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Effect of Cowpea Density and Nitrogen Fertilizer on a Sorghum-Cowpea Intercropping System in Kobo, Northern Ethiopia

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Abstract Sorghum productivity is limited in Kobo area mainly due to deterioration of soil fertility and continuous cropping. Hence, an experiment on sorghum/cowpea intercropping was conducted in 2014/15 cropping season to assess the effect of density of the intercropped cowpea and nitrogen fertilizer rates on yield and yield related traits of sorghum and cowpea as well as to determine the appropriate plant density of cowpea and nitrogen fertilizer rate that maximize the productivity of the intercrop system. Treatments consisted of factorial combinations of three cowpea densities (50, 75 and 100%) and four levels of nitrogen rates (0, 20.5, 41 and 61.5kg N ha^{-1}) accompanied with sole sorghum and sole cowpea, carried out in Randomized Complete Block Design (RCBD) with three replications. The analyzed result showed that plant height and dry biomass yield of sorghum as well as leaf area and leaf area index of both crops showed an increased trend as N level increased linearly. Leaf area index of cowpea was also affected by cowpea density in which the largest data was recorded at high population density. Similarly, grain yields of component crops were significantly influenced ($P<0.01$) due to the interaction effect. Thus, the highest grain yield of sorghum (2370.4 kg ha^{-1}) and cowpea (821.3 kg ha^{-1}) were obtained from the combination of 41 kg N ha^{-1} + 75% sole cowpea density, and 20.5 kg N ha^{-1} + 100% of cowpea density, respectively. Similarly, 20.5 kg N ha^{-1} + 100% planting density produced the highest dry biomass (2375.0 kg ha^{-1}) of cowpea. The land equivalent ratio (LER) and gross monetary value (GMV) showed that sorghum-cowpea intercropping was highly superior to and more advantageous over sole cropping. The highest values of LER and GMV were obtained from combination of 41 kg N ha^{-1} and 75% sole cowpea density. This is, therefore, sorghum-cowpea intercropping was proved to be more productive and efficient system in utilizing land compared to sole cropping with carefully managed N fertilizer and cowpea plant density. Hence, combination of 41 kg N ha^{-1} and 75% sole cowpea density can be recommended for the farmers in the study area to improve sorghum productivity and the cropping system at large.

Keywords Cowpea, Economic analysis, Intercropping, Nitrogen, Plant population, Sorghum

1. Introduction

Sorghum [*Sorghum bicolor* (L) Moench] is among the dominant staple cereals for the majority of Ethiopians. In Ethiopia, it is adapted to a wide range of environments, and hence can be produced in the high lands, medium altitude and low lands. Sorghum is widely produced more than any other crops in the areas where there is moisture stress (MoA, 2010). According to the study of MoA (2010), the grain is used for human food like porridge, *"injera", "Kitta", "Nifro",* infant food, syrup, and local beverages such as "*Tella*", and "*Areke*". Besides to animal feed, the stalk is used for construction of houses and fence, and as fuel wood.

In Ethiopia, during 2013/14, sorghum encompasses about 13.5% of the total of 79.4% area allotted to cereal crop production (*tef*, maize, sorghum, and wheat). Similarly, during the same year, sorghum took 15.2% (3,828,870,103 kg) of the total production (21,583,522,561 kg) allocated for major cereals (maize, *tef*, wheat, and sorghum). In that year, sorghum was the most important staple food crop ranked 3rd and 4th in area coverage and total production, respectively (CSA, 2014). In the country, sorghum is grown in almost all regions occupying an estimated total land area of 1.68 million ha and its national average productivity is 2283 kg/ha (CSA, 2014). However, the productivity of sorghum is limited due to deterioration in soil fertility, shortening of the length of fallow, and the increasing trend towards continuous cultivation of cereal monocrops in place of traditional rotation and intercropping systems, and lack of agricultural

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inputs (UNDP, 1996).

Cereal-legume intercropping is among the approaches that induces productivity of crops. According to the reports across Africa on soybean-sorghum (Hayder *et al*., 2003), cowpea-maize (Eskandari and Ghanbari, 2010), sorghum-legume (Aliyu and Emechebe, 2006) and maize-legumes (Seran and Brintha, 2010; Tilahun *et al*., 2012) intercropping systems have a higher productivity than the sole cereal systems in semi-arid areas. The reason of yield advantage of intercropping are mainly that environmental resources such as water, light and nutrients can be utilized more efficiently in intercropping than in the respective sole cropping systems (Liu *et al*., 2006). By using the land equivalent ratio (LER) one is able to compare the production of the intercrop and express it relative to the yield from a sole crop of the dominant species (Beets, 1982).

Farmers in different parts of the world intercrop different crops according to their preference based on social and biological needs (Andrew and Kassam, 1983). For example, sorghum - cowpea intercropping is an important farming system for small scale farmers in Arid and Semi-Arid Lands of sub-Sahara African (Karanja *et al.,* 2014). In Ethiopia, cowpea [*Vignaun guiculata* (L) Walp] is now becoming among the most commonly cultivated lowland pulse crops. It is grown in rift valley areas of Ethiopia for its fodder and grain value (dual purpose) (Ayana *et al*., 2013). Intercropping with cowpea leads to higher sorghum grain yield which may be related to the benefits of N fixation under cowpea intercropping as well as to induction of suicidal germination of *Striga* seeds away from the host roots. For the success of intercropping system several aspects need to be taken into consideration before and during the cultivation process (Seran and Brintha, 2010). Such considerations include maturity of crop, compatible crops, time of planting and plant density. Report of Francis (1989) revealed that the potential of cereal-legume intercropping system to provide N depends on density of crops, light interception, crop species and nutrients. Accordingly, Adem (2006) reported that leaf area plant^{-1}, leaf area index, and dry biomass yield plant^{-1} of sorghum were significantly affected due to nitrogen application under sorghum-cowpea intercropping. In the same report, leaf area index was significantly affected due to component planting density.

