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Evaluation of Cowpea Plant Density and Nitrogen Fertilizer for Productivity of Sorghum/Cowpea Intercrops at Abergelle, Northern Ethiopia

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Abstract

As mono cropping practice limited sorghum productivity in Abergelle, an experiment on sorghum/cowpea intercropping was conducted in 2014 cropping season to evaluate 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 were carried out in Randomized Complete Block Design (RCBD) with three replications. The analyzed result showed that grain yields of the component crops were highly significantly affected ($P<0.01$) due to interaction effect. The highest grain yield of sorghum (1769.10 kg ha^{-1}) and cowpea (975.67 kg ha^{-1}) was obtained from the combination of 61.5 kg N ha^{-1} with 100% sole cowpea plant density and when 41 kg N ha^{-1} combined with 75% of sole cowpea plant density, respectively. 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 (1.76) and GMV (14313.20 ETB ha^{-1}) were obtained from combination of 41 kg N ha^{-1} and 75% cowpea plant density. This is, therefore, combination of 41 kg N ha^{-1} and 75% sole cowpea plant density can be recommended for farmers of the study area to improve sorghum productivity and the cropping system at large.

Keywords: Cowpea, Intercropping, Nitrogen, Plant population, Sorghum

Introduction

In Ethiopia, sorghum [*Sorghum bicolor* (L) Moench] is adapted to a wide range of environment, and hence can be produced in the highlands, medium altitude and lowlands. It grows most importantly in the moisture stressed parts where other crops can least survive and food insecurity is rampant (Adugna, 2007). In lowlands of Ethiopia, especially in the lowlands of eastern Ethiopia and in the north and north-eastern parts of the country where the climate is characterized by unpredictable drought and erratic rainfall, sorghum is one of the most important cereal crops planted as food insurance (Degu *et al.,* 2009).

Sorghum is among the most dominant staple major cereal crops in central Tigray where Abergelle is located. The agro-ecology of the area best fits for it. In central Tigray, it covered an estimated total land area of 39,958.08 ha and its average productivity is 1.72 ton ha^{-1} which is less than its national average productivity of 2.28 ton ha^{-1} in 2013/ 2014 cropping season (CSA, 2014). Its productivity is limited due to deterioration in soil fertility, shortening of the length of fallow, expansion of production into marginal lands with little use of external soil amendments and the increasing trend towards continuous cultivation of cereal mono crops in place of traditional rotation and intercropping systems, and lack of agricultural inputs (UNDP, 1996).

Therefore, it is necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security. Such technologies include the use of integrated soil fertility management practices (ISFM) which have intercropping cereals with legumes as one of its main components (Sanginga and Woomer, 2009). This practice is an attractive strategy to smallholder farmers for increasing productivity and labour utilization per unit of area of available land through intensification of land use (Seran and Brintha, 2010). 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).

Sorghum - cowpea intercropping is among the most important farming system for small scale farmers in Arid and Semi-Arid Lands of sub-Sahara African (Karanja *et al.,* 2014). In Ethiopia, cowpea [*Vigna unguiculata* (L) Walp] is becoming among the most commonly cultivated lowland pulses. Intercropping with cowpea leads to higher sorghum grain yield which may bring nitrogen into the farming system through biological fixation as well as to induction of suicidal germination of *Striga* seeds away from the host roots (Ayana *et al.,* 2013).

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, intercropping legumes with cereals is particularly important in countries where the cost of N fertilizer is high and / or availability of fertilizer is limited. Moreover, the low fertilizer response of landraces and the extreme drought at the end of growing seasons limit the use of inorganic fertilizer by farmers. Thus, to reduce these constraints, a research on sorghum/cowpea intercropping system under effective management of N fertilizer application and cowpea plant density in the study area to get quantitative information on the productivity of the system, and its influence on yield and yield related traits of the component crops should be conducted.

Therefore, this experiment aimed to evaluate 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.

Materials and Methods

Description of experimental area

The experiment was carried out under rain-fed conditions in Abergelle Agricultural Research Center testing site in the 2014 cropping season. It is located in central zone of Tigray which is 903 km north of Addis Ababa and 120 km south west of Mekelle and situated at $13^0 14'06''$N latitude and $38^0 58'50''$E longitudes. It is agro-ecologically characterized as hot warm sub-moist lowland (SMl-4b) below 1500 meter above sea level (m.a.s.l). The rainfall is a uni-modal pattern. Its long average annual rainfall and temperature is 350 – 700 mm and 24 – 41 ^{0}c respectively (Legesse, 1999).

