THE EFFECT OF PREVIOUS CROP, TILLAGE AND SOURCE OF NITROGEN ON NODUL FORMATION, DRY MATTER ACCUMULATION AND SEED YIELD OF DOUBLE-CROP SOYBEAN (*Glycine max* L. Merr.)

Prof. Dr. Tahsin Sogut[1], Dr. Ferhat Ozturk[1], Prof. Dr. Abdullah Sessiz[2]

[1]Department of Field Crops-Faculty of Agriculture, Dicle University, Diyarbakir 21280, Turkey

[2]Department of Agricultural Machinery-Faculty of Agriculture, Dicle University, Diyarbakir 21280, Turkey

E-mail: tsogut@dicle.edu.tr, fozturk@dicle.edu.tr,

Abstract

The objective of this study was to compare the effects of previous crop residue (wheat vs. lentil), tillage (reduced tillage vs. no-tillage) and nitrogen source (rhizobial inoculant and fertilizer-N application) on nodul formation, dry matter accumulation and seed yield of double crop soybean. The experiment was laid out as split-split plot with three replications. According to results obtained from the study, previous crop residue affected seed yield, and seed yield after cultivation of lentil was higher than after wheat. Nodul nitrogen content decreased at the reduced tillage, while nodule dry matter and seed yield increased compared to no-tillage system. Rhizobium inoculation alone produced the highest seed yield. However, the addition of N-fertilizer to inoculated soybean did not improve seed yields when compared with inoculated only treatment. This research demonstrates that applying rhizobium inoculation in no-tillage system under lentil residue has the potential in increase nodulation and seed yield of soybean grown double-cropping system.

KEYWORDS: SOYBEAN, PREVIOUS CROP, TILLAGE, NITROGEN, NODULATION, DRY MATTER, SEED YIELD

1. Inroduction

Soybean (*Glycine max* [L.] Merr.) is a major grain legume crop for feeding humans and livestock. It serves as an important oil and protein source for large population residing in Asia and the American continents (Ohyama et al. 2009). In order to improve nutrient and water use efficiency, yield and economic sustainability, soybean must be grown under optimum agricultural systems. Double-cropping soybean-wheat, soybean-barley, soybean-chickpea or soybean-lentil is being practiced by farmers in Southern Turkey as a means for improving cash flow, spreading risk, improving use of land and equipment, and achieving greater net returns on investment.

It is widely known that previous crops affect the growth and yield of the following crops through several mechanisms such as changes in water use efficiency (Karlen & Sharpley 1994), nutrient use efficiency (Burle et al. 1997), soil quality (Karlen et al. 1992; Doran & Parkin 1994; Karlen & Stott 1994), and biological diversity (Karlen et al. 1994). Cereal straw can act as a mulch to conserve soil moisture, impede runoff, and prevent surface crusting. Furthermore, inclusion of legumes such as lentil and chickpea in a cropping system helps in improving physical and chemical properties of soil (Godsey et al. 2007).

Different tillage systems also affect soil sustainability. Tillage is among the major practices that influence physical, biological and chemical properties of the soil environment and subsequently affects nitrogen fixation (Kihara et al. 2012). Conservation agriculture including reduced and no-tillage system of crop production is attractive to farmers because of savings in fuel, labor and machinery, increased potential for double-cropping, reduced soil erosion, reduced environmental pollution, and various other advantages (Godsey et al. 2007)

Soybean plants assimilate the N from three sources, N derived from atmospheric nitrogen by symbiotic N_2 fixation in root nodules, absorbed N derived from soil mineralized N, and N derived from fertilizer when applied (Ohyama 2009). Sole N_2 fixation is generally insufficient to support vigorous growth of shoot and roots, which results in the reduction of plant growth and seed yield. Harper (1974) reported that both soil N and symbiotic N are required for the optimum soybean production. On the other hand, a heavy supply of N fertilizer often depresses nodule development and N_2 fixation activity and induces nodule senescence, which also results in the no-effect or sometimes in reduction of seed yield. Therefore, nitrogen fertilizer is not applied for soybean cultivation or only a small amount of N fertilizer is applied as a “starter N” to promote initial growth (Ohyama et al. 2009). The inhibitory effect of nitrate on nodulaion was early reported by Harper (1987) and Streeter (1988) as cited in Ohyama et al. (2009), however, the precise mechanism for the inhibition of nodulation and nitrogen fixation has not been fully understood. Results from field studies with starter-N application have generally been negative or inconclusive (Imsande 1992; Starling et al. 1998).

The objectives of this study were to evaluate the effects of previous crop residue, tillage system and nitrogen source on nodulation, dry matter accumulation and seed yield of soybean grown under double-cropping system in Southern Turkey.