The seedling rate of each crop in intercrop is adjusted below its full rate to optimize plant density. According to Seran and Brintha (2010), by planting full rate of each crop neither would yield well because of intense overcrowding. Morgado and Willey (2003) also reported that dry matter yield accumulation of individual maize plant decreased with increase in bean plant population. Furthermore, studies in Ethiopia indicated that wheat and faba bean were grown in an additive intercropping system which increased the LER by between 3 and 22%. The highest total grain yield was obtained when a full wheat crop was intercropped with a 37.5% faba bean crop (Agegnehu *et al.,* 2008). It is evident from various workers that intercropping gives higher yield when total population in the system is higher than that of sole crops (Willey, 1979b).

Legumes with effective biological nitrogen fixation (BNF) can be grown with less applied N fertilizer. Appropriate fertilization with respect to type, amount, time, and method of fertilizer application can increase the advantage of intercropping (Undie *et al.,* 2012). Due to the rising cost of chemical fertilizers, crop nutrient uptake and utilization must be most efficient to reduce cost of production and achieving higher profit. Hence, intercropping legumes with cereals is particularly important in countries where the cost of N fertilizer is high and / or availability of fertilizer is limited. Rebka *et al.* (2013) reported that unaffordable high costs, the low fertilizer response of landraces and the extreme drought at the end of growing seasons limit the use of inorganic fertilizer by famers in north Wollo. Legumes with effective biological nitrogen fixation (BNF) can be intercropped with cereals with less applied N fertilizer to overcome this problem. Hence, assessing the performance of intercropping cowpea at different population densities with application of N to enhance the overall productivity of the component crops is very important. Accordingly, this study was aimed to assess the effect of density of the intercropped cowpea and nitrogen fertilizer rates on yield and yield related traits of sorghum and cowpea; and also to determine the appropriate plant density of cowpea and nitrogen fertilizer rate that maximize the productivity of the intercrop system.

2. Materials and Methods

2.1. Description of Experimental Area

The experiment was carried out under rain-fed conditions in Kobo Agricultural Research sub-Center testing site in the 2014/15 cropping season. It is 570 km north of Addis Ababa and situated at an altitude of 1470 meters above sea level (m.a.s.l) having a long term average rainfall of 459 mm and its average annual temperature is 15 – 31°C. It lies at latitudes of 12°09’ N and longitudes of 39°38’ E. It has eutricvertisol and eutricfluvisol soil types (Wondimu *et al*., 2005). The area is characterized by bimodal rainfall pattern with a short rainy season (belg) from February to April and a long rainy season (kirmet) from June to September with a peak in August (Tsegaye Gebremariam, personal communication, April 23, 2014).

2.2. Treatments and Filed Experimental Design

Factorial combinations of four rates of nitrogen (0, 20.5, 41, and 61.5 kg N/ha), three rates of cowpea planting densities (50%, 75% and 100%) including sole cowpea and sorghum under sorghum-cowpea intercropping were laid out in a randomized complete block design (RCBD) with three replications in a plot area of (3.75 * 4) m^2. Urea (46%N) was used as source of N. The recommended amount of N fertilizer (41 kg N ha^{-1}) was applied for sole sorghum. Half dose of the N rates was applied during planting time and the remaining was applied at knee stage. Similarly, full dose of P (46 kg P_2O_5 ha^{-1}) was applied as band application in the form of triple super phosphate (TSP) at planting time for both sorghum and cowpea rows in all treatments while N was applied for sorghum rows only. Bekur variety of cowpea and P-9401 (Gubiye) variety of sorghum were used as test crops. Sorghum was planted at a spacing of 75 x 20 cm while **c**owpea, which had been planted three weeks later after sorghum at 1:1 sorghum-cowpea spatial arrangement, was planted with intra-row spacing of 13 cm, 17 cm and 25 cm based on the treatments which represented 100%, 75% and 50% of the recommended cowpea planting density, respectively. Moreover, sole cowpea was planted at a spacing of 60 x 20 cm. *In-situ* soil moisture conservation practice (tied ridging) was done for all plots to harvest water.

2.3. Data Collection

Soil sample at a depth of 0-30 cm was taken from five random spots diagonally across the experimental field using auger before planting. The collected soil samples were composited to one sample. The bulked soil samples were air dried, thoroughly mixed and ground to pass 2 mm sieve size before laboratory analysis.

Five random plants plot^{-1} from the net plot (2.25 m * 3.6 m) were taken to measure leaf area plant^{-1} (cm^2) of sorghum. Physiologically well performed three leaves plant^{-1} were considered. It was determined at 50% heading using the method described by Sticker *et al.* (1961) as: Leaf area = leaf length of the leaves x maximum width of leaf x 0.75. Where, 0.75 is the correction factor for sorghum. Similarly, Leaf area plant^{-1} (cm^2) of cowpea was determined by stacking the leaf laminae of the five sample plants on the table at 50% flowering stage and a cork borer of known area was driven through them to cut out discs. Ten physiological well performed leaves plant^{-1} were sampled. The complete disc where counted and weighed both when fresh and after drying completely. The remaining parts after cutting of discs where combined as per the discs. The weights obtained were used to determine the leaf area as described by Ibrahim *et al.* (2014):

$$A = \left(\frac{a * n}{w}\right) * W$$

Where:

A = Total leaf area plant^{-1} (cm^2); a = area of individual discs (cm^2); n = number of discs taken; w = weight of dry n discs (gm) and W = Total dry weight of leaves plant^{-1} (gm).