Treatments and field 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 (Bekur variety) and sorghum (Gobiye variety) 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. Sorghum was planted at a spacing of 75 x 20 cm while cowpea, 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 sole 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.

Data collection

Before planting, soil sample at a depth of 0-20 cm was taken from five random spots diagonally across the experimental field using auger. The 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.

Leaf area index (LAI) of the component crops were measured using five random plants plot^{-1} from the net plot area (2.25 m * 3.6 m). 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 № of leaves/plants. Plant height (cm) of the sorghum was measured from five randomly taken plants of each net plot area at 90% physiological maturity with a standard meter rule. Similarly, these randomly taken five plants were used to measure panicle length (cm) of sorghum. Effective nodules 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 area and were counted based on their colour (pink colour). Pod length (cm) was determined from the five sampled plants of a net plot area at physiological maturity. 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 dry biomass yield (kg ha^{-1}) of the test crops was also measured after the plants from the net plot area had been harvested and sun dried till constant dry weight was attained.

Land equivalent ratio (LER) and gross monetary value (GMV) were used to evaluate the productivity and profitability of intercrops compared with mono-crops. LER was calculated according to Mead and Willey (1980):

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

Where; Yab= yield per unit area of crop a in intercrop; Yaa= yield per unit area of pure crop a; Yba= yield per unit area of crop b in intercrop; Ybb= yield per unit area of pure crop b; a= sorghum; b= cowpea

Gross monetary value (GMV) was calculated by multiplying yields of the component crops by their respective current market price. Hence, sorghum grain yield was valued at an average existing local market price of Birr 5.50 kg^{-1} and cowpea at Birr 5.50 kg^{-1} in Abergelle district from November 2014 to February 2015.

Data analysis

The collected data were subjected to the analysis of variance (ANOVA) using the SAS computer package version 9.1 (SAS Institute, 2004). The Least significant difference (LSD) test at 5% level of probability was used to separate treatment means (Gomez and Gomez, 1984).

Results and Discussion

Soil analysis

The physical and chemical proprieties of the composite soil samples were analyzed in the Mekelle Soil Research Center soil laboratory following standard procedures. Accordingly, the results in Table 1 indicated that the soil comprised total N of 0.08%, characterizing a low level of N (Berhanu, 1980). According to Olsen *et al.* (1954), it also contained high available P (13.82 mg kg^{-1}). The organic matter content of the soil (0.72%) was very low which is in agreement with findings of Tekalign (1991). It needs supplement or addition of materials that increase the organic matter in the soil.

The pH value was 7.18 which coincide with the finding of Tekalign (1991) who reported that soils having pH value in the range of 7.4 to 8.0 are considered moderately alkaline soils. The CEC of the study area was 22.60 Cmol kg^{-1} (Table 1). This showed high capacity of the soil to retain cations in exchangeable form for the plant. According to Hazelton and Murphy (2007), the EC of the soil (0.18 ds m^{-1}) also indicated that the experimental soil was non-saline.

Table 1. Soil result for major soil characteristics of the experimental site before planting

Soil parameter	Unit	Value
Total N	%	0.08
Available P	mg kg^{-1}	13.82
Organic Matter	%	0.72
Soil pH	-	7.18
EC	ds m^{-1}	0.09
CEC	cmol kg^{-1}	22.60
Particle Size distribution		
Sand	%	47.00
Silt	%	11.00
Clay	%	42.00
Textural class		SANDY CLAY

Sorghum components

Plant height

Plant height of intercropped sorghum was affected significantly ($P<0.05$) only due to the effect of N (Table 2). The tallest plant height (114.81 cm) of intercropped sorghum was recorded due to application of 61.5 kg ha^{-1} and was statistically at par with the plant height obtained due to application of 41 kg ha^{-1}(Table 2). As N increased from nil to 61.5 kg ha^{-1}, plant height also increased from 108.02 cm to 114.81 cm. This increment could be due to the vital role of N in enlargement of vegetative growth of plant parts. In agreement with this result, Abebe *et al.* (2013) reported significant variation in plant height of intercropped maize due to integrated N fertilizer application on maize-soybean intercropping where plant height of maize increased as the level of fertilizer increased.

The plant height of intercropped (110.84 cm) and sole sorghum (111.53 cm) were not significantly different which could be attributed to less competition of growth resources between the intercrops. This result was in agreement with the study by Biruk (2007) who reported that the main effect of common bean planting densities, interaction effect and the cropping system had no significant effect on plant height of sorghum intercropped with common bean.

