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Effect of Soil Incorporated Pruned Pigeon pea and Nitrogen on System Productivity in Maize/Pigeon pea Intercropping

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Abstract

Decline of return in maize monoculture requires amendment of nutrients removed from the soil through retention of biomass on the soil with some addition of inorganic fertilizers. This study was executed for three consecutive years (2013-2015)to evaluate the effect of pruning levels while leaving the upper (0, 2, 4 and 6) parts of perennial pigeon pea and N levels (18, 41, 64, 87 and 110 kg ha^{-1}) on yields of component crops and on some soil nutrients in maize/pigeon pea intercropping. The result indicated that the main effects due to pruning of pigeon pea and incorporation in to the soil and N level were significant for maize biomass weight during 2013 and 2014 and for maize grain yield throughout the experimental periods. Pruning of lower branches of pigeon pea while leaving the upper 2 in maize/pigeon pea intercropping increased grain yield of maize by 8% compared to the sole maize monocropping and produced a mean pigeon pea grain yield of 972 kg ha^{-1}. It also reduced soil acidity, increased soil organic carbon, total N and available P compared to the sole maize monoculture. The highest LER of 1.42 and the highest net benefit of Birr 32,347 ha^{-1} were also obtained due to pruning of pigeon pea while leaving the upper 2 and incorporating in to the soil in intercropping of maize/pigeon pea at reduced N level. This branch management at reduced N level is recommended for the high productivity and reduced resource use efficiency for sub-humid areas of Bako.

Introduction

The sub-humid areas of western Oromia are threatened by soil erosion, low soil fertility and soil acidity contributing to low crop and land productivity. Nutrient depletion due to successive maize monoculture, limited use of organic and inorganic fertilizers, P fixation and N leaching due to high rainfall have limited crop growth and land productivity. Traditionally, farmers fallow their degraded farmlands. However, open livestock grazing practices leaves the fallowed land bare. Such practice lead to the lowest organic carbon contribution compared to the mixed croplands (Asif *et al.,* 2014). Declining in soil fertility aggravated by wide scale continuous cultivation of maize that mines the soil nutrients remained the farmers struggling to maintain yields year after year (Snapp *et al.*, 2010). Rising human consumption from crop source is dramatically increasing depends on agriculture and natural resources which raises challenges for achieving food security (Foley *et al.,* 2011). Through strategic improved crop varieties and inorganic fertilizer use, it might not be enough to feed the growing population requiring production of more food on the same amount of land (Giller *et al.,* 2006).

Cereal-legume cropping system show considerable promise in boosting productivity, helping reverse the decline in soil fertility (Dagne *et al.*, 2012) and improves dietary sources. Incorporating nitrogen-fixing legumes in to maize based cropping systems has the potential to improve soil fertility and mitigate the nutrient mining of maize (Snapp and Silim, 2002). Pigeon pea in the systems with advantages of fertilizer value, dry season animal feed and seeds for human consumption (Abebe and Diriba, 2002) has the potential of reacting with iron-bond phosphate in the soil to release P (Hector and Smith, 2007).

Ethiopia with wide range of ecological suitability to pigeon pea did not widely enter into the multiple uses from the crop. However, research findings by Zerihun *et al.,* (2016) indicated that perennial pigeon pea can be used as a live-stake for climbing bean and production of finger millet as intercrop during the establishment phase. The litter fall reduces soil erosion, improves soil fertility and larger root mass contributes to improvement of soil organic matter. Faster establishment in subsequent years reduces cultivation cost when conservational agriculture is used. The objective of this study was to evaluate the effect of branch removal of pigeon pea and N level on crop yields and system productivity in the maize belt areas of Bako, western Ethiopia.