Five random plants plot^{-1} from the net plot (2.25 m * 3.6 m) were taken to measure Leaf Area Index (LAI) of the component crops. It was calculated as the ratio of unit leaf area per unit ground from the net plot according to Watson (1958) where unit leaf area = leaf area x No. of leaves/plants. Plant height (cm) of the crops was measured from five randomly taken plants of each net plot at 90% physiological maturity with a standard meter rule. Five sampled panicles of sorghum from the net plot were bulked and mixed together at 12.5% moisture level to determine head weight plant^{-1} (gm). Effective nodules number plant^{-1} of cowpea were collected at the time of 50% flower initiation by digging out the roots of five plants randomly from the net plot and were counted based on their colour (pink colour). Number of pods plant^{-1} was determined from the five sampled plants of a net plot at physiological maturity. Number of seed pod^{-1} of cowpea was also determined from 15 pods taken from the five sampled plants.

Similarly, grain yield (kg ha^{-1}) of both crops was determined after the grain had been dried, threshed, cleaned and adjusted to 12.5% moisture level (sorghum) and 10.5% moisture level (cowpea). The above ground biomass (kg ha^{-1}) of the test crops was measured after the plants from the net plot area had been harvested and sun dried till constant dry weight was attained. Harvest index of the crops was also computed as ratio of grain dry weight to above ground dry biomass expressed in percentage.

Land equivalent ratio (LER) was used to evaluate the productivity of intercrops compared with mono-crops. It was calculated according to Mead and Willey (1980):

$$\text{LER} = \frac{\text{Yab}}{\text{Yaa}} + \frac{\text{Yba}}{\text{Ybb}}$$

Where;

Yab = yield per unit area of crop a in mixture; Yaa = yield per unit area of pure crop a; Yba = yield per unit area of crop b in mixture; Ybb = yield per unit area of pure crop b.

Gross monetary value (GMV) and monetary advantage (MA) were calculated from the yield of sorghum and cowpea in order to measure the productivity and profitability of intercropping as compared to sole cropping of the associated component crops (Mead and Willey, 1979). GMV was calculated by multiplying yields of the component crops by their respective current market price. According to Willey (1979a), MA was calculated as:

$$\text{Monetary Value (MA)} = \text{value of combined inercrops yield} * \frac{\text{LER} - 1}{\text{LER}}$$

2.4. Data Analysis

The collected data were subjected to the analysis of variance (ANOVA) using the SAS computer package version 9.1 (SAS Institute, 2004). Mean separation was carried out using least significance difference (LSD) test at 5% probability level as described in Gomez and Gomez (1984).

3. Results and Discussion

3.1. Soil Analysis

Analysis of soil samples before planting was done for the major soil physical and chemical properties at soil laboratory of Mekelle Soil Research Center (Table 1). The results in Table 1 indicated that the soil comprised total N of 0.0784%, characterizing a low level of N (Berhanu, 1980). It also showed that the available P content was rated under high (17.02 mg kg^{-1}, Olsen *et al.,* 1954). The organic matter content of the soil was 1.62%, which rated under low, in agreement with findings of Tekalign (1991).

Moreover, the pH value was 7.61. According to Tekalign (1991), soils having pH value in the range of 7.4 to 8.0 are considered moderately alkaline soils. The soil of the experimental site had a proportion of 21% sand, 33% silt, and 46% clay that can be texturally classified as clay soil (Table 1).

Table 1. Major soil characteristics of the experimental site before planting

Soil parameter	Unit	Value
Total Nitrogen	%	0.0784
Organic Matter	%	1.65
Available P	mg kg^{-1}	17.02
Soil pH	-	7.61
Particle Size distribution		
Sand	%	21.00
Silt	%	33.00
Clay	%	46.00

3.2. Sorghum Component

Plant height of intercropped sorghum was affected significantly (P< 0.05) due to the effect of N (Table 2). The tallest plant height (121.4 cm) was recorded with the application of 61.5 kg ha^{-1} and was statistically similar (P< 0.05) to the plant height (120.2 cm) obtained due to application of 41 kg ha^{-1}. The lowest plant height (113.1cm) was recorded from unfertilized plots. Use of 61.5 kg ha^{-1} gave 7.31% more advance in plant height than nil fertilizer. This increment could be due to the vital role of N in enlargement of vegetative growth of plant parts. This result correlates with Abebe *et al.* (2013), who reported that there was significant variation in plant height of intercropped maize due to integrated N fertilizer application on maize-soybean intercropping.

Leaf area of sorghum was highly significantly affected (P<0.01) by N fertilizer application but no significant effect of cowpea plant density, interaction effect nor cropping system. The highest leaf area was obtained with the application of 61.5 and 41 kg N ha^{-1} as compared to 20.5 and 0 kg N ha^{-1} (Table 2). Leaf area showed an increased trend as level of N increased. Those results insured the importance of N in stimulating and enhancing the photosynthetic and metabolic activities of plants, which reflected on the increase in the vegetative growth of sorghum. A report from Wondimu *et al.* (2005) suggested that the higher leaf, stem and panicle dry mass of sorghum with N fertilization could be due to the positive effect of N on canopy development as a result of alterations in leaf area development. Ayoola and Agboola (2002) similarly reported that application of inorganic fertilizers and farm yard manure increased growth and expansion of leaves in intercropped maize.

