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Effect of Intercrop Row Arrangement on Maize and Haricot Bean Productivity and the Residual Soil

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Abstract- On farm studies were conducted to determine the effects of intercrop row arrangements on the performances of maize (Zea mays L.) and haricot bean (Phaseolus vulgaris L.) crops and the residual soil at Hallabaand Tabaareas, southern Ethiopia. The result revealed that there were significant differences among the cropping patterns on growth and yield components of both crops. Grain yield of the maize crop was observed to be the highest insole stand, which was statistically at par with the maize grown in 1:1 ratio with haricot bean. There was 15.5% yield reduction in maize when the number of haricot bean rows introduced between two maize rows increased from one to three, attributable to aggravation of inter-specific competition in the latter case. In the case of haricot bean crop, compared to the sole stand intercropping of one, two and three rows of haricot bean between two rows of maize had resulted in yield reductions of 56, 44.5 and 28.2%, respectively. Evaluation of the land use efficiency of the system in terms of land equivalent ratio (LER) has, however, showed improvement across the cropping pattern, where by 1:3 maize-haricot bean row ratio gave the highest land use efficiency value, 54% more efficient than growing both crops in sole stand. Total N content of the residual soil has also showed significant improvement due to the introduction of the leguminous haricot bean into the cropping system. In contrast, sole maze stands had contributed the least in amending the acidity problem of the experimental soils.

Keywords: *grain yield; IAI; LER; kernel; row ratio; total soil n.*

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I. Introduction

Agriculture in the next decade will have to produce more food from less area of land through more efficient use of natural resources with minimal impact on the environment in order to meet the growing population demands (Hobbs et al., 2008). Multiple cropping offers one of the best ways of increasing production per unit area by growing two crops of dissimilar growth habit in the same field with little intercrop competition. Traditionally, intercropping is being used by small farmers to increase the density of their products and stability of their output. Cereal-legume mixtures have been adjudged the most productive form of intercropping since the cereals may benefit from the nitrogen fixed in the root nodules of the legumes in the current cropping year (Chalk, 1996; Adu-Gyamfiet al., 2007; Undieet al., 2012) or in the subsequent years (Giller and Wilson, 1993). In this regard, there is a possibility of root exudates or the decay of roots and nodules causing the release of N from legumes into the rhizosphere during the cropping season (Vandermeer, 1989). Legumes in intercropping could also provide N benefits to subsequent crops from the mineralization of N from their residues or from the N sparing effect, where a legume crop can fix atmospheric N_2, thereby reducing competition for soil NO_3^- with a nonlegume crop (Vandermeer, 1989; Anil et al., 1998).

The extent of competition-induced yield loss in intercropping is likely to depend on the spatial arrangement of the component crops. Spatial arrangement of intercrops is an important management practice that can improve radiation interception through more complete ground cover (Heitholtet al., 2005). Choice of appropriate population density, therefore, seems relevant management options in improving the efficiency of this system. Therefore, there is potential for higher productivity of intercrops when intra-specific competition is less than inter-specific competition for a limiting resources (Banik and Sharma, 2009). Arrangement of crops in mixture in the traditional farming systems of Hallaba and Taba areas, Southern Ethiopia is random and without any sufficient attempt to pattern the crops for effective interception of essential resources. Much of the poor crop yields obtained in traditional crop production systems of these areas might be attributable in part to improper crop arrangement with its attendant waste of essential environmental resources.

A wide range of legume-maize intercrops have been found to respond better to two rows of legume after one row of maize (Odhiambo and Ariga, 2001; Mareret al., 2007; Banik and Sharma, 2009). Since crop arrangement is a function of plant density, there is therefore, higher light interception at wider spacing than at narrower spacing (Keating and Carberry, 1993; Prasad and Brook, 2005; Jiao et al., 2008).The performance of an additive or superimposed population of haricot bean in maize as intercrop has not been investigated in this Hallaba and Tabaareas. In view of the above reasons, this research was undertaken with the objective to determine the effects of intercrop row arrangements of haricot bean and maize crops in

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additive model on productivity and residual soil at Hallabaand Tabaareas of southern Ethiopia.