Materials and Methods

The experimental site

The experiment was conducted at Bako Agricultural Research Center, which is situated in the western part of Ethiopia at an altitude of 1650 masl. The area has a warm-humid climate with annual minimum mean and maximum mean temperatures of 13.6^0C and 29.1^0C, respectively. Long-term average annual rainfall of the area is 1264 mm. The annual rainfall received during 2013, 2014 and 2015 cropping seasons was 1431, 1067 and 944 mm, respectively. The experimental site is characterized by reddish-brown clayloam Nitosol, which is strongly acidic with pH of 4.98, organic carbon (2.02%), total nitrogen (0.15%) and CEC of 17.8 cmol/kg.

Planting materials

Maize variety BH661, which is relatively suitable for the intercropping system due to its semi-erect morphology and stay green after maturity and a perennial type of multi-purpose pigeon pea, which is locally adapted to the area, were used as companion crop for the study.

Experimental design and procedure

The experiment was carried out from 2013 to 2015 during main cropping seasons (May-November). Twenty treatment combinations consisting of four levels of pigeon pea branch removals but leaving only 0, 2, 4 and 6 upper branches and five nitrogen levels (18, 41, 64, 87 and 110 kg ha^{-1} N + 46 kg ha^{-1} P_2O_5) were arranged in factorial combinations. In addition, sole maize with 110 46 kg ha^{-1} N P_2O_5 and a sole un-pruned pigeon pea with 18 46 kg ha^{-1} N P_2O_5 (during first year) were considered for comparison purpose. A Randomized Complete Block Design with three replications was used. In the first year, land preparation was implemented by tractor. During planting time of the second and third years of the experiment, regardless of crop residue retention and incorporation, minimum tillage was implemented using local digging hoe. Maize was planted at a spacing of 75 cm x 30 cm (between rows and plants, respectively) on a plot area of 19.125m^2 (3.75m x 5.1m). The pigeon pea was planted the same day with maize planting between two rows of maize at 50cm spacing between plants. Its branches were removed 8 weeks after planting as per the treatment arrangements. During 2014 and 2015 cropping seasons, the branches of pigeon pea were removed right at planting of maize according to the treatment set up. The removed branches were weighed (biomass weight in this context), chopped and incorporated into the soil of respective plots. Data for both crops were collected from 3 center rows (11.25m^2).

The composite soil sample was collected from each experimental plot at depth of 0-20 cm before planting and after harvest of maize and pigeon pea in each cropping season. The samples were air dried, grinded and sieved at particle size of less than 2mm. Soil pH was determined using 1:2.5 soil: water suspension. Available P, Total N and OC were determined using Bray 2, Kjeldhal and Walkley and Black methods, respectively.

Data collection and management

Grain yield was corrected to 12.5% and 10% moisture content standards for maize and pigeon pea, respectively. Above ground biomass of maize and sample biomass of pigeon pea (pruned branches with leaves) were sun-dried until constant weight was maintained. Overall advantage of the intercropping was determined as land equivalent ratio (LER) using the formula suggested by Devaseanapathy *et al.* (2008),

$$LER = \frac{Ymp}{Ymm} + \frac{Ypm}{Ypp}$$

Ymp= grain yield of maize intercropped with pigeon pea; **Ymm**= grain yield of maize in pure stand; **Ypm=** grain yield of pigeon pea intercropped with maize, **Ypp=** grain yield of pigeon pea in pure stand.

Economic evaluation

Economic evaluation was done following partial budget analysis by CIMMYT (1988). Three years' average costs of land preparation, planting of maize and pigeon pea, N fertilizer, branch removal and incorporation, harvesting and threshing were variable costs considered in partial budget. Similarly, three years' average crop yield and price were considered for economic evaluation. Yield was down adjusted by 10% whereby sensitivity analysis was made subjected to cost and price changes considering minimum acceptable MRR as 100%.

Data analysis

Data were analyzed using SAS version 9.1 (SAS, 2002) computer software and were subjected to ANOVA to determine significant differences among factors and their interactions. Means were separated using LSD test. For all analyzed parameters, $P<0.05$ was interpreted as statistically significant.