Table 2. Main effects of component densities of cowpea and N-rates on plant height, Leaf area $plant^{-1}$, leaf area index, dry biomass yield, head weight and harvest index of intercropped sorghum with cowpea

Treatments	Plant height (cm)	Leaf area $plant^{-1}(cm^2)$	Leaf area index	Dry biomass (kg ha^{-1})	Head weight $plant^{-1}$	Harvest Index (%)
Cowpea densities						
50%	117.4	3022.6	2.0	3745.0	42.5	46.9 b
75%	117.3	2853.6	1.9	3782.9	40.6	51.7 a
100%	117.1	2693.3	1.8	3765.0	42.4	47.4 b
SEm ±	1.7	91.3	0.1	69.8	0.8	1.3
LSD (P<0.05)	NS	NS	NS	NS	NS	3.8
N-rate (kg ha^{-1})						
0	113.1 c	2406.2 b	1.6 b	3579.5 c	39.4 b	44.0 c
20.5	114.4 bc	2657.6 b	1.8 b	3641.1 bc	41.5 ab	50.6 ab
41	120.2 ab	3122.0 a	2.1 a	3847.7 ab	43.6 a	53.9 a
61.5	121.4 a	3240.2 a	2.2 a	3988.9 a	42.7 a	46.2 bc
SEm ±	2.0	105.5	0.1	80.6	0.9	1.5
LSD (p<0.05)	5.8	309.3	0.2	236.4	2.7	4.4
CV (%)	5.1	11.1	11.1	6.4	6.7	9.3
Cropping system						
Sole sorghum	115.7	3156.7	2.1	4699.5 a	44.1	51.1
Intercropped sorghum	117.6	2856.5	1.9	3764.3 b	41.8	48.7
SEm ±	2.4	92.6	0.1	138.5	1.5	1.1
LSD (p<0.05)	NS	NS	NS	842.5	NS	NS
CV (%)	3.5	5.3	5.4	5.7	5.9	3.9

Means with the same letter (S) in the same column are not significantly different at P<0.05; NS = Non-significant; SEm = standard error of mean; LSD = least significant difference; CV = coefficient of variation

The applied levels of N affected sorghum LAI in a pattern similar to their respective effects on leaf area. The maximum LAI (2.2) of intercropped sorghum was observed from 61kg N ha^{-1}. It was progressively increased as level of N increased. This finding pointed out that application of 61 kg N ha^{-1} revealed an increment of 35% over the nil fertilizer. The increase in LAI with N supply could be due to the effect of N on the rate of leaf expansion and reduced rate of leaf senescence (Muchow, 1988; Mahmoud *et al.,* 2013). Likewise, Abebe *et al.* (2013) reported that integrated N fertilizer application on soybean-maize intercropping affected significantly LAI of maize.

According to Table 2, however, LAI responded non-significantly to cowpea planting density, interaction effect and cropping system. This could be most likely due to absence of interspecific competition of intercropped cowpea on sorghum for growth resources. This complemented to the work of Biruk (2007) who reported that the main effect of common bean planting densities and interaction effect as well as the cropping system did not affect LAI of intercropped sorghum under sorghum-common bean intercropping system.

The mean comparison table (Table 2) showed the significant effect of N but the non-significant effect of cowpea density, interaction and cropping system on panicle weight. The 0 kg N ha^{-1} gave significantly the lowest head weight as compared to 41 and 61.5 kg N ha^{-1}. This result concurred with the finding of Jat *et al.* (2014) on maize – mungbean intercropping indicated that grain weight cob^{-1} of maize was significantly affected due to N fertilizer. Furthermore, the work of Adem (2006) on sorghum-cowpea intercropping showed that neither the component density nor their interaction and cropping system significantly affected sorghum panicle weight. This non-significance was attributed to reduction of inter specific competition of growth resources.

Nitrogen and the cropping system caused significant response ($P<0.05$) on dry biomass of intercropped sorghum; whereas, cowpea density and the interaction effect did not affect it (Table 2). Increasing doses of N fertilizer resulted in progressive significant increase in dry matter yield of intercropped sorghum (Table 2). Thus, plots that received 61.5 kg N ha^{-1} over yielded 11.4% the unfertilized treatments. The vigor of above ground part of sorghum plants due to high N enable them to harvest ample solar radiation, which resulted in the corresponding increment of photosynthetic rate. This higher photosynthetic rate also results in higher accumulation of dry matter. Related to this finding Jat *et al.* (2014) found significant effect of N fertilizer on stover yield of maize under maize-mungbean intercrops. Congruently, Abebe *et al. (*2013) reported that the pooled mean for biological yield of maize varied significantly due to integrated N fertilizer on soybean-maize intercropping. Sole sorghum was significantly superior ($P<0.05$) than the intercropped sorghum. This could be due to efficient utilization of resources without any competition. This result is in line with Siddig *et al*. (2013), who reported that dry matter weight of sorghum was influenced due to sorghum-ground nut intercropping.

Table 2 indicated that significant difference ($P<0.05$) was observed due to the main effects, but not due to the interaction effects and cropping system in harvest index (HI) of intercropped sorghum. The highest HI (51.7%) of intercropped sorghum was obtained from 75% of sole cowpea density while the smallest HI (46.9%) was due to 50% sole cowpea planting density and was statistically comparable ($P<0.05$) to 100% cowpea density. There was an increased trend in HI till 41 kg N ha^{-1} application, but declined beyond that (Table 2). It is true that N enhances vegetative growth of plants. The proportional conversion of this part (biomass) to grain yield amplified the HI of plants. Thus, high HI indicates the presence of good partitioning of dry matter to grain yield. This result agrees with finding of Karanja *et al* (2014) on sorghum-cowpea intercropping.

Table 3. Interaction effects of component densities of cowpea and N-rates on sorghum grain yield of intercropped sorghum with cowpea

Cowpea densities	N rates (Kg ha^{-1})				
	0	20.5	41	61.5	
50%	1523.3 e	1569.6 e	1879.6 bcd	2065.4 b	
75%	1630.0 de	2070.0 b	2370.4 a	1745.4 cde	
100%	1569.6 e	1884.6 bcd	1972.1 bc	1713.3 cde	
Intercrop mean					1832.8 b
Sole sorghum					2401.4 a

	Density X Nitrogen	Sole X Intercrop
SEm ±	99.4	81.0
LSD (p<0.05)	291.6	492.7
CV (%)	9.4	6.6

Means with the same letter (s) are not significantly different at P<0.05; SEm = standard error of mean; LSD = least significant difference; CV = Coefficient of variation