2. Materials and Methods

The study was carried out at University of Dicle, Faculty of Agriculture, Field Crops Department, Diyarbakir located in South East Anatolian Region of Turkey in 2010. The region has a warm climate in summer, and the mean annual rainfall is around 450 mm, most of which fall in a major cropping season which extends from November to June. The treatments were replicated three times in split-split plot based on randomized complete block design with previous crop residue (wheat vs. lentil) in the main plots, tillage methods (reduced tillage vs. no-tillage) in the sub-plots and nitrogen sources (control, 200 kg N ha^{-1}, rhizobial inoculant and rhizobial inoculant+50 kg N ha^{-1} fertilizer as ammonium nitrate) in the sub-sub plots. The reduced tillage treatment involved rotary tiller before sowing. All plots were fertilized with 100 kg P ha^{-1} applied as basal dose in the form of triple super phosphate fertilizer prior to sowing. *Bradyrhizobium ssp.* which contains a minimum 4 x 109 viable cells per gram was used as inoculant (HiStick, Becker Underwood, UK.) in this study. Seed inoculation was applied at planting. Soybean cultivar SA 88 (MG III) was sown on June 30. The size of each plot was 2.8 x 5.0 m. Row spacing (four rows) was 0.7 m and the distance between plants in the row was 0.05 m, providing a sowing density of 28.6 plants m^2. Weeds were controlled by both Trifluralin (2.5 L ha^{-1}) as pre plant and by hand as needed. The field was uniformly irrigated at 10-day intervals until harvest period using overhead sprinklers. Biomass partitioning, nodule number and dry matter were measured on 3 plants $treatment^{-1}$ at R5 growth stage. The root and nodules were separated at the end of the assay, and the number of nodules per plant was counted and recorded. The shoot, root and nodule samples were dried separately in an oven with air circulation at 70 ^{o}C for 48 h and dry weights were recorded. Samples were subsequently milled and the nitrogen concentration determined N analyzer (Leco FP-2000; Leco Corp., St. Joseph, MI). All plots were harvested from two central rows at mid-October. The seeds were air-dried and weighed, and seed yield recorded on a dry weight basis. Protein content of seed was measured as N×6.25.

Data was subjected to an analysis of variance (ANOVA) using a statistical software package (JMP version 5.0.1a). Least significant difference (Tukey's HSD test) was used to compare treatment means at P=0.05.

3. Results and Discussion

According to the results of the experiment, previous crop and tillage system did not affect the nodul number of soybean, whereas the nitrogen source effect on nodule number of inoculated soybean (Table 1). Fertilizer N had a significant, negative effect on the number of nodules formed on the soybean roots. On avarage, application of 50 kg ha^{-1} as starter nitrogen decreased the number of nodules by 43% compared to inoculation alone. Seneviratne et al. (2000) reported similar results, which they concluded that addition of 50 kg N ha^{-1} at the beginning of flowering resulted in a reduction of nodulation in inoculated plots. These results are similar to those obtained by other authors in which the application of small amounts of N-fertilizer did not provide a major benefit for number of nodules (Zhang et al. 2000; Hungría et al., 2006). Previous crop, tillage system and nitrogen source had interactive effects on number of nodules. Under lentil previous crop, reduced tillage and inoculation + 50 kg N ha^{-1} conditions decreased the nodule number by 80% as compared to combination of wheat previous crop, no-tillage and inoculation alone (Table 2). Lafond et al., (1992) reported that under previous crop lentil and reduced tillage system condition decreased soil moisture content and this reduction in water stress may decrease number of nodules. Furthermore, inoculation + 50 kg N ha^{-1} affected nodul number negatively. These interactive effects resulted in a reduction of nodulation in soybean.

***Table 1.** Previous crop, tillage and nitrogen source effects on nodule number, nodule nitrogen content, nodul dry matter content, shoot nitrogen content, shoot dry matter content, seed yield, seed protein and oil content of soybean.*

Application	Nodule number (no plant^{-1})	Nodul N content (%)	Nodul dry matter content (%)	Shoot N content (%)	Shoot dry matter content (%)	Seed yield (kg ha^{-1})	Seed protein content (%)	Oil content (%)
		Means						
Previous crop (A)								
Wheat	50.11	37.62	30.30	25.33	31.02	2295.7 b	34.95	21.38
Lentil	37.36	39.51	32.01	23.80	30.26	2802.1 a	35.76	20.95
Significance	ns	ns	ns	ns	ns	*	ns	ns
LSD (%5)	31.51	5.36	5.65	4.38	1.24	315.4	1.71	1.19
Tillage (B)								
No-tillage	51.30	39.58 a	29.98 b	24.90	30.63	2289.7 b	34.49	21.25
Reduced	36.16	37.55 b	32.32 a	24.23	30.65	2806.2 a	36.22	21.08
Significance	ns	*	*	ns	ns	**	ns	ns
LSD (%5)	21.57	0.33	2.66	1.16	1.20	155.9	2.56	0.86
Nitrogen source (C)								
Control	-	-	-	25.05	30.94	1847.2 b	35.87	20.14 b
200 kg N ha^{-1}	-	-	-	25.17	30.09	2771.6 a	35.47	21.81 a
Inoculation (I)	55.62 a	39.68	32.31 a	23.57	30.55	2812.9 a	34.61	21.38 a
I + 50 kg N ha^{-1}	31.84 b	37.45	29.99 b	24.47	30.97	2760.1 a	35.45	21.31 a
Significance	*	ns	*	ns	ns	**	ns	*
LSD (%5)	20.77	3.97	2.29	2.28	1.15	203.9	1.94	1.10
Significance of interactions								
AxB	ns	**	ns	ns	ns	ns	ns	ns
AxC	ns	*	ns	ns	ns	ns	**	ns
BxC	ns	ns	*	ns	ns	**	*	*
AxBxC	*	ns	ns	ns	ns	**	ns	ns