Leaf area index

According to Table 2, leaf area index (LAI) was varied significantly ($P<0.01$) due to the main effect of N; however, the variation due to cowpea density and interaction effect was non-significant. Accordingly, the highest numerical value of LAI was obtained due to application of 61.5 kg N ha^{-1}. This result indicated that application of 61.5 kg N ha^{-1} revealed an increment of 34.46% 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), and so far few studies have been focused upon this aspect (Eyob, 2007 ; Mahmoud *et al.,* 2013). Likewise, Abebe *et al.* (2013) reported that integrated N fertilizer application on soybean-maize intercropping significantly affected LAI of maize.

As indicated in Table 2, cropping system did not affect LAI significantly. This could be most likely due to absence of competition nature of intercropped cowpea on sorghum. In conformity with this result, Adem (2006) on sorghum/cowpea intercropping showed that neither the component density nor their interaction and cropping system significantly affected sorghum LAI.

Table 2. Effect of cowpea plant densities and N-rates on plant height, leaf area index, panicle length (cm) and dry biomass (kg ha^{-1}) of intercropped sorghum with cowpea

Treatments	Plant height (cm)	Leaf area index	Panicle length (cm)	Dry biomass (kg ha^{-1})
Cowpea densities				
50%	111.90	1.86	25.71	3407.95
75%	110.47	1.75	25.18	3442.44
100%	110.16	1.65	24.96	3426.12
LSD (0.05)	NS	NS	NS	NS
N-rates (kg ha^{-1})				
0	108.02 c	1.48 b	24.29 b	3257.30 c
20.5	108.81 bc	1.63 b	24.48 b	3313.40 bc
41	111.72 ab	1.92 a	26.21 a	3501.40 ab
61.5	114.81 a	1.99 a	26.16 a	3629.90 a
LSD (0.05)	4.11	0.19	1.63	215.11
CV (%)	4.69	11.05	6.6	6.42
Cropping system				
Sole sorghum	111.53	1.94	25.29	4252.04 a
Intercropped sorghum	110.84	1.75	25.28	3425.50 b
LSD (0.05)	NS	NS	NS	306.62
CV (%)	6.63	5.28	4.87	4.27

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

Panicle length

As indicated in Table 2, N resulted in significant variation ($P<0.05$) in panicle length of intercropped sorghum, but there was no significant effect due to cowpea density. The highest panicle length (26.21 cm) was recorded when 41 kg N ha^{-1} was applied which was statistically at par with the panicle length recorded at 61.5 kg N ha^{-1} (Table 2). Application of N fertilizer improved panicle length as compared to nil fertilizer. This might be most probably due to the attributes of N fertilizers to increase the vegetative growth of crops. Similary, Eyob (2007) on sorghum-faba bean intercropping study reported that an increasing rate of N resulted in highly significant difference ($P<0.01$) of intercropped sorghum panicle length. The current finding also showed that the panicle length of sole and intercropped sorghum was not significantly different which could be associated with the compatible use of growth resources of the intercrops without affecting each other.

Dry biomass yield

Nitrogen showed highly significant ($P<0.01$) effect and cropping system had significant ($P<.05$) effect on above ground dry biomass of intercropped sorghum; whereas, the main effect of cowpea density and the interaction were not significant (Table 2). Application of N fertilizer resulted in progressive increase in dry matter yield of intercropped sorghum. Thus, plots received 61.5 kg N ha^{-1} out yielded by 11.44% dry biomass over those which did not get any N fertilizer. Unlike to the other N rates, 41 kg N ha^{-1} was statistically at par with 61.5 kg N ha^{-1} on influencing the dry biomass yield. 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. Likewise, 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.

Cropping system highly significantly affected dry biomass yield of sorghum where sole sorghum had 24.13% more dry biomass yield than the intercropped sorghum (Table 2). This might be attributed to free access of sole sorghum to growth resources with no competition. This result was in line with that of Siddig *et al*. (2013) who reported that dry matter weight of sorghum was significantly influenced due to sorghum-ground nut intercropping.