Nitrogen and the interaction effect showed highly significant differences ($P<0.01$) on grain yield of intercropped sorghum. Equally important, cowpea densities and cropping system also significantly affect it ($P<0.05$, Table 3). The highest grain yield (2370.4 kg ha^{-1}) was obtained from the interaction of 41 kg N ha^{-1} and 75% sole cowpea density which was statistically the highest. Nevertheless, the lowest numerical grain yield of 1523.3 kg $ha^{-1}$was obtained from the unfertilized plots received 50% sole cowpea density. Table 3 also showed that cropping system prompted significant ($P<0.05$) difference on grain yield. Sole sorghum exceeded 31.0% of the intercropped sorghum yield. This yield variation could be most probably due to interspecific competition for resources like soil nutrients, sunlight and water in the intercropped sorghum. Similarly, Karanja *et al*. (2014) reported that yield reductions involving one or all intercropping components in intercropping could be associated to interspecific competition for nutrients, moisture and/or space. Furthermore, similar work was reported by Getachew *et al.* (2013) on maize-forage legumes intercropping where cropping system affected grain yield. Moreover, Abraha (2013) on maize-forage legumes (lablab and cowpea) intercropping indicted that grain yield of sole maize yielded the highest (3056.0 kg ha^{-1}) and lower (2305.0 kg ha^{-1}) for maize - cowpea integration.

3.3. Cowpea Component

Neither of the main effects (cowpea density and nitrogen) nor their interactions and cropping system caused a significant influence on plant height of intercropped cowpea (Table 4). This might be attributed to less shading effect of sorghum and competition on the intercropped cowpea. This result confirms the finding of Ibrahim *et al.* (2014), who reported that plant height of cowpea did not give significant response ($P\leq0.05$) to sorghum-cowpea intercropping. Likewise, Abraha (2013) reported that the height between lablab-maize and sole lablab was not statistically affected.

Leaf area of intercropped cowpea was significantly affected ($P<0.05$) by N rate. The highest leaf area was recorded when 61.5 kg N ha^{-1} was applied (Table 4). It was clearly seen that leaf area increased as the N trend increased progressively. Increase in leaf area with increment in N rates could be ascribed to superior cell expansion, more rapid cell division and parallel augmented photosynthate construction. In agreement with this finding, Adem (2006) studied that N caused significant difference on leaf area of cowpea on sorghum – cowpea intercropping.

Cowpea densities showed highly significant ($P<0.01$) difference on LAI of intercropped cowpea where increasing cowpea density caused a corresponding increment of LAI (Table 4). Accordingly, the largest LAI (1.9) was recorded in 100% of cowpea density and it was significantly ($P<0.01$) different from 50 and 75% of cowpea densities. The smallest LAI (1.0) was seen on plots with 50% of the sole cowpea density and was significantly inferior to the other cowpea densities. Treatments with high densities resulted in higher LAI because of lower ground area occupied by plants which ultimately affected the LAI. The highest LAI observed in 100% density could be also due to high competition for light, moisture, nutrients and other growth resources. This current result is coherent with the finding of Adem (2006) on sorghum-cowpea intercropping where LAI was varied significantly because of component density.

As shown in Table 4, significant differences ($P<0.05$) also existed among the N levels. The highest LAI (1.6) was obtained with 61.5 kg N ha^{-1} and produced 24.4% LAI more than unfertilized plots. The result showed that N fertilizer application could enhance nutrient availability which probably increase the photosynthetic efficiency and consequently increased the vegetative growth and plant development. The current result agrees with the finding of Abebe *et al.* (2013) on soybean-maize intercropping.

Table 4 revealed that cowpea planting density and the interaction effect did not significantly affect nodule number of intercropped cowpea. However, N and cropping system significantly influenced the nodule number $plant^{-1}$ of cowpea. The maximum nodule number $plant^{-1}$ of intercropped cowpea (13.8) was recorded from nil N and was significantly higher than any of the N levels while the lowest (9.9) was recorded from 61.5 kg N ha^{-1}(Table 4). Increasing rate of N reduced number of nodules $plant^{-1}$. The reason is justified by many researchers. According to the report of Herridge (1982) and Noel *et al.* (1982), higher N in the soil depresses nodulation and N fixation through inhibition of thread, slowing of nodule growth and more rapid senescence of nodules when either NO_3^- or $NH4^+$ is added. Similar report by Cenpukdee and Fukai (1991) further indicated that additional N directly antagonizes rhizobium N_2 fixation in the legume. Moreover, Lucius and Vanslayke (2010) pointed out that the bacteria use available form of N compounds, and when supplied with available nitrogenous compounds, they fail to use atmospheric N. The sole cowpea produced significantly higher nodule number compared to the intercropped cowpea (Table 4). The low nodule number in intercropped cowpea could be due to the shading effect of sorghum that hinders N-fixation. Similar result on maize-soybean intercropping could possibly be due to the shading effects of maize that significantly reduced light interception potential of the associated soybeans and reduced the photosynthetic assimilate (Abebe *et al.,* 2013). Reduced assimilate might be resulted in limited food supply for associated *Rhizobium* bacteria, and consequently their atmospheric fixation capacity were diminished (Tisdale *et al.,* 1995). The result is in harmony with the work of Tamado and Eshetu (2000) who reported that intercropping significantly affected haricot bean number of nodules $plant^{-1}$ where the lowest number was recorded in intercropping.

