ha ⁻¹)	SGY (Mg ha ⁻¹)	MGY (Mg ha ⁻¹)	SGY (Mg ha ⁻¹)	MGY (Mg ha ⁻¹)
Manyala	D1	1.1	4.5	1.0	4.5	0.8	4.7
	D2	1.3	2.7	1.5	2.8	1.2	2.8
	D3	1.7	2.4	1.8	2.5	1.7	2.5
	SS	2.3	-	2.6	-	2.4	-
	SM	-	4.4	-	4.4	-	4.4
	LSD SGY	0.1**					
	LSD MGY	0.3***					
Lubino	D1	0.6	2.7	0.7	1.7	0.6	3.1
	D2	0.7	2.5	1.3	1.5	0.7	2.6
	D3	0.9	2.2	1.6	1.2	0.9	2.2
	SS	0.9	-	1.4	-	1.0	-
	SM	-	2.5	-	2.5	-	2.5
	LSD SGY	0.2***					
	LSD MGY	0.6***					

Note. SGY: Soybean grain yield; MGY: Maize grain yield; LSD = Least significant difference between means, ** $P < 0.01$; *** $P < 0.001$.

3.3 Nitrogen Balances of Intercrops

Net N balances of intercrops varied from -37 to +47 kg N ha⁻¹ when only harvest soybean grain was removed and from -107 to -5 kg N ha⁻¹ when both soybean and maize grain were removed (Table 7). With only soybean grain removed, positive N balances were recorded at Manyala site in all intercrops with TGx1987-18F, and at Lubino site in D2 with TGx1987-18F and in D3 with Namsoy 4m. Overall, the N balance of intercrops was less negative with increasing soybean plant population, where intercrops with TGx1987-18F had less negative N balances, while the intercrops with SC Squire had more negative N balances.

Table 7. Nitrogen balances ($\text{kg ha}^{-1} \text{ year}^{-1}$) in maize-soybean intercropping of different planting densities at Manyala and Lubino sites, Western Kenya. Balances are averages of 2012 and 2013 short rainy seasons, and 2013 and 2014 long rainy seasons

Location	Planting density	Total N harvested in grains									Net balances					
		Total N-fixed			Soybean grain			Maize grain			Soybean grain removed			Soybean + maize gain removed		
		v1	v2	v3	v1	v2	v3	v1	v2	v3	v1	v2	v3	v1	v2	v3
Manyala	D1	65	93	87	78	108	60	90	92	94	-13	-15	+27	-103	-107	-67
	D2	77	121	127	102	156	84	58	59	61	-25	-35	+43	-83	-94	-18
	D3	115	143	161	126	180	114	52	53	52	-11	-37	+47	-63	-90	-5
	SS	101	151	168	162	240	162	0	0	0	-61	-89	+6	-61	-89	+6
	LSD _{N-fixed}	9***														
	LSD _{N-soy grain}	40**														
	LSD _{N-bal. Soy grain removed}	9***														
	LSD _{N-bal. Soy grain + Maize Grain Removed}	12***														
Lubino	D1	39	72	55	42	60	60	59	75	76	-3	12	-5	-62	-63	-81
	D2	51	100	78	54	120	72	61	59	62	-3	-20	+6	-64	-79	-56
	D3	75	122	90	66	138	90	50	49	50	+9	-16	0	-41	-65	-50
	SS	86	100	123	78	138	132	0	0	0	+8	-38	-9	+8	-38	-9
	LSD _{N-fixed}	6***														
	LSD _{N-soy grain}	20**														
	LSD _{N-bal. Soy grain removed}	4***														
	LSD _{N-bal. Soy grain + Maize Grain Removed}	5***														

Note. v = soybean variety, where v1 = Namsoy 4m; v2 = SC Squire and v3 = TGx1987-18F; LSD = Least significant difference between means, ** $P < 0.01$; *** $P < 0.001$.