Results and Discussion

Maize component

Mean maize biomass and grain yield reduction of 12% and 15% were recorded respectively during 2014 compared to 2013 presumably due to reduced annual rainfall during 2014. The reduction during 2015 compared to 2014 cropping season was not magnified, 5% (for biomass) and 3% (for grain yield) might have attributed due to differences in pigeon pea biomass incorporated in to the soil. In 2013, maize mean grain yield obtained from maize/pigeon pea intercropping regardless of pruning options resulted in 6% yield advantage over maize grown sole. With respect to the overall maize grain yield, 1.25% yield advantage was recorded from maize pigeon pea intercropping, which could be due to addition of organic matter from pigeon pea incorporated in to the soil.

The main effect due to branch removal of pigeon pea was significant for maize biomass during 2013 and 2014 cropping seasons and for maize grain yield during the three experimental seasons. Removing pigeon pea branches but leaving 0 and 2 upper branches produced significantly the highest grain yield, but not significantly different from each other across the three cropping seasons. Indeed, the three years mean maize grain yields of 8940 kg ha^{-1} and 8884 kg ha^{-1} were recorded for branch removals leaving 0 and 2 upper ones, respectively against 8471 kg ha^{-1} obtained by maize grown sole with recommended 110 46 kg ha^{-1} NP_2O_5. Higher maize grain yield in maize/pigeon pea intercropping might have attributed by less competition by pigeon pea, improvement of soil moisture due to addition of pigeon pea biomass in to the soil and addition of organic matter to the soil. On the other hand, removing branches but leaving 6 upper ones produced significantly the lowest maize grain yield throughout the cropping seasons (Table 1) presumably due to high shading effect and competition for resources like sun light. Study by Daniel and Ong

(1990) confirmed that perennial pigeon pea intercropped with sorghum improved yield of component crop when lower branches were removed. Unaffected grain yield of component crop was also reported by ICRISAT (1987) when plant population of pigeon pea was reduced below 28000 and lower branches were removed.

The main effect due to nitrogen level also affected maize biomass and grain yield during the three cropping seasons. Application of 110 kg ha^{-1} N and 87 kg ha^{-1} N produced significantly the highest, but not significantly different from each other on maize grain yield during the three cropping seasons (Table 1). Application of 41 kg N ha^{-1} to maize in 2013 and 2104 showed similar yield responses when compared with sole crops under recommended NP rates (110/46 kg ha^{-1} N/P2O5). This indicates that N enhancement due to the presence of pigeon pea in maize could be observed, and hence 62% reduction of N fertilizer source to the crop can give an equivalent yield when compared with sole crops under recommend fertilizer rates. This might be due to the availability of soil N through biological nitrogen fixation and decomposition of pigeon pea litter fall or biomass retention to the soil, which could enhance both total nitrogen and organic carbon of the soil. The utilization efficiencies might have also enhanced due to the effect of pigeon pea through either biomass retention or N fixation so that soil physical, biological, and chemical properties are improved; hence, increased nutrient use efficiencies. On the other hand, the highest maize yields that were not significantly different from each other were recorded for 110 and 87 kg ha^{-1}N. Application of 18 kg ha^{-1} N produced significantly the lowest maize grain yield throughout the three cropping seasons but, which was not significantly different from application of 41 kg ha^{-1} N during 2013 and 2015 cropping seasons. Despite the significance of main effect of branch removal and nitrogen level, maize grain yield was not significant due to the interaction terms of branch removal by nitrogen level.