Table 4. Main effects of component densities of cowpea and N-rates on parameters of cowpea planted in sole and intercropped with sorghum

Treatments	Plant height (cm)	Leaf area plant^{-1}(cm^2)	Leaf area Index	Nodule number plant^{-1}	Number of pods plant^{-1}	Number of seed pod^{-1}	Harvest Index (%)
Cowpea densities							
50%	52.0	1797.8	1.0 c	11.5	12.9	9.1	27.3
75%	51.7	1811.8	1.4 b	11.7	13.2	9.1	29.0
100%	54.2	1848.0	1.9 a	12.3	12.9	8.5	28.8
SEm ±	0.9	90.5	0.1	0.4	0.6	0.4	1.2
LSD (P<0.05)	NS	NS	0.2	NS	NS	NS	NS
N-rate (kg ha^{-1})							
0	52.2	1653.8 b	1.2 c	13.9 a	12.7	7.5 b	26.1
20.5	52.4	1674.9 b	1.3 b	12.5 b	14.3	8.8 ab	30.3
41	52.7	1894.7 ab	1.5 ab	11.1 c	12.9	9.9 a	28.5
61.5	53.3	2053.4 a	1.7 a	9.9 c	12.0	9.4 a	28.6
SEm ±	1.1	104.5	0.1	0.4	0.7	0.4	0.01
LSD (p<0.05)	NS	306.4	0.2	1.2	NS	1.2	NS
CV (%)	6.1	17.2	15.4	10.8	17.2	14.3	14.4
Cropping system							
Sole cowpea	52.9	2225.5	1.7	16.4	13.4	12.2 a	41.3
Intercropped cowpea	52.6	1819.1	1.4	11.8	14.0	8.9 b	28.4
SEm ±	1.1	83.5	0.1	0.7	0.7	0.4	1.2
LSD (p<0.05)	NS	NS	NS	3.9	NS	2.3	7.1
CV (%)	3.7	7.2	5.3	7.9	7.2	6.2	5.8

Means with the same letter (s) in the same column are not significantly different at P<0.05; NS = non-significant; SEm = standard error of mean; LSD = least significant difference; CV = Coefficient of variation

The main effects, their interaction effect and cropping system did not cause significant effect on number of pods plant^{-1} (Table 4). The number of pods plant^{-1} ranged from 12.0 to 14.3. The sole and intercropped cowpea were in statistical parity (P<0.05). Solomon *et al.* (2014) reported related finding on maize- soybean intercropping.

The number of seed pod^{-1} of intercropped cowpea was affected by neither the cowpea density nor the interaction effects. This was possibly due to the reason that population differences in cowpea did not aggravate competition of available growth resources. In agreement with the present finding, Minale *et al.* (2001) reported that a non-significant effect of number of seed pod^{-1} was observed in the maize-faba bean intercropping. Similar finding was reported by Solomon *et al.* (2014) on maize-soybean intercropping system. Nitrogen and cropping system caused significant variation (Table 4). Application of N fertilizer enhanced the seed holding capacity of a pod. It has positive effect on number of seed pod^{-1}. Application of no fertilizer produced lower number of seeds pod^{-1} than the others. Number of seed pod^{-1} of sole cowpea exceeded 37% of the intercropped. This attributed to absence of more competition of resources (light, moisture, nutrients) in the sole cropped. Results related to this finding were reported by Ajeigbe*et al*. (2005) and Ibrahim *et al.* (2014).

Cropping system caused significant difference on HI of cowpea. The highest HI percentage (41.3) was recorded on sole cropped while the lowest (28.4) was from intercropped cowpea (Table 4). The reason for high percentage of HI in sole cowpea could be due to partitioning of more dry matter to seed yield. Consistent with the obtained result, Karikari *et al.* (1999) reported that the effect of intercropping with maize or sorghum on HI of Bambara groundnut was significant. Correspondingly, Saleem *et al.* (2015) on maize-mungbean intercropping reported that HI of mungbean significantly varied due to cropping system where sole mungbean comprised higher HI than the intercrop. Generally, improved HI represents increased physiological capacity to mobilize photosynthates and translocate them into organs having economic yield. This is, therefore, a fact that the economic yield of a cropping system is determined by the harvest index (HI) (ratio of grain yield to above ground biomass). The higher the HI is, the higher the dry matter conversion efficiency (Karanja *et al*., 2014).

The main effects and their interaction revealed highly significant effect (P<0.01) on grain yield. Accordingly, the highest grain yield (821.3 kg ha^{-1}) was obtained when 20.5 Kg N ha^{-1} added to 100% of cowpea density (Table 5). Numerically, the lowest grain yield had been produced when nil N fertilizer was applied to 50% of sole cowpea density

(Table 5). This finding is harmonized with the finding of Solomon *et al.* (2014) on maize-soybean intercropping where soybean planting density affected grain yield of intercropped soybean. This is also consistent with other related research (Oma e*et al.* 2014). Table 5 also indicated that cowpea grain yield ha^{-1} showed significant difference in terms of cropping system. The intercropped cowpea yield was reduced by 58.34% of sole cropped (Table 5). This might be because of competition for light. A report by Fisher *et al.* (1986) indicated that competition for light had an effect on bean yield in maize-bean intercropping. Similarly, Egbe (2010) reported that shading by the taller plants in mixture could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields. In agreement with the current finding, Solomon *et al*. (2014) also reported that sole cropped soybean produced higher yields than when intercropped with maize. Similar result was also reported by Abebe *et al.* (2013).

Dry biomass of intercropped cowpea was significantly affected (P<0.01) in terms of cowpea planting density and cropping system. Moreover, interaction effect significantly (P<0.05) influenced the dry biomass. However, N did not incur any significant (P<0.05) difference (Table 6). It is obvious that intercropping encompassed higher competitiveness due to existence of high population density as compared to sole crop. This competition can be reduced by application of fertilizer. Thus, fertilizers are more efficiently used in an intercropping system, due to the increased amount of nutrients taken up. The result displayed in table 6 revealed the interaction of 20.5 kg N ha^{-1} and 100% cowpea planting density produced the highest dry biomass (2375.0 kg ha^{-1}) and it was statistically at par to combinations of 41 kg N ha^{-1} with 50 and 100% cowpea planting densities. The lowest dry biomass had been recorded when no fertilizer was applied to 50 and 75% of the recommended cowpea densities as well as when 20.5 kg N ha^{-1} was applied to 50% of sole cowpea density (Table 6). In line to the current finding, Adem (2006) reported that dry biomass of cowpea was significantly affected by interaction of main effects on sorghum-cowpea intercropping. Furthermore, Omae *et al.* (2014) on millet-cowpea intercropping reported that biomass of cowpea was influenced due to cowpea density. The dry biomass of sole crop was significantly higher than the intercropped cowpea. Sole cropped cowpea over yielded 56.83% the dry biomass of the intercropped cowpea. The increment in dry biomass production of sole cropped cowpea was attributed to absence of competition and thus, more dry matter accumulation in stem, branches and leaves matter as a result of its good vegetative cover to harvest ample solar radiation important for its photosynthesis. This result is in conformity with the findings of Karanja *et al*., (2014). Likewise, Getachew *et al.* (2013) reported that dry biomass of forage legumes was significantly affected due to cropping system when intercropped with maize.