*, ** and ns denote the difference at $P \leq 0.05$, $P \leq 0.01$, and no significance, respectively.

In this experiment, N content in nodule was not significantly affected by previos crop although it tended to be higher in lentil previous crop compared to wheat (Table 1). This was possibly due to the high mineral-N content in the soil. A significant difference was found between tillage methods with higher N content in nodule from no-tillage plots (Table 2). Similarly, Herridge & Holland (1992) observed that soybean grown using no-tillage had increased N content compared with soybean grown using reduced-tillage, which they attributed to improved soil water conservation and water use efficiency with no tillage compared to other tillage methods. Differences in N content of nodule between inoculation and inoculation + 50 kg N ha^{-1} treatments were not significant statistically. However, the addition of 50 kg N ha^{-1} as starter nitrogen resulted in a reduction of N content of nodule. According to interactive effect of previous crop x tillage system, reduced tillage significantly decreased N content of nodule in the plots where wheat had been grown previously (Fig.1). One reason for this is the possibility that larger amounts of soil N may have been lost by denitrification under the no-tillage system. This has been verified by Aulakh et al., (1998) and Rennie et al., (1998). N content in nodule was significantly influenced by previous crop and nitrogen source. Among the previous crop x nitrogen source combinations, N content in nodule was significantly higher in rhizobium inoculation alone of lentil residue than in any other treatment combination (Fig. 2).

Table 2. *Nodule number (no plant^{-1}) as affected by previous crop, tillage system and nitrogen source.*

Previous crop	Tillage system	Nitrogen source		Mean
		I	I + 50 kg N ha^{-1}	
Wheat	No-tillage	78.50 a	31.72 bc	55.11
	Reduced	55.00 ab	35.22 bc	45.11
	Means	66.75	33.47	50.11
Lentil	No-tillage	50.00 ab	45.00 abc	47.50
	Reduced	39.00 bc	15.44 c	27.22
	Means	44.50	30.22	37.36
LSD: previous crop * tillage system*nitrogen source				33.92

I=Rhizobium inoculation

Dry matter content of nodule are not significantly affected by previous crop, however, it was significantly affected by the tillage system and nitrogen source (Table 1). Dry matter content of nodule in soybean grown under reduced tillage was 8% higher than under no-tillage system. Similarly, Herridge & Holland (1992) observed that soybean grown using reduced tillage had increased dry matter content of nodule compared with soybean grown using no-tillage.

The addition of N fertilizer (50 kg N ha^{-1}) to rhizobium inoculation depressed nodule dry weight (Table 1). The inoculated treatment gave more nodule dry weight than that of the fertilized plant. This result indicated that rhizobium inoculation treatment responded better than other treatment. Ahmed et al. (2014) reported that the control treatment significantly gave more nodules weight over that of the inoculated and fertilized treatments. Among the tillage and nitrogen source combinations, dry matter weight of nodule was significantly higher in reduced tillage treatment of inoculation alone (34.74%) than in any other treatment combination(Fig.3).