3.4 Land Equivalent Ratio of Intercropping Systems

All planting densities (D1, D2 and D3) for the three soybean varieties were lying above the linear line of sole maize and its corresponding soybean variety grown as sole crop, indicating an advantage of intercropping (Figure 2). Across sites and seasons, LER figures were highest in D2 with SC Squire, high in D2 with Namsoy 4 m and lower in D3 with TGx1987-18F.

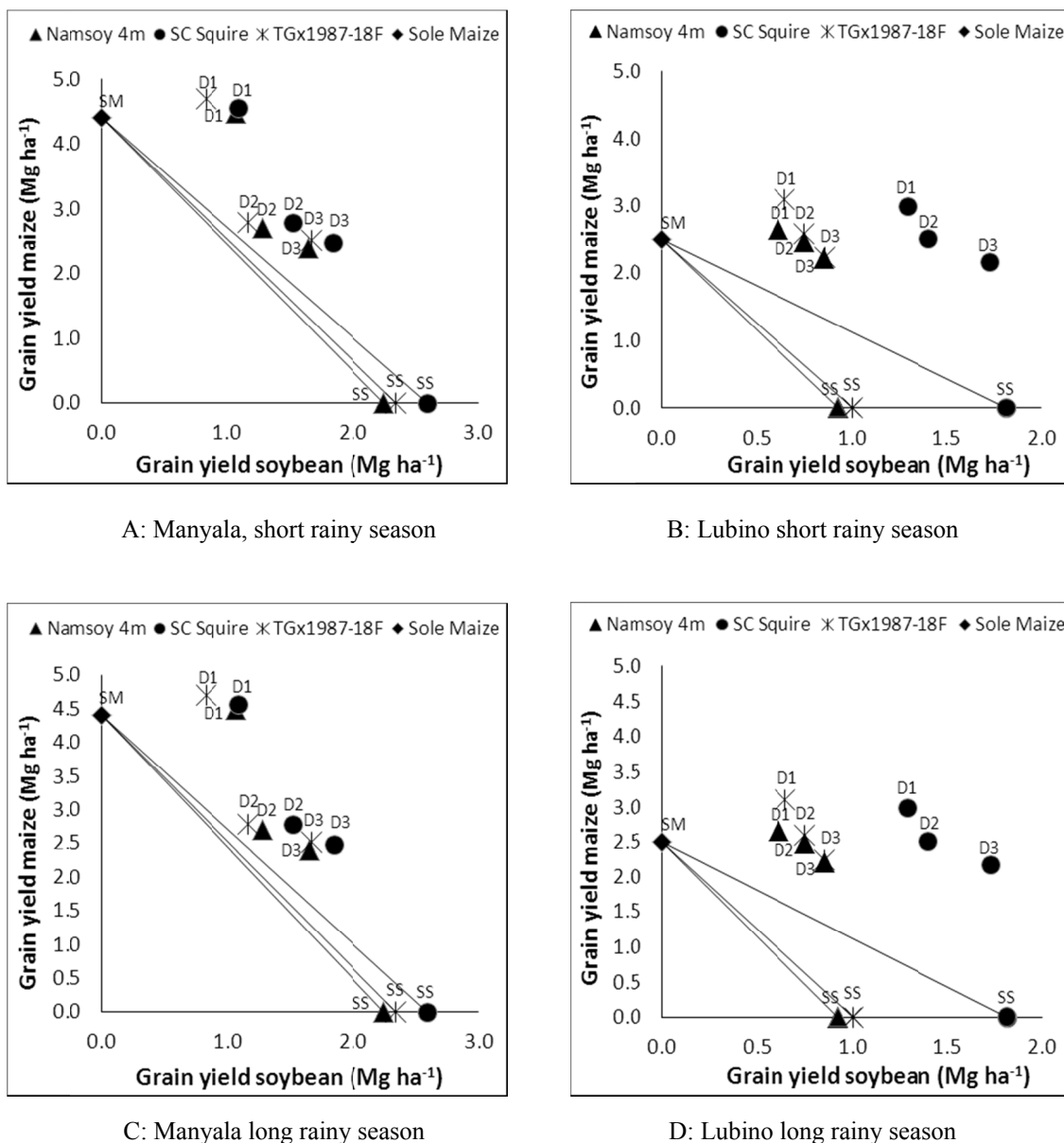


Figure 2. Relationships of maize and soybean grain yield in the intercrops and sole crops per season and site