II. Materials and Methods

a) *Description of the Study Areas*

On farm studies were carried out in the cropping seasons of 2013 at Hallaba and Taba areas, southern Ethiopia, to determine of effects of intercropping maize with haricot bean crop at different population densities on the productivity of component crops. In the 2013 cropping season Hallaba and Taba, received annual rainfall of 970 and 1326 mm, respectively. The annual mean maximum temperatures of the two areas were 26.3 and 24.0^{0}C while the mean minimum temperatures are 14.2 and 11.5^{0}C, respectively (Fig. 1). The soil of the study areas are clay loam in texture, acidic in reaction, low in organic matter, N and other essential nutrients (Table 1).

b) *Experimental Treatments and Data Collection*

In this study 333,333 plants ha^{-1}obtained from a 20cm by 15cm inter and intra-row spacing, respectively, was considered as optimum plant population for sole crop and the three different proportions of haricot bean: 25% (83,333 plants ha^{-1}), 50% (166,666 plants ha^{-1}) and 75% (249,999 plants ha^{-1}) was interplanted with constant maize population (50,000 plants ha^{-1}) in an additive model, which resulted into three maize: haricot bean row arrangements: 1:1, 1:2 and 1:3. A constant 80cm by 25cm inter and intra-row spacing, respectively, was maintained for maize in both cropping systems (sole and intercrop); because any variation in intercropped maize compared with sole cropping would be attributed to the addition of beans between maize rows.. Experimental plots were 19.6m^2 (3.5m x5.6m) size each. The experiment was arranged in a randomized complete block design with three replicates. Planting materials of maize and haricot bean used in this study were BH-540 and Hawasa-Dume varieties, respectively.