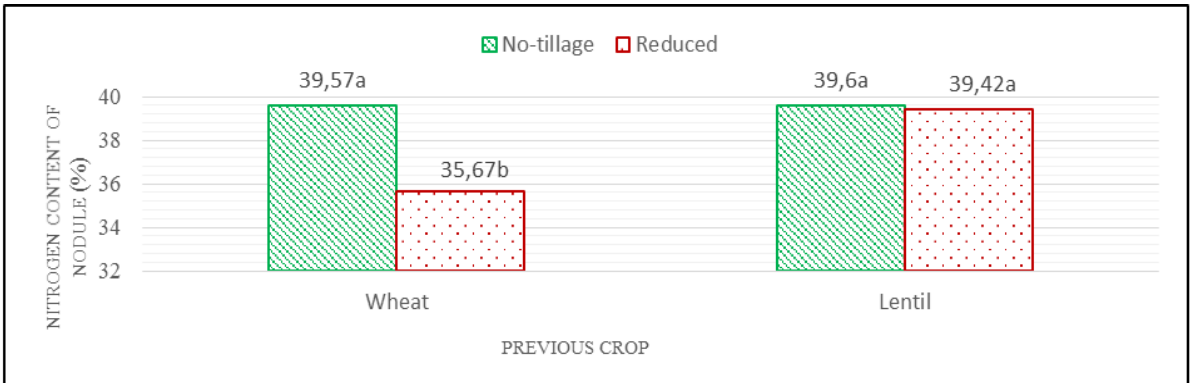

Figure 1. Nitrogen content of nodule affected by previous crop and tillage system (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

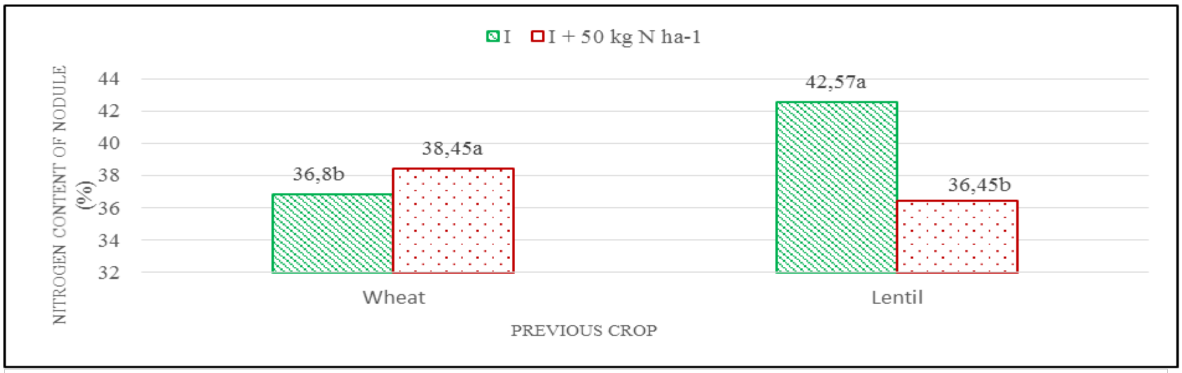

Figure 2. Nitrogen content of nodule affected by previous crop and nitrogen source (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

The above results were supported by Mendes et al. (2003) who reported that the use rhizobium inoculation alone under conventional tillage remarkable benefical on dry matter of nodule in soybean.

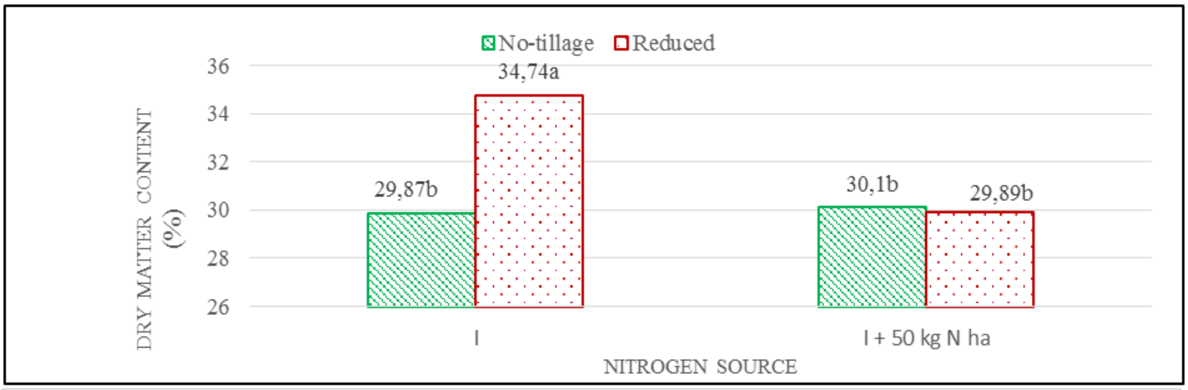

Figure 3. Dry matter content of nodule affected by tillage system and nitrogen source (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

As seen in Table 1, shoot nitrogen and dry matter content were not influenced by previous crop, tillage, nitrogen source or their interactions. However, shoot nitrogen and dry matter content were greater in soybean following wheat than following lentil. Shoot nitrogen content in the plants tended to be higher in control and 200 kg N ha^{-1} applications compared to inoculation alone or inoculation + 50 kg N ha^{-1}. Seed yields of soybean (Table 1) were significantly affected by the previous crop. Seed yield after cultivation of lentil was higher than after wheat. The values for seed yield of soybean after lentil and wheat as previous crop were 2802.1 and 2295.6 kg ha^{-1}, respectively. Higher yields after lentil could be due to increased soil fertility owing to biological nitrogen fixation or due to other rotational effects (Shyam et al., 2007). Arihara et al. (1991) reported that previous crops might affect the growth of succeeding crops by altering the soil physical properties, and in lentil-based cropping systems, seed yields of crops are generally higher after lentil as compared to after non-legumes including cereals, oilseeds, etc.