4. Discussion

4.1 Performance of Crops at Experimental Sites and Seasons

Biomass yield, N-accumulation, N-fixed and yield of both maize and soybean were high at Manyala site and low at Lubino site. At both sites, the rainfall patterns during the experimental period followed similar trend and were more at Lubino in the short rainy season of 2013 and in the long rainy season of 2014. The observed poor crop performance at Lubino site could be attributed to soil acidity (pH < 5.5) and associated large exchangeable Al (700 > mg kg⁻¹) (Table 1). High levels of exchangeable Al reduce the availability of P by precipitating or adsorbing P and inhibit the root growth, resulting in lesser exploration of bulk soil and lesser uptake of water and nutrients by plants (Landon, 1991; Vanlauwe et al., 2015). It also reduces the degree of colonization by soil rhizobia (Giller, 2001). These consequences, taken together, may have decreased biomass accumulation, which is the key for nitrogen fixation and grain yield of legumes. A number of studies have highlighted the challenge of high Al levels in soils across Western Kenya, where crops are responding poorly to N, P, and K fertilizers (Keino et al., 2015; Kihara et al., 2016; Titttonell, Vanlauwe, Leffelaar, Rowe, & Giller, 2005). Such soils (referred to as non-responsive) are common in the densely populated areas like Lubino, where minimal inorganic and/or

organic inputs are in short supply. Although the current results are based on few sites, they support the need for tailoring soil and crop management practices to site-specific conditions to increase crop productivity in smallholder farms in SSA (Giller, Schilt, & Franke, 2013).

Soybeans accumulated more biomass and fixed more N in the short rainy season compared to long rainy season (Tables 3 and 4). This may be due to favorable temperatures and soil moisture conditions that prevailed in the short rainy season when the crop was at vegetative growth stage. According to Jaetzold and Schmidt (2005), temperatures in Western Kenya vary between 25 and 29 °C in the short rainy season, the optimal temperatures for soybean growth (Nteranya Sanginga, 2003). Poor soybean grain yield in the short rainy season could have been caused, in large part by moisture stress caused by dry spells that occurred mid-November through December (Figures 1a and 1b). At the beginning of dry spells, Namsoy 4m and SC Squire were at R4 (seed filling stage) and TGx1987-18F at R1 (flowering stage) reproductive stage. In soybean, soil-water deficit at reproductive stage results in increased flower abortion, reduced pod number, reduced grain per pod, and the size of the grain, which affect negatively the grain yields of the crop (Frederick, Camp, & Bauer, 2001; Purcell & King, 1996).

4.2 Performance of Soybean in the Intercrops

The effect of intercropping three varieties of soybean with maize were significant for biomass yield, N-accumulation, amount of N-fixed and grain yield of both crops. The observed higher biomass and N-accumulation of soybean in D3 relative to D2 and D1, and D2 relative to D1 might be associated with higher soybean plant population. Intercropping of maize and soybean at D3, is equivalent to reducing maize plant population to half the recommendation (53.000 to 24.240 plants per ha) and soybean plant population to two third the recommendation (444.440 to 363.630 plants per ha). Our results agree with those of Zhang et al. (2015) who reported higher biomass accumulation and N uptake in maize-soybean intercrop ratio of 1:3, compared to the ratio 1:1. Good performance of soybean at low population of maize may be attributed to the wide space available between alternate maize lines in intercropping leading to increased light use efficiency and enhanced photosynthesis of soybean.

