Effect of conservation tillage systems on growth, yield and yield components of soybean

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Abstract: Conservation tillage systems have been used during recent years in many areas of Iran. In this study, the effect of conservation tillage on soybean yield, yield components and phenological characteristics was evaluated in Golestan province located at the northern Iran. Four different treatments including conventional tillage (CT), minimum tillage (MT), no- tillage with no-till planter (NT-Planter) and no-tillage with no-till grain drill (NT-Grain Drill) were considered. A randomized complete block design with four replications was designed for the experiment. Soybean yield and yield components and some phenological characteristics were measured. Data were analyzed using SAS software and Duncan's multiple range tests was used to compare the means. The results of two year experiments showed that in year 2012, NT-Grain drill with mean yield of 3612 kg ha-1 had the highest yield while the treatment MT had the lowest yield of 2794 kg ha-1. In year 2013, NT-Planter had the highest yield of 3617 kg ha-1 whereas CT method had the lowest yield of 3054 kg ha-1. It was concluded that NT methods with respect to yield increase are appropriate alternative to replace conventional tillage method in soybean cultivation. Phenological characteristics gave promising response to conservation tillage especially to no tillage.

Keywords: conservation tillage, minimum tillage, no-till, soybean

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1 Introduction

More than 65% of the area sown to soybean in Iran is located in the northern areas, Golestan province. Also, in this province, the wheat-soybean production system covers about 60000 ha, that is vital for rural development and natural resources conservation in the areas. Despite the availability of improved varieties of wheat and soybean with increased yield potential, the potential increase in production has not been attained because of poor crop system management. In current agricultural management systems, both crops are requiring large amounts of water, labor, time, nonrenewable energy and heavy farm machinery for their successful cultivation.

Conservation tillage is defined by the Conservation Technology Information Center, USA as "any tillage and planting system that covers 30% or more of the soil surface with crop residue, after planting, to reduce soil erosion by water" (CTIC, 2015). Minimum and no-tillage methods are important components of conservation tillage systems. Conservation tillage improves soil and water resources, saves energy and time, and reduces the costs of farm operations. Serraj and Siddique (2012) synthesized the recent research findings of conservation agriculture (CA) in dry areas especially in smallholder farming systems. They analyzed agronomic, socio-economic, and agro-ecological factors leading to its success or failure and identified potential points for future research priorities on CA in dry areas.

Thiagalingam et al. (1991) investigated the effects of no-till and conventional tillage methods in a maize-soybean rotation on a clay loam soil during a four years study. They concluded that the average soybean

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yields were 20% higher under no-till compared to the conventional tillage and the germination of soybean was better than that of conventional tillage. Dibert et al. (1989) stated that no-till method could cause higher yield of soybean varieties with increase in soil moisture content. Wilhelm and Wortman (2004) resulted that the yield of soybean under no-till system was the same as the conventional tillage method. While no-till method decreased the yield of corn compared to the conventional tillage. Romero et al. (2011) reported the response of faba bean root growth and yield to no-tillage and conventional tillage systems in a Vertisol under rainfed Mediterranean conditions. They suggested that no-tillage system had significantly higher values of the root parameters studied including root diameter, root length and root biomass than conventional tillage. Grain yield and yield components of faba bean were higher under no-tillage systems than conventional tillage. Fabrizzi et al. (2005) evaluated the effect of conservation tillage on corn yield and reported that no-till had lower corn yield compared to the minimum tillage method.

Busari et al. (2015) reviewed the previous studies done on the impact of conservation tillage on soil properties, crop performance and environment. They concluded that conservation tillage practices becomes more and more important to reach the food security with minimum effect on soil and environment in the present world than before. Despite other studies, the results of some previous work also indicated that using no-till systems increased grain yield in soybean cultivation (Grabau and Pfeiffer, 1990; Wagger and Denton, 1989a). However, other investigations reported that the application of no-tillage systems have been positively affected on many parts of the USA (Smika and Unger, 1986; Unger et al., 1988). In contrast, there are a few studies that reported conservation tillage may decrease crop yield and attributed it to soil moisture, temperature and nutrition (Wang et al., 2007; Su et al. 2007; Xie et al., 2008).

Conservation tillage systems have been noticed and used by governmental agricultural organizations and farmers since 2007 in Iran. Although this system is becoming popular and used by farmers but there is still a need to study more on the use of such systems and related machines in cultivation of agricultural crops like soybean. Therefore, the study was conducted to evaluate the effect of conservation tillage systems on soybean yield and phenological characteristics in the northern areas of Iran, Golestan province.

2 Materials and methods

2.1 Specification of research station

The study was conducted in Gorgan Agricultural Research Station, Golestan province located at the northern areas of Iran (20' 54 °East Longitude and 36' 55 ° North Latitude, 6 m above sea level and annual precipitation of 450 mm). The area has temperate climate. The soil texture was silt clay loam. Soil physical properties of experimental field are given in Table 1. The crop rotation was wheat-soybean.