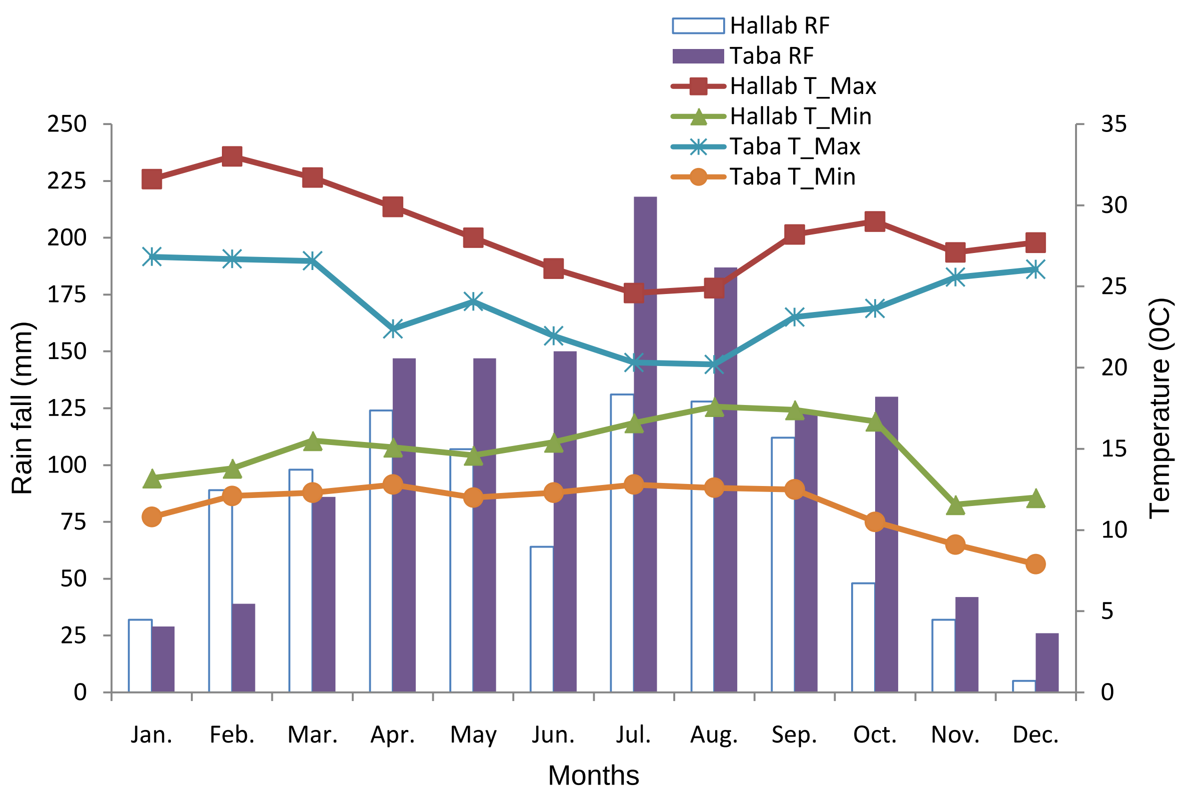

Fig. 1 : Monthly Mean Minimum and Maximum Temperature (^{0}C) and Rain Fall (Mm) Data of Hallaba and Taba Areas

RF = Rain fall; T = Temperature.

Table 1 : Selected Characteristics of the Initial Topsoil (0-20 Cm) at the Two Trial Sites

Soil parameters	Hallaba site	Taba site
pH H_2O (1:2.5)	5.83	5.85
Organic C (%)	0.63	0.65
Total N (%)	0.22	0.22
Aval. P (mg/kg soil)	29.33	48
Exch. K (cmol (+) /kg soil)	0.64	0.56
CEC (cmol(+)/kg soil)	20.93	17.2
EC (ds/m)	0.18	0.16
Clay (%)	33	30
Silt (%)	37	36
Sand (%)	30	34

To determine the response of maize haricot bean crops to intercropping, data were collected on some selected growth, yield and yield related parameters. The production efficiency of intercropping system vis-à-vis the respective monocultures was computed using competition indices like land equivalent ratio (LER), land equivalent coefficient (LEC) competitive ratio (CR). LER was calculated by summing the relative intercrop yield of the components (maize yield in mixture/maize yield in sole) + (haricot bean yield in mixture/haricot bean yield in sole).Whereas the formula used for computing the LEC is: $LER_{maize} \times LER_{haricot\ bean.}$ The formula used to calculate CR was the ratio of the partial LERs of the components multiplied by the inverse ratio of their sown proportion. To determine the effect of N-fixing haricot bean on soil, sampling of soil was done twice; at pre-planting and right after harvesting. Soil samples were air dried, crashed, sieved to prepare for the analysis of chemical properties like soil pH, total organic C content, total N, available P, exchangeable K and the CEC of the soil using the standard laboratory procedures.

The crop (agronomic) and soil data collected at the two sites during the course of the study were subjected to analysis of variance using SAS. Least significant difference (LSD) test at 95% confidence interval was used to separate treatment means when ever significant effects were observed on parameters. Since the error variable was homogenous, instead of site wise data, pooled values were given for discussion and interpretation.

III. Results and Discussion

a) Effect on Maize Crop

In the present study, combined analysis of data over location showed that height of maize was non-significantly affected by cropping system. However, significant differences were observed among the treatments with regard to leaf area index (LAI) values, whereby maize in 1:1 row ratio with bean produced the highest value (4.3), even more than the sole stand, while the maize plants in 1:3 row combination gave the least (Table 2) attributable to complementarity between the components at lower population density and aggravated completion from the higher densities.

Table 2 : Effect of Row Proportion of Haricot Bean in Intercrop on Growth of Maize Crop (Pooled Data of 2 Sites)

Maize: Haricot bean row proportion	Growth parameters		
	Plant height (cm)	LAI	Stover yield (t/ha)
Sole maize	2.19	4.1a	10.8a
1:1	2.14	4.3a	9.5ab
1:2	2.09	3.7ab	9.5ab
1:3	2.01	3.1b	8.3b
LSD(0.05)	NS	0.82	2.29

Values within a column followed by the same letter are not significantly different at 5% probability level.