Table 1. Maize biomass and grain yield as affected by the main effects of pigeon pea branch removal and N level in maize/pigeon pea intercropping at Bako

Factor	Biomass weight kg ha^{-1}			Grain yield kg ha^{-1}		
Pigeon pea branch removal leaving upper	2013	2014	2015	2013	2014	2015
0	24677^{a}	22501^{a}	19547	9987^{a}	8602^{a}	8232^{a}
2	23822^{ab}	21347^{ab}	19616	9822^{a}	8569^{a}	8260^{a}
4	23189^{ab}	20054^{bc}	19891	9523^{ab}	7933^{b}	7897^{ab}
6	22646^{b}	19376^{c}	20031	9011^{b}	7658^{b}	7429^{b}
SE ±	637	210	547	456	109	221
LSD (5%)	1819	1303	NS	599	312	632
Sole maize	22411	18767	21363	9040	8193	8179
N level kg ha^{-1}						
18	21749^{b}	18783^{b}	17017^{c}	8426^{b}	7015^{c}	6819^{c}
41	24124^{a}	20959^{a}	17953^{c}	9017^{b}	8243^{b}	7158^{c}
64	23654^{ab}	20827^{a}	20041^{b}	10071^{a}	8145^{b}	8132^{b}
87	24366^{a}	21623^{a}	21340^{ab}	10205^{a}	8730^{a}	8671^{ab}
110	2406^{a}	21907^{a}	22505^{a}	10209^{a}	8818^{a}	8995^{a}
SE ±	712	234	612	510	122	247
CV %	10.45	8.49	10.78	8.47	5.17	10.72
LSD 5%	2034	1457	1750	669	349	707

Even though soil fertility improved from 2013 to 2015 cropping seasons, the performance of maize was unexpectedly decreased across the years. The soil improvements in terms of total nitrogen, organic carbon and even acidity were observed across the seasons due to retention of pigeon pea biomass and N-fixation by the legume. However, the nutrient uptake and utilizations by the crop entirely depend on soil moisture availability. The result of the study also confirmed that shortage of moisture, particularly during the development stages of maize (from time of silking to daughing stage) in 2014 and 2015 cropping seasons resulted lower grain yield compared to 2013 (Fig. 1). For instance, daily rainfall distribution during September to the October in 2015 season was very low and even no rainfall in the month of October, critical period of grain filling stage. Consequently, grain filling was affected and this might contributed to the yield reduction.

Similarly, yield reduction of maize crop during 2014 cropping season was observed when compared with 2013. Though considerably better when compared with 2015, the rainfall amount and distribution during the development stage was relatively suitable for growth of the crop. This variation might be related to the effect of rainfall amount and distribution during the growing seasons, particularly at the critical period of maize development stages (Fig.1). In addition to significantly differently monthly rainfall amount during crop development stage, the daily rainfall distribution in the particular development stages were highly variable across the seasons, which resulted in reduction of the yield.

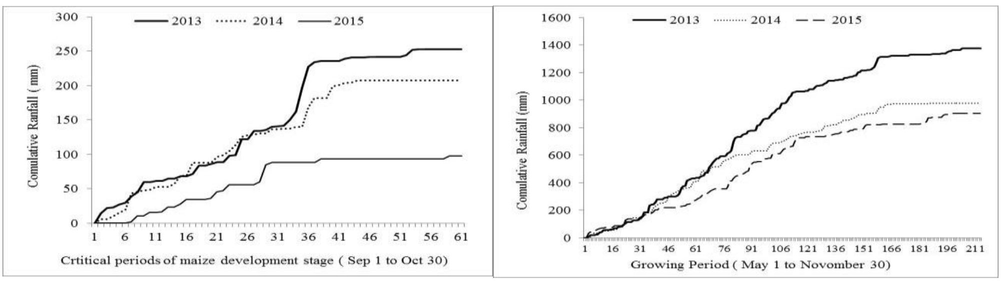

Figure 1: Distribution of cumulative rainfall during the growing periods and at critical development stages of maize at Bako, during 2013-2015

Pigeon pea component

Removed biomass weight increased as the rate of pigeon pea branch removal increased throughout the cropping seasons and showed increasing trend for subsequent cropping seasons. Pruning all branches but leaving the growing meristem produced significantly the highest weight (8299 kg ha^{-1}, 8546 kg ha^{-1} and 9255 kg ha^{-1}) but not significantly different from removing all branches but leaving 2 upper ones during 2013, 2014 and 2015, respectively (Table 2). Mean biomass weight for removal of all lower branches leaving the upper 6 and 4 were significantly the lowest but not significantly different from each other during the three cropping seasons. No matter how there is weight differences between branch removals, there was weight increase for all branch removals through the experimental periods. Biomass weight was not affected by the main effect of nitrogen level, yet there was weight increase from year 1to3 (Table 2).