Table 1 Soil physical properties of experimental field

Depth, cm	Soil particles			Texture	Field capacity, %	Wilting point, %	Bulk density, g cm^{-3}
	Clay	Silt	Sand				
0-15	32	50	18	Silt clay loam	27.7	13.1	1.44
15-30	34	48	18	Silt clay loam	27.0	12.3	1.41

2.2 Treatments and experimental design

Four tillage methods including conventional tillage (CT) (Disk harrow+planting with planter), minimum tillage (MT) (Chisel packer+planting with planter), no tillage with no-till planter (NT-Planter) and no tillage with no-till grain drill (NT-Grain drill) were used in the first year 2012. Three tillage methods including CT, MT and NT-Planter were considered in the second year 2013 in

this study. Experimental design was a randomized complete block design (RCBD) with four treatments and four replications. The size of plots was 8 m×20 m. The study was carried out for two years of 2012 and 2013.

2.3 Technical specification of machines

Technical specifications of used machines in the study are presented in Table 2. Some of the machines are imported and some are domestically manufactured.

Table 2 Technical specifications of used machines in the study

Machine type	Specifications	Weight, kg	Hitch type	Working width, m
No-till planter	Six planter unit, seed hopper capacity of 25 liter, fertilizer hopper capacity 450 liter, required power of 70-80 hp, pneumatic seed meter, equipped with disc, fluted coulters, plastic press wheel	1235	Three point hitch	2.50
No-Till grain drill	Fifteen planter units with 17 cm row space, fluted feed seed meter, feed roll type fertilizer meter, double disc openers, ripple disc coulter, plastic press wheel	3500	Pull	2.55
Chisel packer	Five sweep tines at front with steel roller at rear	350	Three point hitches	1.40
Disk harrow	Twenty eight discs, tandem, notched discs at front and ordinary discs at rear, hydraulic jack	610	Pull	2.50
Row crop planter	Four planter units, drum hopper, horizontal plate seed meter, hoe furrow opener, wide rubber press wheel	600	Three point hitches	2.10

2.4 Farm operations

In year 2012, the four treatments including CT, MT, NT-Planter and NT-Grain drill were used. Seed gates were closed to every other one for reaching to a 51 cm row space in no-till grain drill. A soybean variety called DPX with 60 kg ha^{-1} was planted in this study. Weed control was done in the middle of summer by spraying of one liter Persuit herbicide (100 g lit^{-1}). There was a need to spray with a mix of Supergalant and Bentazon herbicides due to high density of weeds. Pest control was also performed by spraying of 2 lit ha^{-1}. An amount of 100 kg ha^{-1} fertilizer (with a proportion of 15% K, 8% P, 15% N) during planting below seed in no-till planter, within seed in no-till grain drill and along with disk harrow in other treatments were used. During the growth season, the field was irrigated three times by sprinkler method and two times raining happened.

In year 2013, the three treatments were used. An amount of 80 kg ha^{-1} soybean planted. At the time of sprinkler irrigation, an amount of 100 kg ha^{-1} fertilizer (46% N) was used. The Gramaxon herbicide (4 lit ha^{-1}) was used for weed control and Somiton pesticide (1.5 lit ha-1) used for pest control. During the growth season, the field was irrigated three times by sprinkler method.

2.5 Measured parameters

Yield and yield components parameters were measured in the experiments during years 2012 and 2013. These parameters included plant height, number of pod per plant, 1000-grain weight, grain yield, above ground dry matter and harvest index of soybean. These are the most important parameters of soybean which usually have been noticed and measured in other research works (Liu et al., 2005; Liu et al., 2010; Stipecevic et al., 2009). Some phenological characteristics of soybean including number of days to flowering, number of days to maturity, height to first pod and number of sub branches were also measured.

3 Results and discussion

The results of variance analysis of yield and yield components for year 2012 are shown in Table 3. As it is shown in the table the grain yield, above ground dry matter and harvest index of soybean obtained using different tillage methods are significantly different at probability level of 1%. Whereas other measured parameters including plant height, number of pod per plant and 1000-grain weight are not significantly different.

The results of mean comparison of yield and yield components parameters measured in year 2012 are shown in Table 4. NT-Grain drill with yield of 3612 kg ha^{-1} had the highest yield while the treatment MT had the lowest

yield of 2794 kg ha^{-1} among the treatments. However, the negative effect of minimum tillage on sorghum grain yield and cowpea has been suggested in Southern Africa (Mashingaidze et al., 2012). The highest value of plant height, number of pod per plant, above ground dry matter and harvest index belongs to NT-Grain drill.