Table 3. Interaction effects of cowpea plant densities and N-rates on grain yield (kg ha^{-1}) of intercropped sorghum with cowpea

Cowpea densities	N rates (kg ha^{-1})				
	0	20.5	41	61.5	
50%	1202.80 e	1236.90 e	1397.60 cde	1270.30 cde	
75%	925.90 f	1251.00 de	1626.70 ab	1480.20 bc	
100%	665.70 g	1414.10 bcd	1448.90 bcd	1769.10 a	
Intercrop mean					1307.40 b
Sole sorghum					1876.60 a
			Cowpea density X Nitrogen		
LSD (0.05)			211.51		
CV (%)			9.55		

Means with the same letter (s) are not significantly different at $P<0.05$; LSD= least significant difference; CV= coefficient of variation

Sorghum Grain yield

Sorghum grain yield was highly significantly ($P<0.01$) affected by N and interaction effect (Table 3). As shown in Table 3, the highest grain yield (1769.10 kg ha^{-1}) was obtained from the combination of 61.5 kg N ha^{-1} and 100% sole cowpea plant density which was significantly the highest, while the lowest grain yield of 665.70 kg ha^{-1} was obtained from the unfertilized plots intercropped with 100% sole cowpea plant density. Further, cropping system had significant ($P<0.05$) effect on grain yield at which sole sorghum exceeded by 43.54% of the intercropped sorghum yield (Table 3). The most probable reason for this variation could be 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. Moreover, Abraha (2013) on maize-forage legumes (lablab and cowpea) intercropping indicted that grain yield of sole maize yielded the highest (3056 kg ha^{-1}) and lower (2305 kg ha^{-1}) for maize/cowpea integration.

Cowpea Components

Leaf area index

The obtained result showed that leaf area index (LAI) of intercropped cowpea was significantly affected due to cowpea plant density where the highest LAI was obtained from the highest population density. Increasing cowpea plant density caused a corresponding increment of LAI (Table 4). Treatments with high densities resulted in higher LAI because of lower ground area occupied by a plant which ultimately increased the LAI. This result was in conformity with the findings of Adem (2006) on sorghum/cowpea intercropping.

Nitrogen affected LAI of intercropped cowpea where the largest LAI (1.44) was recorded due to 61.5 kg N ha^{-1} and produced 24.14% LAI over the unfertilized plots (Table 4). The result indicated that N fertilizer application could enhance nutrient availability which probably increase the photosynthetic efficiency and consequently increased the vegetative growth and development. The current result agrees with the finding of Abebe *et al.* (2013) on soybean-maize intercropping where the highest LAI was found to be at application of the highest integrated N fertilizer. Table 4 also revealed that cropping system did not cause significant effect on LAI which is in agreement with Ibrahim *et al.* (2014) who reported that LAI of cowpea was not significantly affected due to sorghum-cowpea cropping system.

Pod length

Cowpea density did not reveal significant difference ($P<0.05$) on pod length plant^{-1} of intercropped cowpea (Table 4). Rather, they confined a disparity of less than one among them. This statistical similarity might come due to compatible utilization of resources among them to have the required pod length of cowpea. However, N rates showed significant effect on pod length of intercropped cowpea. It was clearly seen that the value of this parameter increased as the N rate increased progressively where the highest numerical value for panicle length was obtained from 41 kg N ha^{-1} while the lowest value was due 0 kg N ha^{-1}. Generally, application of nitrogen exhibited more pod length than nil nitrogen fertilizer. This could be due to the fact that one among the functions of nitrogen is to increase the vigorous growth of vegetative parts of plants. Table 4 further showed that pod length did not varied significantly due to cropping system. This is in conformity with the finding of Abraham (2013) who described that intercropping was not significantly affecting pod length of lablab-maize intercropping and cowpea-maize intercropping.

Nodule number plant^{-1}

Regardless of cowpea density and interaction effect, N and cropping system significantly influenced the nodule number plant^{-1} of cowpea (Table 4). The maximum nodule number plant^{-1} of intercropped cowpea (15.28) was recorded from plots received nil N and was significantly higher than any of the N levels while the lowest (11.17) 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 Noel *et al.* (1982), higher N in the soil depresses nodulation and N fixation through inhibition of thread, slowing of nodule growth, inhibition of fixation with the established nodules, and more rapid senescence of nodules when either NO_3^- or $NH4^+$ is added. Moreover, Lucius and Vanslayke (2010) pointed out that the bacteria use available form of N compounds, when reach in the soil, and therefore, 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 possible reason for the lower mean value in intercropped cowpea could be due to high environmental growth resource competition and 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 soybean 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). Likewise, Tamado and Eshetu (2000) reported that intercropping significantly affected haricot bean number of nodules plant^{-1} where the lowest number was recorded in intercropping.