Grain yield

Unlike the biomass weight, grain yield increased as the rate of branch removal decreased throughout the cropping seasons. Similar to the biomass weight, grain yield also showed increasing trend consecutively. Grain yield was neither influenced by the N level nor by the interaction of factors. However, the main effect of branch removal affected grain yield of pigeon pea throughout the cropping seasons. Certainly, significantly high grain yields of 1234 kg ha^{-1}, 1339 kg ha^{-1} and 1441 kg ha^{-1} during 2013, 2014 and 2015, respectively, were obtained from branch removal but leaving 6 upper ones. All branches removal leaving only the upper meristem produced significantly the lowest grain yields, but as high as 807 kg ha^{-1} during 2015 cropping season (Table 2). Fast re-growth habit of the branches favored annual seed harvest from perennial pigeon pea.

Table 2. Biomass and grain yield of pigeon pea as affected by the main effect of pigeon pea branch removal in maize/pigeon pea intercropping at Bako

Factor	Branch weight (kg ha^{-1})			Grain yield (kg ha^{-1})		
Pigeon pea branch removal leaving upper	2013	2014	2015	2013	2014	2015
0	8299^{a}	8546^{a}	9225^{a}	721^{d}	747^{c}	807^{c}
2	7016^{ab}	7238^{ab}	7813^{ab}	836^{c}	1001^{b}	1079^{b}
4	6937^{b}	7197^{b}	7642^{b}	931^{b}	951^{b}	1010^{b}
6	5763^{b}	5910^{b}	6360^{b}	1234^{a}	1339^{a}	1441^{a}
SE ±	471.29	466.57	512.39	31.76	37.16	41.87
LSD (5%)	1346	1334	1465	88	106	120
Nitrogen level (kg ha^{-1})						
18	6427	6629	7154	894	958	1034
41	7433	7657	8182	969	1063	1134
64	6892	7058	7629	947	1030	1115
87	6511	6756	7285	898	971	1044
110	7756	8018	8552	945	1026	1095
SE ±	34.61	521.64	572.87	52.7	41.55	46.81
CV %	12.88	25.02	25.57	26.04	14.25	14.96
LSD 5%	NS	NS	NS	NS	NS	NS

System productivity and economic benefit

In maize/pigeon pea intercropping, application of 87 kg ha^{-1} N and pigeon pea branch removal while leaving 2 upper ones, 42% of a hectare of land was saved to grow both crops in pure stand to produce the grain yields obtained by their association. Maize/pigeon pea intercropping with application of 87 kg ha^{-1} N regardless of branch removals has produced partial LER of maize greater than 1, indicating maize was not affected by intercropping; rather produced higher grain yield compared to sole grown maize. Moreover, on average, 7103 kg ha^{-1} year^{-1} dry branch cuttings was obtained and incorporated to the soil of respective plots.

Three years' average net benefit of 500 Birr ha^{-1} was obtained by application of 87kg ha^{-1}N associated with pigeon pea branch removal while leaving 2 upper branches compared to similar N rate and pigeon pea branch removal while leaving 4 upper branches in maize/pigeon pea intercropping. Higher MRR of 238% was obtained for changing from application of 87kg ha^{-1} N and pigeon pea branch removal while leaving 4 upper branches to 87kg ha^{-1} N and pigeon pea branch removal while leaving 2 upper branches. In the latter case, for addition of 1 Birr investment, the return was Birr 2.38. Sensitivity analysis resulted in application of 87 kg ha^{-1} N and pigeon pea branch removal while leaving 2 upper branches remain profitable even if the cost of production rises by 25% and the output cost remain unchanged (Table 3). Besides several advantages of pigeon pea biomass incorporated to the soil, it also saves cost of tillage whereby conservation agriculture was used for maize/pigeon pea during the second and third years of the experiment. It was also reported by Zerihun *et al.* (2014) that conservation agriculture saves cost of tillage and weeding. Indeed, maize/pigeon pea intercropping system with reduced N level (87 kg ha^{-1} N) is economically profitable.