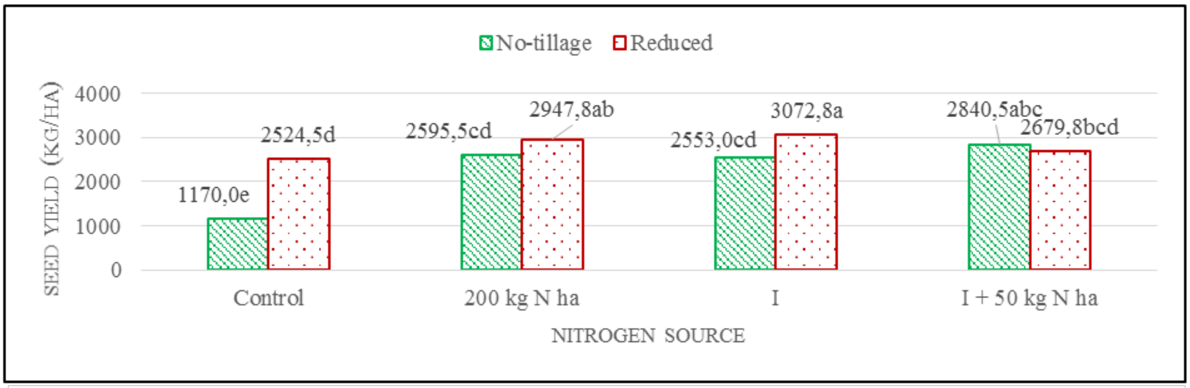

Figure 4. Seed yield affected by tillage system and nitrogen source (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

Differences in seed yield between reduced tillage and no-tillage treatments were also significant statistically. Reduced tillage increased seed yield of soybean by 22.5% relative to no-tillage treatment (Table 1). Since reduced tillage allows for greater root penetration of the soil, the higher seed yield for the reduced tillage treatment was probably due to better plant-water or plant-nutrient relations. Voorhees & Lindstrom (1984) reported that reduced tillage produced better soil porosity and overall soil quality. The addition of N-fertilizer to inoculated soybean did not improve seed yield when compared with inoculated only treatment (Table 1). Also, the un-inoculated and N-fertilized (200 kg N ha^{-1}) produced equal seed yields with inoculated alone or inoculated + 50 kg N ha^{-1} additional fertilizer. These results are similar to those obtained by other authors in which the application of N-fertilizer did not provide a major benefit compared to inoculation alone (Seneviratne et al., 2000; Albareda et al., 2009). Inoculation alone and 200 kg N ha^{-1} applications yielded higher seed yield with reduced tillage system than with no-tillage. In contrast, no-tillage with inoculation + 50 kg N ha^{-1} produced higher seed yield as compared with inoculation + 50 kg N ha^{-1} under reduced tillage (Fig. 4). Previous crop x tillage system x nitrogen source interaction had significant effect on seed yield (Table 1). Highest seed yield was obtained from previous crop lentil x reduced tillage x inoculation alone combination (Table 3).

***Table 3.** Seed yield (kg ha^{-1}) as affected by of previous crop, tillage system and nitrogen source.*

Previous Crop	Tillage	Nitrogen Source				
		Control	200 kg N ha^{-1}	I	I + 50 kg N ha^{-1}	Mean
Wheat	No-tillage	1014.0 d	2032.6 c	2399.3 bc	2736.0 ab	2045.4
	Reduced	1967.3 c	2863.0 ab	2933.0 ab	2421.0 bc	2546.0
	Means	1460.6	2447.8	2666.1	2578.5	2295.7
Lentil	No-tillage	1326.0 d	3158.3 a	2706.6 ab	2938.6 ab	2533.9
	Reduced	3081.6 ab	3032.6 a	3212.6 a	2941.8 ab	3066.3
	Means	2203.8	3095.4	2959.6	2760.1	2800.1
LSD previous crop*tillage system*nitrogen source						407.9

I=Rhizobium inoculation

It was detected that previous crop, tillage and nitrogen source had insignificant effect on seed protein content of seed. However, there were significant differences between previous crop x nitrogen source, and tillage x nitrogen source interactions in terms of effect on seed protein content (Table 1.). Under lentil previous crop, the highest seed protein content were obtained at 200 kg N ha^{-1} and RI + 50 kg N ha^{-1} applications, respectivelly (Fig. 5).