3.4. Total Land Productivity and Gross Return Evaluation

The productivity of this experiment was evaluated by land equivalent ratio (LER) and gross monetary value (GMV) as indices. Thus, the analyzed data in Table 7 depicted that land equivalent ratio (LER) was highly significantly affected (P<0.01) by main effects, interaction of main effects and cropping system.

The highest LER (1.46) had been achieved when 41 kg N ha^{-1} was applied to 75% sole cowpea density. Statistically, it was at par with the interaction of 20.5 kg N ha^{-1} and 100% cowpea density. Nevertheless, the lowest LER (0.98) was recorded on plots having 50% of sole cowpea density with no N fertilizer (Table 7). Concerning to the result in Table 7, in all interactions the LER was more than unity except in the treatment that received 50% of sole cowpea density with no N fertilizer application validating that limited soil fertility significantly reduces the productivity of intercropping system. LER more than unity implied that intercropping of sorghum and cowpea is advantageous in many instances rather than sole planting.

Table 5. Interaction effects of component densities of cowpea and N-rates on grain yield of intercropped cowpea with sorghum

Cowpea densities	N-rates (kg ha^{-1})				
	0	20.5	41	61.5	
50%	448.7 d	452.3 d	580.3 bc	510.3 bcd	
75%	486.3 cd	512.7 bcd	606.3 b	552.0 bcd	
100%	505.3 bcd	821.3 a	573.3 bc	528.3 bcd	
Intercrop mean	-	-	-	-	548.1 b
Sole cowpea	-	-	-	-	1315.7 a
		Density X Nitrogen		Sole X Intercrop	
SEm ±		40.7		47.2	
LSD (p<0.05)		119.2		287.5	
CV (%)		12.8		8.8	

Means with the same letter (s) are not significantly different at P<0.01; SEm = standard error of mean; LSD = least significant difference; CV = Coefficient of variation

Table 6. Interaction effects of component densities of cowpea and N-rates on above ground dry biomass of intercropped cowpea with sorghum

Cowpea densities	N-rates (kg ha^{-1})				
	0	20.5	41	61.5	
50%	1758.3 d	1729.1 d	2108.3 abc	1795.8 cd	
75%	1750.0 d	1856.0 cd	1891.5 cd	2046.0 bcd	
100%	1977.9 bcd	2375.0 a	2255.0 ab	1783.3 cd	
Intercrop mean					1943.8 b
Sole cowpea					3548.5 a

	Density X Nitrogen	Sole X Intercrop
SEm ±	117.0	97.1
LSD (p<0.05)	343.1	590.7
CV (%)	10.4	6.1

Means with the same letter (s) are not significantly different at P<0.05; SEm = standard error of mean; LSD = least significant difference; CV = Coefficient of variation

Table 7. Interaction effects of cowpea plant densities and N-rates on total land equivalent ratio (LER) of the intercropped sorghum and cowpea

Cowpea densities	N rates (kg ha^{-1})				
	0	20.5	41	61.5	
50%	0.98 e	1.00d e	1.23 c	1.25 c	
75%	1.05 de	1.26b c	1.46 a	1.16 cd	
100%	1.04 de	1.42 ab	1.26 bc	1.12 cde	
Intercrop mean					1.19

	Density X Nitrogen
SEm ±	0.06
LSD(P<0.05)	0.17
CV (%)	8.35

Means with the same letter (s) are not significantly different, NS = non-significant; LSD = least significant difference; CV = Coefficient of variation; SEm = standard error of mean

Table 8. Interaction effects of cowpea plant densities and N-rates on gross monetary value (ETB ha^{-1}) of sorghum-cowpea intercrops

Cowpea densities	N rates (kg ha^{-1})			
	0	20.5	41	61.5
50%	9322.70 e	9551.10 ed	11650.00 bc	12101.20 bc
75%	10009.80 ed	12134.70 bc	14001.70 a	10890.40 cd
100%	9842.50 ed	12998.00 ab	12027.70 bc	10615.80 cde

	Density X Nitrogen
SEm ±	529.72
LSD (P<0.05)	1553.60
CV (%)	8.15

Means with the same letter (s) are not significantly different, NS = non-significant; ETB = Ethiopian birr; LSD = least significant difference; CV= Coefficient of variation; SEm = standard error of mean

Tauro *et al.* (2013) showed that when the LER > 1, intercropping is advantageous because environmental resources are used more efficiently for plants growth and LER < 1, there is disadvantage as environmental resources utilized less efficiently. Moreover, yield advantages have been recorded in many legume-cereal intercropping systems, including soybean-sorghum (Hayder *et al*., 2003), maize-mungbean (Saleem *et al.,* 2015) and cowpea-maize (Eskandari and Ghanbari, 2010). The reason of yield advantage of intercropping are mainly that environmental resources such as water, light and nutrients can be utilized more efficiently in intercropping than in the respective sole cropping systems (Liu *et al*., 2006). Intercropping also gives higher yield advantage when total population in the system is higher than that of sole crops (Willey, 1979b).