Table 3. Mean LER and economic benefit of maize/pigeon pea intercropping at Bako, western Oromia, during 2013, 2014 and 2015 main cropping seasons

Pigeon pea branch removal leaving upper	N (kg ha^{-1})	LER	TCV	Net benefit	MRR
6	18	1.31	1470	31148	
4	18	1.27	1680	30250	D(Dominated)
2	18	1.30	1890	30751	D
6	41	1.37	2008	31279	1.31
0	18	1.26	2100	29861	D
Sole maize mono cropping	110		2176	25608	D
4	41	1.33	2218	31181	D
2	41	1.36	2428	31682	D
6	64	1.37	2546	31452	D
0	41	1.32	2638	30792	D
4	64	1.33	2756	30555	D
2	64	1.35	2966	31055	D
6	87	1.42	3084	31145	D
0	64	1.32	3176	30165	D
4	87	1.39	3294	31847	0.38
2	87	1.42	3504	32347	2.38
6	110	1.42	3622	32237	D
0	87	1.38	3714	31457	D
4	110	1.39	3832	31339	D
2	110	1.42	4042	31840	D
0	110	1.39	4252	30950	D

Soil recation

The pH of initial soil and after 2013 and 2014 cropping seasons, regardless of treatment variations fall under similar ranges, strongly acidic. However, the pH significantly increased from 5.06 to 5.3 (Fig. 2), moderately acidic as rated by Takalign (1991) during 2015 cropping season as compared to soil pH obtained in the previous two years. Indeed, the main effect of branch removal affected soil pH; being significantly higher (5.26) for removal of all lower branches, leaving the upper meristem (Fig. 2). Complete decomposition of organic residues is expected from removal of all branches pending the time interval of the treatment and soil sample collection. Consequently, formation of weak organic acid favoring acidity due to intermediate decomposition was lower favoring increased pH.

Soil available P

Available P initially (during 2013) was significantly lower compared to other treatments. However, the highest available P was found during 2015 when all lower branches were removed leaving upper 4 followed by leaving upper 6 branches on the main stem. The available P obtained from pruning all branches leaving 2 and 0 upper ones were lower during 2014 (Fig. 2), presumably due to weak stem unable to extend deeper roots to access insoluble phosphates. The lowest available P was recorded in each cropping season when continuous maize monocropping was practiced, which could be due to the depletion of P through continous cultivation of maize. In this study, the highest available P in maize/pigeon pea intercropping might have attributed as reported by Hector and Smith (2007), due to the ability of pigeon pea to access insoluble phosphates in soils low in P.

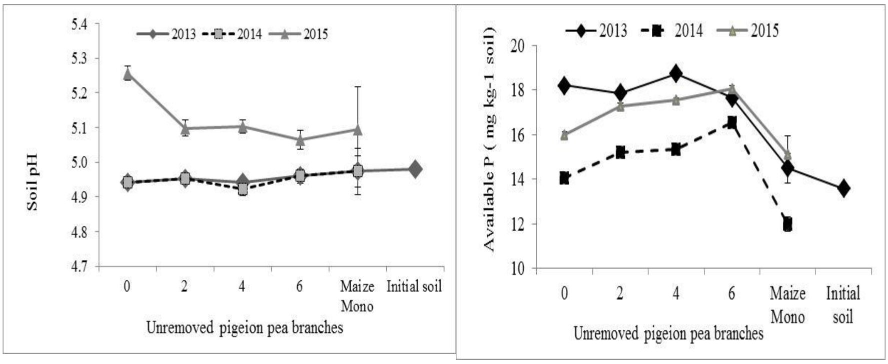

Fig 2 Soil pH and Available P as affected by pigeon pea branch removal in maize/pigeon pea intercropping at Bako during 2013, 2014 and 2015 cropping seasons