The effect of the spatial arrangement of haricot bean intercropped with fixed population of maize was also found significantly affecting the stover yield of the main crop (maize), whereby maize in the sole stand produced the highest stover yield (10.8 t/ha). According to this data, raising the population of bean plant from 1:2 to 1:3 reduced the biomass production of maize by about 12.6% (Table 2).

Number of cobs produced on per m^2 basis was observed to be unaffected by the adopted cropping system. On the other hand, cob length was found to be significantly affected by intercrop row ratio of haricot bean, in which the largest cobs being produced under sole stand of maize crop, which is at par with that of maize in 1:1 row ratio with haricot bean (Table 3). In this regard the smallest cobs were recorded in plots where the highest number of haricot bean rows were introduced between the two maize rows (1:3). Similar to cob length the number of kernels per row of maize cobs was observed to be significantly affected by the adopted cropping system, whereby maize grown in 1:1 row combination with bean produced cobs with the highest kernels per row, while 1:3 row ratio producing the least (Table 3).

Table 3 : Effect of Row Proportion of Haricot Bean in Intercrop on Yield Related Parameters of Maize Crop (Pooled Data of 2 Sites)

Maize:Haricot bean row proportion	Yield related parameters		
	Cobs/m^2	Cob length (cm)	No. kernels/row
Sole maize	3.8	16.06a	34.0a
1:1	3.6	15.66ab	34.6a
1:2	3.4	14.38bc	30.6b
1:3	3.4	13.66c	29.5b
LSD(0.05)	NS	1.30	2.96

Values within a column followed by the same letter are not significantly different at 5% probability level.

Grain production on per plant basis was found to be affected by the cropping system where maize in 1:1 row combination produced the highest (131 g), 32.7% more grain yield per plant than that of 1:3 row ratio (Table 4). The results therefore suggest that a bean spatial arrangement of one bean row in between maize rows was less competitive to maize in the intercrop. Similarly Silwana and Lucas (2002) and Morgado and Willey (2008) reported decreased grain yield per maize plant by more than 30% compared to sole cropping. While considering the total grain yield on per hectare basis the maize crop grown in 1:1 ratio with haricot bean was the highest yielding among the intercropped plots, and it's also statistically at par with the highest of all, sole crop (Table 4). As haricot bean population increases total grain yield of maize keeps on decreasing, showing 12.8% yield reduction as the proportion of haricot bean population increased from 25 to 75% of its pure stand in constant maize population (1:1 to 1:3 maize: haricot bean row ratio). Maize yield difference of 0.54 t/ha between 1:1 and 1:3 row combinations with haricot bean is attributable to magnified completion in the latter case. In corroboration to present finding, Zama and Malik (2000) and Mutungamiriet al. (2001) have reported lower grain yield records from plots where maize was intercropped with two and three rows, respectively, of bean compared to 1:1 row arrangement. Harvest index (HI) and 100-kernel weight of the maize crop were, however, found unaffected by the row arrangement adopted for this study. Similarly Undies et al. (2012) have reported that intercropping and crop arrangement had no significant effect on 100-grain weight.

Table 4 : Effect of Row Proportion of Haricot Bean in Intercrop on Productivity of Maize Crop (Pooled Data of 2 Sites)

Maize:Haricot bean row proportion	Grain yield per plant (g)	Total grain yield (t/ha)	HI	100-kernel weight (g)
Sole maize	116.7b	3.68a	0.27	26.76
1:1	131.4a	3.49ab	0.26	28.25
1:2	104.5bc	3.00b	0.25	26.73
1:3	99.11c	2.95b	0.23	26.55
LSD(0.05)	16.01	0.56	NS	NS

Values within a column followed by the same letter are not significantly different at 5% probability level.

b) Effect on Haricot Bean Crop

Table5 shows that there was significant effect of intercrop row ratio observed with respect to the height of haricot bean plants. In this regard the tallest and shortest plants were recorded from the 1:2 maize-bean row combination and the sole stand, respectively. Among the intercrop combinations, however, plots with the highest bean population recorded the least height of the bean plants, attributable to aggravations of both intra- and inter-specific completion for growth resources. Similarly, Undies et al. (2012) reported that soybean plant height increased above its sole crop at different intercrop row arrangements. In contrast to the present finding, Zama and Malik (2000) have reported that height of ricebean plants in intercropping with maize significantly reduced as compared to plants in the sole crop.