Table 9. Influence of interaction effects of cowpea plant densities and N-rates on monetary advantage (ETB ha^{-1}) of sorghum and cowpea intercrops

Cowpea densities	N rates (kg ha^{-1})			
	0	20.5	41	61.5
50%	-223.60 e	-19.40 de	2152.00 c	2452.00 bc
75%	476.80 de	2508.80 bc	4382.80 a	1464.40 cd
100%	399.00 de	3832.70 ab	2475.00 bc	1151.60 cde

	Density X Nitrogen
SEm ±	528.25
LSD(P<0.05)	1549.30
CV (%)	52.15

Means with the same letter (s) are not significantly different, NS = non-significant, LSD = least significant difference; CV = Coefficient of variation; SEm = standard error of mean

The data for LER (1.19) in Table 7 showed that intercropping gave 19% advantage in efficiently utilizing land than planting the crops sole. The sole cropping of either sorghum or cowpea would require 0.19 more unit of land to get the same yield obtained from the intercropping system. This result agreed with the report of Chemeda (2003) who found up to 28% higher total productivity increase of maize-bean intercropping compared with pure stand. Likewise, Getachew *et al.* (2013) also reported that intercropping gave a 45%, 29%, and 21% yield advantages than planting sole crops on maize-forage legumes (vetch and lablab) intercropping system. These values were achieved when vetch was row-sown at 50% seed rate of its sole followed by vetch broadcast at the same rate and lablab broadcast at 75% seed rate of its sole.

The analysis for GMV showed highly significant (P<0.01) difference due to the influence of main effects, interaction effect and cropping system. Values of GMV appeared in the same pattern as to LER. Thus, the highest GMV (14001.70 ETB ha^{-1}) was due to combination of 41 kg N ha^{-1} and 75% of sole cowpea density. On the other hand, the least GMV (9322.70 ETB ha^{-1}) was obtained from plots planted with 50% of sole cowpea density with nil N fertilizer (Table 8). Generally, based on this result of economic analysis, intercropping of cowpea with sorghum was more advantageous than sole crop. In agreement to this result, Solomon *et al.* (2014) reported that the GMV of intercrops was higher than sole maize on maize-soybean intercropping.

Regarding to monetary advantage (MA), it varied significantly in terms of main effects and their interaction. Similar to LER, the maximum and minimum MA was recorded in the same trend. The maximum MA (4382.80 ETB ha^{-1}) was obtained due to combination of 41 kg N ha^{-1} and 75% sole cowpea density. The minimum MA (-223.60 ETB ha^{-1}) had been seen in plots received 50% cowpea with nil N fertilizer (Table 9). This indicated that no MA of intercropping incurred, here. The negative value indicates a loss of Birr 223.60 ha^{-1} from unfertilized intercrops. Solomon *et al.* (2014) found that the highest MA was obtained at high planting density of soybean on maize – soybean intercropping system. Similarly, the current result showed that statistically at par MA was obtained at high planting densities (Table 9). Related work by Abebe *et al.* (2013) on soybean-maize intercropping also reported that integrated fertilizer application with various proportions of NP with FYM significantly increased MA over the unfertilized intercrops.

Generally, the LER and GMV analysis assured that sorghum-cowpea intercropping was superior to and more advantageous over sole cropping. Intercropping is more reliable for sustainable and environmentally safe cereal crop production as to N fixation nature of cowpea and its compatible nature. It also provides high insurance against crop failure, especially in areas subject to extreme weather conditions such as frost, drought, flood, and overall provides greater financial stability for farmers, making the system particularly suitable for labor-intensive small farms (Lithourgidis *et al*., 2011). Furthermore, intercropping led to greater land utilization and increased the net return over sole crops (Khola and Singh, 1996).

4. Conclusions

This experiment was conducted to assess the effect of plant densities of the intercropped cowpea and N fertilizer rates on yield and yield related traits of sorghum and cowpea as well as to determine the appropriate plant density of cowpea and nitrogen fertilizer rate that maximize the productivity of the intercrop system. Hence, it was found that N significantly affected plant height, leaf area, leaf area index and dry biomass of sorghum. Increasing of N rate enhanced performance of those parameters. Accordingly, the highest of each was registered due to 61.5 kg N ha^{-1}. Needless to say, grain yield was affected by the main effects, their interaction and cropping system. The highest grain yield (2370.4 kg ha^{-1}) was obtained from the combination of 41 kg N ha^{-1} and 75% sole cowpea density.

Similarly, leaf area and leaf area index (LAI) of cowpea showed statistically significant response to N. They showed an increased trend at high level of N. LAI was also significantly affected due to cowpea density where the highest LAI was obtained at 100% cowpea density. The main effects as well as their interaction and cropping system considerably affected the grain yield. As a result, the highest grain yield (821.3 kg ha^{-1}) was obtained when 20.5 Kg N ha^{-1} interacts with 100% of cowpea density. As explained in grain yield, similar situation also occurred in dry biomass yield of cowpea.

The LER and GMV analysis showed that sorghum-cowpea intercropping was highly superior to and more advantageous over sole cropping. The highest LER (1.46) and GMV (14001.70 ETB ha^{-1}) were achieved at combination of 41 kg N ha^{-1} and 75% sole cowpea density while the lowest LER (0.98) and GMV (9322.70 ETB ha^{-1}) were recorded on plots having 50% of sole cowpea density without N fertilizer.

In general, the system is more reliable for sustainable and environmentally safe cereal crop production due to the N fixation nature of cowpea and its compatible nature. This is, therefore, sorghum-cowpea intercropping was proved to be more productive and efficient system in utilizing land compared to sole cropping with carefully managed N fertilizer and cowpea plant density. Hence, combination of 41 kg N ha^{-1} and 75% sole cowpea density can be recommended for the farmers in the study area to improve sorghum productivity.

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