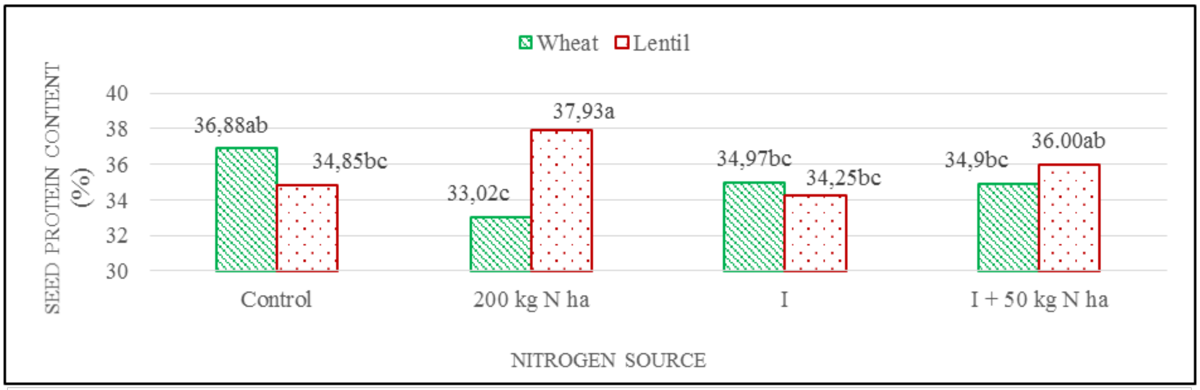

Figure 5. Seed protein content affected by previous crop and nitrogen source (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

This indicated that seed protein content tended to increase in previous crop of legume with added nitrogen fertilizer to rhizobium inoculation. However, under previous crop of wheat and application of 200 kg N ha^{-1} caused the lowest seed protein content. The increase in seed protein content because of fertilizer N addition with previous crop of legume agrees with findings of Saini & Chongtham (2011) who reported that fertilizer N addition increased protein content of seed in soybean by increasing the beneficial effects of the previous legume crop.

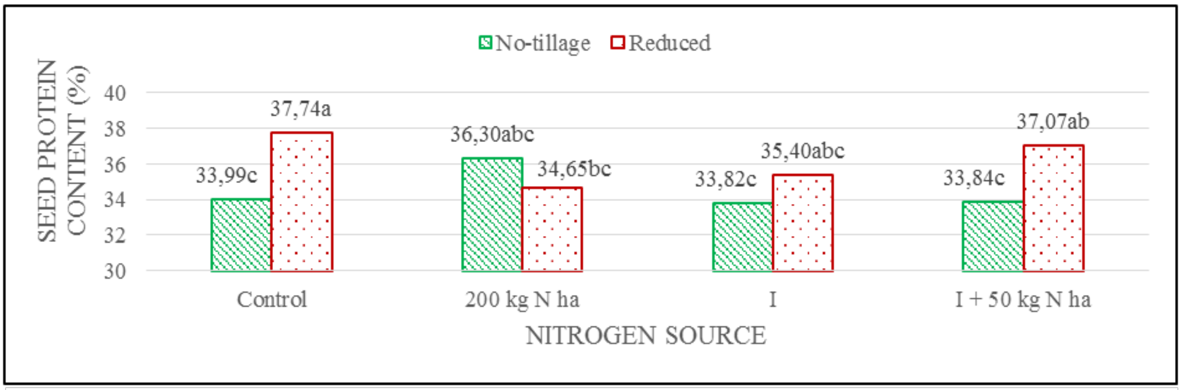

Figure 6. Seed protein content affected by tillage system and nitrogen source (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

Interaction of reduced tillage x control where no fertilizer was applied produced the highest seed protein content (Fig. 6). The highest seed protein content could be attributed to decomposition of residues in reduced tillage system thus releasing nutrients to the soil particularly nitrogen. Thus, lower seed protein content was observed under no-tillage system accompanied with minimal levels of nitrogen fertilizer. These results are in line with Boomsma et al. (2009) who stated that chiseled maize grown can up took the nitrogen and water up to 40 cm depth which increased chlorophyll contents and thus causing more protein content.