The branching pattern and dry matter production of the haricot bean crop were also observed to be significantly affected by sown proportion of the intercrops (Table 5); in which the highest mean branching and dry weight values were observed in one-to-one ratio, the least values being recorded from one-to-three row ratio (Table 5). Presumably lower inter and intra-specific competition due to the lower population density at 1:1 row ratio might have provided a better soil resource condition with higher light availability for bean plants to grow vigorously. Similar to present finding, Morgado and Willey (2003) also found that dry matter per plant of beans decreased significantly as bean population increased in intercrop with maize.

Table 5 : Effect of Sownproportion on Growthof Haricot Bean Intercropped with Maize (Pooled Data of 2 Sites)

Maize:Haricot bean row proportion	Growth parameters				
	Plant height (cm)	No. of branches	Dry weight (g)	Total no. of nodules	No. of effective nodules
Sole haricot bean	31.48b	2.0ab	20.4b	6.1ab	1.3ab
1:1	44.90a	2.4a	30.4a	11.8a	2.1a
1:2	45.98a	1.9b	21.2b	5.8ab	1.0ab
1:3	40.85a	1.6b	19.9b	4.6b	0.3b
LSD(0.05)	7.46	0.43	8.09	6.41	1.34

Values within a column followed by the same letter are not significantly different at 5% probability level.

Nodulation pattern, being the prerequisite for symbiotic N^2 fixation, showed a highly significant difference among the intercropping patterns where haricot bean plants in 1:1 row ratio produced the highest mean number (11.8 $plant^{-1}$) as averaged across the locations (Table 5). According to Mandalet al. (2014) nodule formation in soybean had been observed to be unaffected due to intercropping with maize. Similar to total count the number of effective nodules, nodules which developed pink-red color when slice opened, were highest at 1:1 ratio. Intercropping effects on nitrogen fixing attributes of haricot bean were influenced by population density. Symbiotic N_2 fixation is highly dependent upon the flow of photo-assimilates to nodules (Paul and Kucey, 1981; Akundu, 2001). This relation is also coupled to yield. Thus any factors that influence photosynthesis will concomitantly influence nitrogen fixing attributes. Plant density influenced canopy development. Intercropped haricot bean provided a heavy shading as though they were a cover crop. Light penetration in such heavy shading was minimal. This in turn influenced photosynthetic process. Such response may have been responsible for the observed decreases in number of total and effective nodules at 1:3 row ratio, 24.6% and 76% respectively, compared to the sole stand.

In this study numbers of pods/plant and seeds/pod were found statistically identical (Table 6). Nudunguet al. (2005) similarly reported non-significant ($P<0.05$) influence of special arrangement on grain accumulation in each pod. On the other hand, hundred seed weight of the haricot bean grown in differential mix proportion at the two sites was observed to be significantly affected, where byall the intercrop treatments produced higher (and statistically identical) 100-grain weight than the sole stand (Table 6). In difference with present finding Zama and Malik (2000)and Undieset al. (2012) have observed significantly lower test weight of the seeds of the legume components in intercrop than the sole stand.

Total grain yield of the haricot bean crop was observed to be affected by varying mix ratio. In this regard the highest yield was recorded from the sole haricot bean plot, and grain yield declined with the proportion of haricot bean rows in the mixture (Table 6). This is attributable to proportion of the land occupied by bean crop in the intercrop as yield is linearly related to plant population. Intercropping of one, two and three rows of haricot bean between maize rows in the present study resulted in 56, 44.5 and 28.2% reduction of haricot bean yield, respectively compared with haricot bean in sole stand. Undies et al. (2012) in the same way reported a significantly lower grain yield of soybean under intercropping with sorghum as compared with the pure stand.