Dry biomass yield

The current finding showed that dry biomass yield of intercropped cowpea was significantly affected due to cowpea plant density where the highest dry biomass yield was from the lowest cowpea plant density (Table 4). Increasing cowpea plant density caused a decreasing trend in dry biomass yield due to presence of high competition for growth resources at densely populated areas. Similarly, Table 4 revealed that N rates showed significant effect on dry biomass yield of intercropped cowpea. Accordingly, dry biomass yield increased as the N rate increased progressively where the highest numerical value was obtained from 61.5 kg N ha^{-1}. This increment could be attributed to superior cell expansion, more rapid cell division and parallel augmented photosynthate construction. Similarly, Saleem *et al.* (2015) on maize-mungbean intercropping reported that biological yield of mungbean was significantly affected by fertilizer amendments.

Furthermore, dry biomass yield of sole cropped cowpea out yielded the intercropped cowpea by 38.16% (Table 4). The increment in dry biomass production of sole cropped cowpea might be 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 was in conformity with the findings of Karanja *et al.* (2014) who reported that sole cropped gave higher dry biomass yield than the intercropped. Likewise, Getachew *et al.* (2013) reported that dry biomass of forage legumes was significantly affected due to cropping system when intercropped with maize.

Table 4. Leaf area index, pod length (cm), № of nodules plant^{-1} and dry biomass yield of cowpea as influenced by cowpea plant densities and nitrogen rates under sorghum/cowpea intercropping

Treatments	Leaf area Index	Pod length (cm)	№ of nodules plant^{-1}	Dry biomass (kg ha^{-1})
Cowpea densities				
50%	0.87 c	19.04	12.83	1990.76 a
75%	1.29 b	19.75	13.05	1783.73 b
100%	1.72 a	19.26	13.61	1732.32 b
LSD (0.05)	0.17	NS	NS	161.35
N-rates (kg ha^{-1})				
0	1.16 c	18.33 b	15.28 a	1618.09 b
20.5	1.22 bc	19.33 ab	13.83 b	1844.94 a
41	1.36 ab	20.22 a	12.38 c	1908.55 a
61.5	1.44 a	19.48 ab	11.17 c	1970.82 a
LSD (0.05)	0.19	1.16	1.28	186.31
CV (%)	15.34	6.15	9.94	10.38
Cropping system				
Sole cowpea	1.71 a	16.76	16.71 a	2535.80 a
Intercropped cowpea	1.30 b	19.35	13.17 b	1835.60 b
LSD (0.05)	0.28	NS	2.99	567.90
CV (%)	5.36	8.84	5.69	7.40

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

Cowpea grain yield

The N and interaction of main effects revealed highly significant ($P<0.01$) response on grain yield of intercropped cowpea where the highest grain yield (975.67 kg ha^{-1}) was obtained when 41 kg N ha^{-1} combined with 75% of sole cowpea plant density. On the other hand, the lowest grain yield (437.00 kg ha^{-1}) had been produced when nil N fertilizer was applied to 75% of sole cowpea plant density (Table 5). In line with this result, Solomon *et al.* (2014) on maize-soybean intercropping reported that soybean planting density significantly affected grain yield of intercropped soybean. This result was also consistent with other related research on millet-cowpea intercropping where the highest cowpea yield was produced from high cowpea plant density (Omae *et al.* 2014).

Table 5 also indicated that cowpea grain yield ha^{-1} was significantly influenced due to cropping system. The intercropped cowpea yield was reduced by 39.04% of sole cropped (Table 5). This could be attributed to competition for light and other environmental growth resources. A report by Egbe (2010) indicated that shading by the taller plants in mixture could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields. Similar result was reported by Solomon *et al*. (2014) and Abebe *et al.* (2013) on maize-soybean intercropping.

Table 5. Interaction effects of cowpea plant densities and N-rates on grain yield (kg ha^{-1}) of intercropped cowpea with sorghum

Cowpea densities	N-rates (kg ha^{-1})				
	0	20.5	41	61.5	
50%	455.33 ef	745.67 bc	770.33 bc	814.67 b	
75%	437.00 f	744.33 bc	975.67 a	670.00 cd	
100%	474.00 ef	818.33 b	685.33 bcd	577.67 de	
Intercrop mean					680.69 b
Sole cowpea					1116.61 a
		Cowpea density X Nitrogen			
LSD (0.05)		137.58			
CV (%)		11.94			

Means with the same letter (s) are not significantly different at $P<0.05$; LSD= least significant difference; CV= coefficient of variation

Total land productivity and gross return evaluation

Land equivalent ratio (LER) and gross monetary value (GMV) were used to evaluate the productivity and profitability of this experiment. Table 6 depicted that LER was highly significantly affected by N, interaction of main effects and cropping system. Thus, the highest LER (1.76) had been achieved when 41 kg N ha^{-1} was applied to 75% sole cowpea plant density while the lowest LER (0.78) was recorded on plots having 100% of sole cowpea plant density with no N fertilizer (Table 6). The LER was more than unity except in the treatment that received 100% and 75% of sole cowpea 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. This showed complementarity in resource utilization by the component crops. Furthermore, the reasons 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).