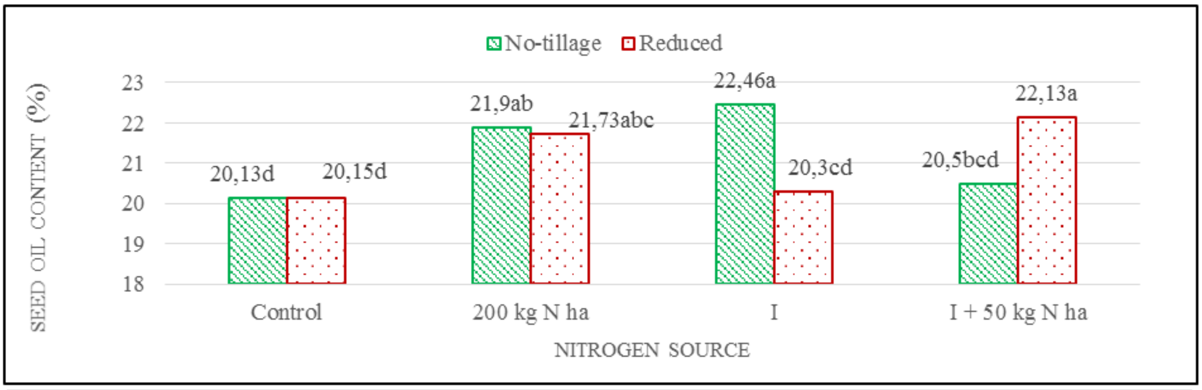

Figure 7. Seed oil content affected by tillage system and nitrogen source (values followed by the same letter are not significantly different at a 5% level-Tukey Test).

Oil content was higher slightly after wheat than after lentil, although differences were not significant. However, there was statistically difference in seed oil content among nitrogen source, and control treatment had a lower oil content compared with other treatments (Table 1). Figure 7 present the influence of tillage system x nitrogen source interaction on oil content of soybean. The highest oil content was observed in no-tillage + inoculation alone treatment which is statistically at par with those of no-tillage + 200 kg N ha^{-1}, reduced tillage + 200 kg N ha^{-1}, and reduced tillage + inoculation + 50 kg N ha^{-1} applications. Treatment effects on oil content was inconsistent between tillage system and source of nitrogen, however, the interaction occurred because application of nitrogen fertilizer increased oil content. No-tillage treatment had the highest and the lowest oil content with the rhizobium inoculation and control treatments with rhizobium inoculation alone having the highest and control having the lowest. This results are compatible with those obtanied by Fecak et al. (2010) who reported seed oil content of soybean was higher at no-tillage with low starter nitrogen treatment.

4. Conclusions

This experiment has shown that retention of residues in a soybean-wheat or soybean-lentil rotation affected seed yield of soybean grown double-cropping system. There was a substantial increase in seed yield of soybean cultivated after lentil compared to wheat. Thus, we recommend to include of legumes such as lentil in these systems to reduce fertilizer N requirements. Nodul nitrogen content, nodule dry matter content and seed yield influenced by tillage system. Nodule nitrogen content was higher in no tillage treatment, while nodule dry matter and seed yield were higher in reduced tillage than those of no-tillage. The addition of N-fertilizer to inoculated soybean caused to decrease nodule number and nodule dry matter content. Furthermore, inoculation alone provided equal benefits with other treatments except control. The small differences in yield obtained in this study may not be sufficient to offset additional fertilizer cost. According to findings of this experiment, reduced tillage system with rhizobium inoculation alone are recommended to attain high seed yield under lentil previous crop.

5. Acknowledgement

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6. Literature

Ahmed, AE., Mukhtar, NO., Babiker, HM., Adam, AI. 2014. Effect of nitrogen fertilization and Bradyrhizobium inoculation on the growth, symbiotic properties and yield of pigeon pea (Cajanus cajan). Jour. of Nat. Resour. & Environ. Stu., 2 (1), 27-31.

Albareda, M., Rodríguez-Navarro, DN and Temprano FJ 2009. Use of Sinorhizobium (Ensifer) fredii for soybean inoculants in South Spain. Eur. J. Agron. 30, 205–211.

Arihara, J, Ae, N, & Okada, K 1991. Soil physical conditions and crop production in Alfisols and Vertisols of the Indian semii-arid tropics. Soil Phys. Cond. Plant Growth, 63, 13-18.

Boomsma, CR., Santini, JB., Tollenaar, M., Vyn, TJ. 2009. Maize morphological responses to intense crowding and low nitrogen availability: An analysis and Review. Agron J. 101, 1426-1452.

Burle, ML, Mielniczuk, J., Focchi, S., 1997. Effect of cropping systems on soil chemical characteristics with emphasis on soil acidification. Plant Soil, 190, 309-316.

Doran, JW. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Science Society of America Journal, 44, 765-771.

Doran, JW., Parkin, TB. 1994. Defining and Assessing Soil Quality, in JW Doran et al. (ed), Defining Soil Quality for Sustainable Environment, SSSA Spec. Pulbl. 35, Madison, WI, 3-22.

Fecák, P., Šariková, D., Černý. I 2010. Influence of tillage system and starting N fertilization on seed yield and quality of soybean (Glycine max (L.) Merrill.), Plant Soil Environ., 3, 105-110.

Godsey, CB., Pierzynski, GM., Mengel, DB., Lamond, RE. 2007. Changes in soil pH, organic carbon, and extractable aluminum from crop rotation and tillage. Soil Sci. Soc. Am J. 71, 1038-1044.

Harper, JE 1974. Soil and symbiotic nitrogen requirements for optimum soybean production. Crop Sci. 14, 255-260.