Across plant densities, sites and seasons, the soybean variety TGx1987-18F accumulated more biomass and nitrogen and fixed more N than the rest of varieties. These results agree with Vanlauwe, Mukalama, Abaidoo, & Sanginga (2011) who reported a range of soybean total biomass of 1.7 to 4.5 Mg ha⁻¹ in Vihiga district, Western Kenya. In their study, long maturing varieties were found to accumulate more biomass and fix more N than the short maturing varieties. Long maturing cultivars are known to grow slowly and take this advantage to absorb and utilize more nutrients and solar energy and fix more N that is converted to plant tissues (Giller, 2001). Rusinamhodzi, Corbeels, Nyamangara, & Giller (2012) reported similar observations when pigeon pea (*Cajanus cajan*) varieties with different maturity periods were evaluated under intercrop with maize in northern Mozambique.

The N-fixed in SS was not significantly different from N-fixed in D3, but it was 50% and 22% higher than the N-fixed in D1 and D2 respectively. The amount of N-fixed in SS was within the range of 18 to 95 kg N ha⁻¹ observed by Osunde et al. (2003) in various farms in Nigeria. The use of universal *B* values and a reference crop with different root-structure from a legume crop tested is reported to influence the calculations of %Ndfa, especially when the $\delta^{15}\text{N}$ of reference is lower than the $\delta^{15}\text{N}$ of a legume plant (Giller, 2001). In our study, the $\delta^{15}\text{N}$ of reference plant was 4.67‰ for Manyala site and 4.42‰ for Lubino site, almost double the $\delta^{15}\text{N}$ recorded in soybeans samples, suggesting that the *B* value and the reference crop used were appropriate (Unkovich et al., 2008). However, the reported quantities of N-fixed in the present study could be an underestimation because did not account for the belowground contributions, comprising of N associated with roots, nodules and rhizodeposition via exudates and decaying root cells and hyphae, which is estimated to be 31% of N-fixed at pod-filling stage (Ofosu-Budu et al., 1990). Other researchers, accounting for the N-fixed in the belowground plant parts, have reported higher amounts of N-fixed. For instance, Eaglesham, Ayanaba, Rao, and Eskew (1982) reported N-fixed by soybean of 114 to 188 N kg ha⁻¹ per season, and Nteranya Sanginga (2003) of 24 to 168 kg N ha⁻¹ per season.

4.3 Soybean and Maize Grain Yield

Soybean grain yield ranged between 0.1 and 1.7 Mg ha⁻¹ in the intercrops and 0.4 to 2.6 in SS. Kihara, Martius, Bationo, and Vlek (2011) had reported similar maize yields when soybean was intercropped or rotated with maize. SC Squire produced more grains because of its high yield potential, associated with many pods per plant, large and heavy grains, when compared to TGx1987-18F and Namsoy 4m. High yields in SC Squire, relative to other soybean varieties, have also been reported in other locations (Woomer et al., 2014), where SC Squire was

identified among the best varieties in terms of grain yield in different agro-ecological zones in Southern, Central and in East Africa.

Although maize yield was low than reported elsewhere in SSA, it was within the range (0.6 to 5.0 Mg ha⁻¹) reported in western Kenya (Wambugu, Mathenge, Auma, & VanRheenen, 2012). The observed lower yields of maize with increasing soybean population can be attributed to a reduction in maize plant population as in most cases no significant differences were detected between D1 and SM, treatments which had the same maize plant population. The tall nature of maize in relation to soybean and its more widespread rooting system might have favored maize in D1. Dolijanović, Kovačević, Oljača, and Simić (2009) showed that, in the intercropped of soybean and maize, the maize component, which has often fast growth rate, height advantage and more widespread rooting system gives it an advantage in the competition with the associated soybean. The observed consistent, but slight increase in maize yield under D1, relative to SM in the long rainy season, may be due to N obtained through nitrogen fixation from associated soybean. It has been reported cereal crops can benefit for symbiotic N-fixed by the legume crop grown as intercrop through N-transfer (Wilson, Giller, & Jefferson, 1991). Such performances of component crops in intercropping were also observed by Fujita et al. (1992); Layek et al. (2014). The N-transfer is considered to occur through root excretion, N leached from leaves and leaf fall (Fujita et al., 1992).