Table 6. 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%	1.05 c	1.33 b	1.45 b	1.41 b	
75%	0.89 cd	1.34 b	1.76 a	1.40 b	
100%	0.78 d	1.49 b	1.39 b	1.47 b	
Intercrop mean					1.32
				Cowpea density X Nitrogen	
	LSD(0.05)			0.17	
	CV (%)			7.57	

Means with the same letter (s) are not significantly different, LSD= least significant difference; CV= coefficient of variation

According to Table 6, intercropping gave 32% advantage in efficiently utilizing land than planting the crops sole. The sole cropping of either sorghum or cowpea would require 0.32 more unit of land to get the same yield obtained from the intercropping system. Solomon *et al.* (2014) on maize-soybean intercropping, and Abraha (2013) on maize-forage legumes intercropping supported this finding.

The analysis for GMV showed highly significant ($P<0.01$) difference due to the influence of N, interaction of main effects and cropping system. The highest GMV (14313.20 ETB ha^{-1}) was due to combination of 41 kg N ha^{-1} and 75% of sole cowpea plant density which was statistically highly superior to the others. However, the least numerical GMV (6268.60 ETB ha^{-1}) was obtained from plots planted with 100% of sole cowpea plant density combined with nil N fertilizer (Table 7). Generally, application of no fertilizer decreases the economic value of the system confirming that less fertile soil limits the economic advantage of intercropping. Based on this result of economic analysis, it was noted that intercropping of cowpea with sorghum was more advantageous than sole crop. In agreement to this finding, Solomon *et al.* (2014) reported that the GMV of intercrops was higher than sole maize on maize-soybean intercropping.

Table 7. 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%	9119.90 e	10904.30 d	11923.40 bcd	11467.40 cd
75%	7495.70 e	10974.30 d	14313.20 a	11828.90 bcd
100%	6268.60 e	12278.30 bc	11738.20 bcd	12907.20 b
			Cowpea density X Nitrogen	
	LSD (P=0.05)		1296.50	
	CV (%)		7.00	

Means with the same letter (s) are not significantly different, ETB= Ethiopian birr; LSD= least significant difference; CV= coefficient of variation

Conclusions

Deteriorated soil fertility and mono cropping practice limited the production and productivity of sorghum in the study area. As a result, this experiment was conducted in Abergelle district in 2014 cropping season on sorghum/cowpea intercropping to evaluate 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.

Sorghum/cowpea intercropping was proved to be more productive and efficient system in utilizing land compared to sole cropping under proper cowpea plant density and N fertilizer. Thus, the main effect of N significantly influenced plant height and panicle length of sorghum. It also significantly affected pod length and number of nodules plant^{-1} of cowpea. Similarly, above ground dry biomass yield and leaf area index of both crops showed significant response to N. Cowpea plant density caused significant effect on LAI and dry biomass yield of intercropped cowpea. Moreover, grain yields of the component crops were highly significantly affected due to interaction effect. The highest grain yield of sorghum (1769.10 kg ha^{-1}) and cowpea (975.67 kg ha^{-1}) was obtained from the combination of 61.5 kg N ha^{-1} with 100% sole cowpea plant density and when 41 kg N ha^{-1} combined with 75% of sole cowpea plant density, respectively.

The LER and GMV analysis showed that sorghum/cowpea intercropping was highly superior to and more advantageous over sole cropping. The highest LER (1.76) and GMV (14313.20 ETB ha^{-1}) were achieved at 41 kg N ha^{-1} + 75% sole cowpea plant density while the lowest LER (0.78) and GMV (6268.60 ETB ha^{-1}) were recorded on plots having 100% of sole cowpea plant density without N fertilizer.

This is, therefore, combination of 41 kg N ha^{-1} and 75% sole cowpea plant density can be recommended for farmers of the study area to improve sorghum productivity and the cropping system at large.

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