Harper, JE 1987, Nitrogen metabolism. Soybeans: Improvement, production and uses. 2nd ed. Agronomy Monograph no.16. ASA-CSSA-SSSA. 497-533.

Herridge, DF., Holland, JF. 1992. Production of summer crops in northern New South Wales. I. Effects of tillage and double cropping on growth, grain and N yields of six crops. Aust. J. Agric. Res. 43, 105-122.

Hungría, M., Franchini, JC., Campo, RJ., Crispino, CC., Moraes, JZ., Sibaldelli, RNR., Mendes, IC., Arihara, J. 2006. Nitrogen nutrition of soybean in Brazil: contributions of biological N_2 fixation and N fertilizer to grain yield. Can. J. Plant Sci., 86, 927–939.

Imsande, J. 1992. Regulation of nodule efficiency by the undisturbed soybean plant. J. Exp. Bot. 42, 687–691.

Karlen, DL., Eash, NS., Unger, PW. 1992. Soil and crop management effects on soil quality indicators. Am. J. Alternative Agric., 7, 48-55.

Karlen, DL., Varvel, GE., Bullock, DG., Cruse, RM. 1994. Crop rotations for the 21 st century, Adv. Agron., 53, 1-45.

Karlen, DL., Stott, DE. 1994. A framework for evaluating physical and chemical indicators of soil quality, in JW Doran, DC Coleman, DF Bezdicek & BA Stewart (ed), Defining Soil Quality for a Sustainable Environment. Soil Sci.Soc. Am. Madison, WI, 53-72.

Karlen, DL., Sharpley, AN. 1994. Management strategies for sustainable soil fertility, in JL Hatfield and DL Karlen (ed), Sustainable Agriculture Systems, Lewis Publ.,CRC Press,Boca Raton, FL, 47- 108.

Kihara, J., Mukalama, J., Ayuke, F., Njoroge, SO., Waswa, B., Okeyo, J., Koala, S., Bationo, A. 2012. Crop and soil response to tillage and crop residue application in a tropical ferralsol in sub-humid Western Kenya, in A Bationo et al. (ed.), Lessons learned from Long-term Soil Fertility Management Experiments in Africa, Springer Science Business Media Dordrecht.

Lafond, GP., Loeppky, H., Derksen, DA. 1992. The effects of tillage systems and crop rotations on soil water conservation, seeding establishment and crop yield. Can. J. Plant Sci., 72, 103-125.

Mendes, IC., Hungria, M., Vargas, MAT. 2003. Soybean response to starter nitrogen and bradyrhizobium inoculation on a cerrado oxisol under no-tillage and conventional tillage systems. R. Bras. Ci. Solo. 27, 81-87.

Ohyama, T., Ohtake, N., Sueyoshi, K..,Tewari, K., Takahashi, Y., Ito, S., Nishiwaki, T., Nagumo, Y., Ishii, S., Sato, T. 2009. Nitrogen Fixation and Metabolism in Soybean Plants, in ES Hany (ed), Soybean physiology and biochemistry, Nova Science Publishers, Inc., New York, 333-364.

Rennie, RJ., Rennie, DA., Siripaibool, C., Chaiwanakupt, P., Boonkered, N., Snitwongse, P. 1988. N_2 fixation in Thai soybeans: effect of tillage and inoculation on ^{15}N-determined N^2fixation in recommended cultivars and advanced breeding lines. Plant and Soil, 112(2), 183- 193.

Saini, KS., Chongtham, SK. 2011. Effect of different residue management practices and nitrogen levels on growth, yield and economics of soybean [Glycine max (L.) Merrill]. Crop Res., 42 (1, 2 & 3), 110-113.

Seneviratne, G., Van Holm, LHJ., Ekanayake, EMHGS. 2000. Agronomic benefits of rhizobial inoculant use over nitrogen fertilizer application in tropical soybean. Field Crops Res., vol 68, pp. 199–203.Shyam, S, Yada, D & McNeil, PC 2007, Lentil: An ancient crop for modern times Yadav. Springer. 472, 259.

Starling, ME., Wesley Wood, C., Weaver, DB. 1998. Starter nitrogen and growth habit effects on late-planted soybean, Agron. J., 90, 658-662.

Streeter, JG 1988. Inhibition of legume nodule formation and N_2 fixation by nitrate. CRC Crit. Rev. Plant Sci., 7, 1-23.

Voorhees, WB., Lindstrom, MJ. 1984. Long-term effects of tillage method on soil tilth independent of wheel traffic compaction. Soil Sci. Soc. Am. J., 48, 152-156.

Zhang, F., Mace, F., Smith, DL. 2000. Mineral nitrogen availability and isoflavonoid accumulation in the root systems of soybean [Glycine max (L) Merr.], J. Agron. Crop Sci., 184, 197-204.