4.4 Nitrogen Balances of Intercrops

Nitrogen balances of crop fields that include grain legumes vary widely and are affected by site conditions, grain harvest and N input (Giller, 2001). Although in the present study the N obtained from N₂ fixation ranged between 39 and 168 kg ha⁻¹ yr⁻¹ (Table 7), this could not turn the N balances into positive one. Similar soybean N balances have been reported in Argentina, Brazil, China, Canada and Thailand (Salvagiotti et al., 2008) and in Nigeria (Singh, Carsky, Lucas, & Dashiell, 2003). In their review of biological nitrogen fixation studies that had been conducted between 1999 and 2006, (Salvagiotti et al., 2008) observed that the amount of N-fixed by soybean was, in most cases, insufficient to replace all the N removed in harvested grain. Overall, planting late maturing variety TGx1987-18F resulted in net addition, or less N removal of N from the soils, while the intermediate maturing variety SC Squire resulted in net N removal from the soil. Similar to the present study, Singh et al. (2003) also obtained more negative N balance values for early and intermediate maturing soybean varieties when compared to late maturing varieties. The short and intermediate maturing varieties are known to efficiently translocate N to the grain, thus leaving behind only a small proportion of N in the stover (N Sanginga, Abaidoo, Dashiell, Carsky, & Okogun, 1996). Assuming 31% N contribution of below ground, the values of N balances in D1, D2 and D3 become less negative when only soybean grain is removed from the field. However, after removal of maize grain, net N balances of intercropped became more negative suggesting that in less productive soils, combinations of legume intercropping, and mineral N fertilizer application would be the best option.

4.5 Efficiency of Intercropping Systems

All the intercropped had LER greater than 1 suggesting that at all planting densities, maize and soybean complemented each other mutually in the utilization of resources. The observed decrease in LER values with increasing density of soybean suggest decreased efficiency in land resource utilization with increasing density of soybean. Zhang et al. (2015) had observed LER reductions in soybean intercropped with maize in Northern China and associated the LER depression to increase interspecific completion at higher soybean population. With the exception of Lubino site in the short rainy season, greater advantage of intercropping maize with soybean was obtained with variety SC Squire, closely followed by Namsoy 4m in D2. This intercropping pattern could be an effective way of optimizing soybean and maize production in areas like Western Kenya where farmers are experiencing reduction in the amount of land available due to the rapid increase in human population. The high grain yields obtained at Manyala did not translate into higher LER values, suggesting that the LER was not influenced by the quantity of grain yields obtained in the location, but by the ratios of grain yields of maize and soybean in the intercropped and in sole crop. Although D3 performed almost equally as SS in terms of biomass accumulation, N-accumulation, N-fixed and soybean grain yield, it had lower LER when both soybean and maize yield were considered (section 3.6), making it difficult to be adopted by smallholder if maize is a major crop.

5. Conclusions

Above ground biomass, N-accumulation and N-fixed was higher in D3 with the long maturing soybean variety TGx1987-18F, while higher grain yield was recorded in D3 with SC Squire, a variety with intermediate growth duration. An increase in the population of soybean in the intercropped implied a reduction in maize grain yield, but

improved the N balances, when soybean and maize grains were removed from the system. LER figures were above unity under all intercrop combinations, but it decreased with increasing density of soybean. Greater advantage of intercropping maize with soybean was obtained with SC Squire, closely followed by Namsoy 4m and in D2. Small scale farmers in Western Kenya, and those living in areas with similar conditions in the highlands of East and Central Africa, can take greater advantage of biological nitrogen fixation by adopting 1:2 maize soybean intercropping system, using the intermediate growth types of soybean. Owing to the fact that the N-fixed in the intercrop cannot compensate for the entire N harvested in the maize grain, this practice should be combined with (i) the application of mineral N targeted to maize (ii) application of fertilizers especially blended for legumes (e.g. SYMPAL) to supply secondary and micronutrients, (iii) returning to the field the soybean residues after removal of grain, (iv) liming of soil to increase the pH and reduce Al toxicity and (v) management of soil and crop to reduce drought stress.

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