Table 6 : Effect of Rowproportion on Yield Components of Haricot Bean Intercropped with Maize (Pooled Data of 2 Sites)

Maize:Haricot bean row proportion	Yield and yield components			
	Pods/plant	Seeds/pod	100 seed weight (g)	Grain yield (t/ha)
Sole haricot bean	13.3	4.6	27.4b	3.73a
1:1	15.0	4.2	29.7a	1.64c
1:2	14.5	4.7	29.6a	2.07bc
1:3	14.1	4.4	29.9a	2.68b
LSD(0.05)	NS	NS	1.92	0.67

Values within a column followed by the same letter are not significantly different at 5% probability level.

NS = Non-significant.

Generally, the yield of haricot bean in pure stand maintained supremacy over the intercropping system due to the obvious reason of lower proportion of sown area. This may also be due to limited disturbance of the habitat and interactional competition under sole cropping environment (Banik, 1996). On the other hand, when maize was grown with the association of haricot bean, irrespective of different combinations, the maize crop benefitted in respect of the proportionate yield of sole crop. This can be attributed to the complementary effect of legume association (Adhikaryet al., 1991; Banik and Bagchi, 1993; Banik, 1996).

c) Intercrop Efficiency

As an indication of land use efficiency partial land equivalent ratio of haricot bean (LER_h) was significantly affected by the row proportion of haricot bean in the mixture but that of maize (Table 7). Accordingly, a 1:3 maize-to-haricot bean row ratio gave the highest value (0.73), while 1:1 row mix being the lowest in its partial land equivalent ratio (Table7). Evaluation of the overall land use efficiency ($LER_t = LER_m + LER_h$) in the present study showed a significantvariation among the treatments of cropping pattern (Table 7). The data revealed that intercropping of maize with haricot bean in 1:3 ratio gave the highest land use efficiency value, 54% more efficient than growing both crops in sole stand.

Table 7 : Efficiency of Intercropping Maize and Haricot Bean Crops as Affected by Row Proportion (Pooled Data of 2 Sites)

Maize:Haricot bean row ratio	Intercrop efficiency					
	LER			CR		LEC
	LER_h	LER_m	LER_t	CR_h	CR_m	
1:1	0.48b	0.95	1.43ab	0.51a	2.2	0.46b
1:2	0.58ab	0.82	1.40b	0.39ab	3.75	0.43b
1:3	0.73a	0.81	1.54a	0.31b	3.39	0.58a
LSD(0.05)	0.16	NS	0.11	0.18	NS	0.11

Values within a column followed by the same letter are not significantly different at 5% probability level.

CR = Competitive ratio; LEC = Land equivalent coefficient; LER = Land equivalent ratio; NS = Non-significant.

According to Adetiloyeet al. (1983), for a two-crop mixture the minimum expected productivity coefficient is 25%; meaning a yield advantage is obtained if land equivalent coefficient (LEC) value exceeds 0.25. In this regard all maize: haricot bean intercrop combinations in this study had LEC values above 0.25, suggesting yield advantages. Though, all maize haricot bean mixes exhibited LEC values greater than the critical, the highest population density (1:3) recorded the largest (0.58) of all mixes (Table 7). Egbe (2010) has similarly reported LEC values greater than the critical in intercropping sorghum with soybean at different spatial arrangements. The data of competition ratio (CR) indicate that maize is the dominant crop in this mixture though non-significantly affected by the cropping pattern. Even though haricot bean crop was found to be dominated by the vigorous maize, change were observed in competitive behavior of haricot bean across the intercropping pattern. In this aspect adding 25% of the pure haricot bean stand in in maize (1:1 row ratio) was observed to exhibit the highest competitive value, attributable to minimized intra and interspecific competitions at lower population density (Fisher et al., 1986).

d) Effect on Residual Soil

Laboratory analysis of soil samples collected both at pre-planting and post-harvest indicate that all soils are in slightly acid range, but the acidity has significantly decreased by all of the adopted cropping system from the initial (pH = 5.83). Pure maze plots had the lowest soil pH (6.20) compared to plots intercropped with haricot bean and the sole haricot bean stand (Table 8), implying that bean in intercropping and sole have better potential in ameliorating soil acidity than sole maize. Concomitant to present finding, Ossom and Rhykerd (2007) have reported that sole field bean had superiority in raising the soil pH over pure maze. Ariel et al. (2013) however, have reported that pH values of the rhizosphere soil remained fairly constant during the cropping cycles of intercropping maize with soybean.