Soil organic carbon

Initial soil OC content of the soil was significantly lower compared to the OC after crop harvest regardless of treatment and seasonal variations. Soil organic carbon build up was significantly increased from initial cropping season (2013) to end of the experiment (2015). The highest OC was recorded for 2 upper branches unremoved through out the three cropping seasons. Soil OC content under continuous maize based mono-cropping practice in each cropping season was considerably lower compared to other treatments (Fig. 3). The result obtained is further justified by Johnson *et al.* (2007), organic carbon build up is favored by conservation agriculture, standing biomass, long term harvested products and living biomass in the soil.

Soil total nitrogen

Similar to soil OC content, the total N of the soil significantly increased from year to year, and the maximum total N was recorded during 2015 cropping season when all branches were removed and incorporated into the soil. However, similar nitrogen content, regardless of treatment variation except for maize mono crops, were recorded in 2014 and 2013 cropping seasons (Fig. 3). The result obtained is supported by Peoples *et al.*,(1995) who reported pigeon pea produces more N per unit area than any other legumes and findings of Kumar *et al.,* (1983), other than transfering fixed N to the interplanted crop, it has the ability to bring minerals from deeper soil to the surface. Indeeed, the presence of pigeon pea under different prunning options can significantly improve total nitrogen content whereas maize monocropping considerably reduced the N content of the soil.

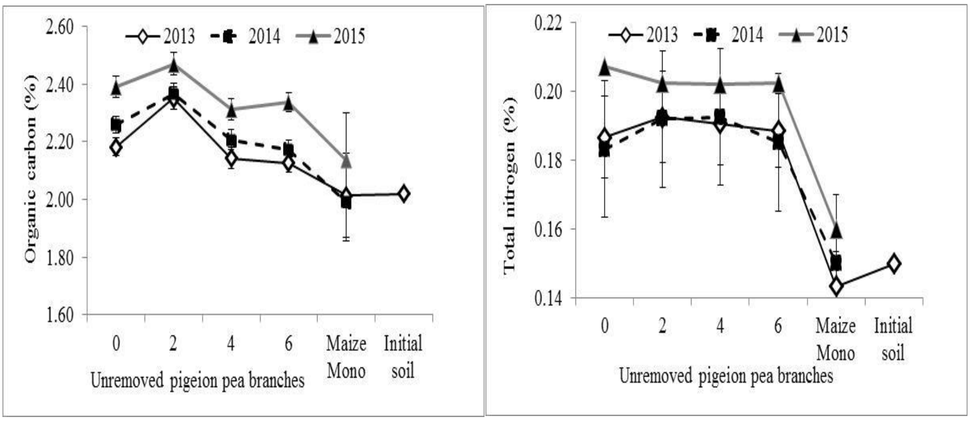

Figure 3 Soil organic carbon and total N as affected by branch removal of pigeon pea in maize/pigeon pea intercropping at Bako during 2013, 2014 and 2015 cropping seasons

Conclusion

In maize belt areas of western Ethiopia, a number of hybrid varieties with high yielding potentials are released by research. Obviously, the potential of the crop and land productivity could decrease due to continuous cultivation of the same crop. It is also very difficult to put single technological solutions for multiple productivity threats of the area. The study has demonstrated that pigeon pea is an important crop with great potential to reverse the soil fertility decline, improves the yield potential of component crops, reduces cost of production and increases net benefit. The large biomass incorporated in to the soil improved soil organic carbon, increased soil total nitrogen and soil pH. Thus, incorporation perennial pigeon pea to the maize dominated cropping system requires due attention by research and extension.

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