Although the organic C content of the soilremained statistically unchanged during the cropping cycle, plots under intercropping tended to showed increasedorganic C content, while the pure stands of both crops recorded a reduction compared to the initial (Table 8).Similar observation was also made by Ossom and Rhykerd (2007).Total N content of the soil before and after the experiment revealed that there is significant improvement in N status due to the introduction of the leguminous species (Phaseolus vulgaris) into the cropping system. In this respect growing the haricot bean crop as a sole stand enhanced the N in the soil by about 27.3%; whereas 1:1 maize-haricot bean row combination improved the total N of the soil by about 18.2% from the initial (Table 8). Likewise, Szumigalski and Van Acker (2008) also reported a higher residual N content of the soil in plots allocated to sole pea than the intercropped with wheat. The improvement of soil N in plots where haricot bean was grown both as a sole and intercrop in the present study could be due to a possibility of root exudates or the decay of roots and nodules causing the release of N from the legume components into the rhizosphere during the cropping season (Vandermeer, 1989, Szumigalski and Van Acker, 2008).

Table 8 : Effects of Intercropping System of Maize with Haricot Bean on Some Selected Soil Chemical Properties (Pooled Data of 2 Sites)

Cropping system (maize:haricot bean row ratio)	pH H_2O (1:2.5)	Organic C (%)	Total N (%)	Aval. P (mg/kg soil)	Exch. K (cmol(+)/kgsoil)	CEC (cmol(+)/kgsoil)
Initial soil	5.84b	0.64	0.22bc	35.16a	0.60	19.06
Sole maize	6.20ab	0.59	0.25ab	29.33a	0.65	17.87
Sole haricot bean	6.57a	0.59	0.28a	22.00ab	0.72	18.13
1:1	6.57a	0.81	0.26ab	18.00b	0.71	19.07
1:2	6.50a	0.67	0.24abc	17.33b	0.72	18.07
1:3	6.43a	0.76	0.20c	18.67b	0.59	18.73
LSD (0.05)	0.57	NS	0.04	8.90	NS	NS

Values within a column followed by the same letter are not significantly different at 5% probability level.

With regard to the effect on the available P in the soil, significant treatment effect was observed in the present study, whereby plots of all intercrop combinations recorded reduction and statistically identical concentration of av. P in the soil as compared to the initial and pure maize plots (Table 8), attributable to inter-specific competition for the essential resource. Mandalet al. (2014) correspondingly showed that av. P content was reduced in post-harvest soils of all plots in which maize was intercropped with soybean and groundnut at varying row proportion compared to the initial and sole maize. The exchangeable K content and the CEC of the soils were non-significantly affected by the adopted cropping patterns (Table 8). Ossom and Rhykerd (2007) also reported the non-significant of intercropping maize with field bean.

IV. Conclusions

According to the data of the present study, significant differences among treatments of row combination were observed in some selected growth and yield attributes of maize and haricot bean crops. The grain yields of maize and haricot bean were highest in the respective pure stands, attributable to the absence of inter-specific competition and stand count per unit area, respectively. Looking at the overall land use efficiency, however, all of plots under intercropping recorded LER values greater than a unit, where maize + 75% pure stand haricot bean (1:3 row ratio) being the most efficient one, 54% more efficient than growing both crops in sole stand. Post-harvest soil condition of current experiments revealed that legume intercropping with maize could be better option not only for higher yield to sustain soil fertility as well. Moreover, it has been observed that haricot bean crop, either in intercrop or pure stand, have great role to ameliorate the acidity problems of soils of the study areas. The ultimate consideration for selection of best intercropping system is the advantages and production efficiency. Thus, on the basis of the results of this experiment, maize + haricot bean in 1:3 row additive series intercropping system may be recommended for the Halaba and Taba areas of southern Ethiopia.

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