Table 3 Mean squares of yield and yield components in year 2012

Source of variation	df	Plant height	Number of pod per plant	1000 – grain weight	Grain yield	Above ground dry matter	Harvest index
Replication	3	104**	44.1^{ns}	10.0^{ns}	164562^{ns}	1509779*	1.75*
Tillage	3	3.85^{ns}	57.2^{ns}	4.5^{ns}	532694**	3158626**	2.92**
Error	9	1.21	30.8	5.2	43819	312588	0.42
CV. %		2.20	9.2	1.3	6.7	6.9	1.67

ns: not significant * , **: significant at level of 5 % and 1%, respectively, F test

Table 4 Mean comparison of yield and yield components in 2012

Treatment	Plant height, cm	Number of pod per plant	1000 – grain weight, gr	Grain yield, kg ha^{-1}	Above ground dry matter, kg ha^{-1}	Harvest index, %
NT-Planter	50.0^{a}	60.0^{a}	182^{a}	3203^{b}	8264^{b}	38.8^{ab}
NT-Grain drill	51.8^{a}	65.8^{a}	182^{a}	3612^{a}	9223^{a}	39.2^{a}
CT	50.8^{a}	58.0^{a}	180^{a}	2909^{bc}	7319^{c}	39.8^{a}
MT	49.6^{a}	57.5^{a}	180^{a}	2794^{c}	7407^{bc}	37.8^{b}

Mean follows by the same letters in a column are not significantly different at level of 5% by LSD test

The results of means comparison of some phenological characteristics for different tillage methods in year 2012 are shown in Figures (1, 2, 3 & 4). The number of days to flowering is not significantly different at probability level of 5% between all treatments. The number of days to maturity of NT method is significantly different compared to CT and MT. The mean of number of days to maturity for both NT methods, 131.2 and 130.8 days, are smaller than CT and MT. Three days sooner is taken for soybean to be matured in NT than CT with the coefficient of variation of 0.26%. However, there is no significant difference between CT and MT for the number of days to maturity. The value of height to first pod of NT-Grain drill is greater than the other tillage method and significantly different at level of probability 5%. The value of sub branches is not significantly different and has put in the same group in all tillage systems. In overall, phenological characteristics gave the good response to conservation tillage systems especially to no tillage systems. Moreover, it should be pointed out that the same response was seen in yield and yield components of soybean for no tillage systems. The results obtained are in consistence to previous researchers' suggestions (Thiagalingam et al., 1991; Dibert et al., 1989; Wagger and Denton, 1989a and 1989b, Mashingaidze et al., 2012)

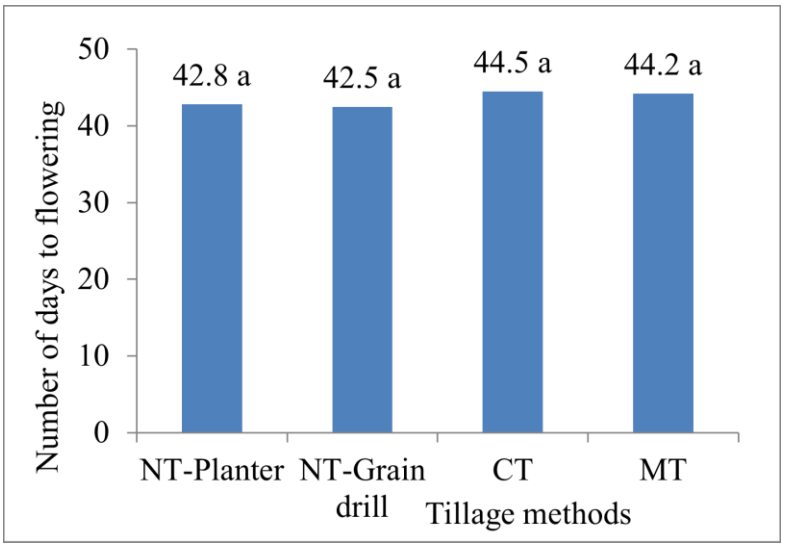


Figure 1 Mean comparison of number of days to flowering, CV. = 3.59% in year 2012

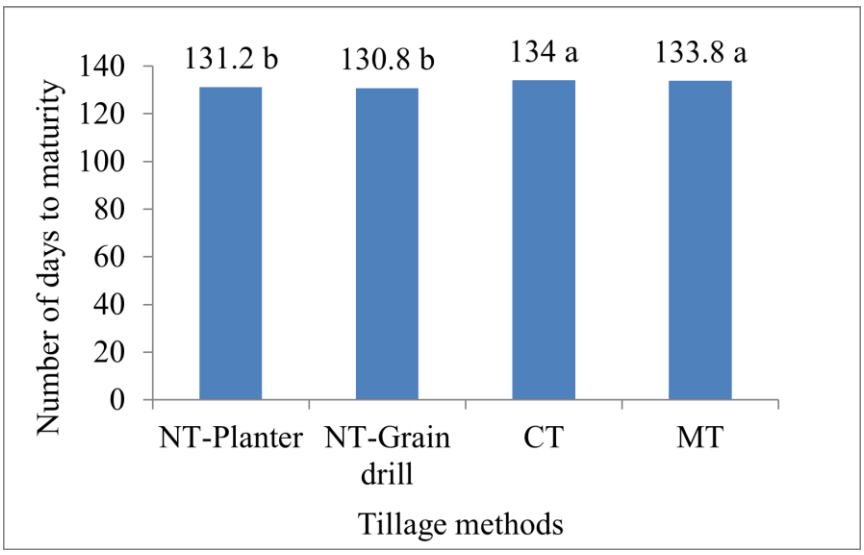


Figure 2 Mean comparison of number of days to maturity, CV. = 0.26% in year 2012

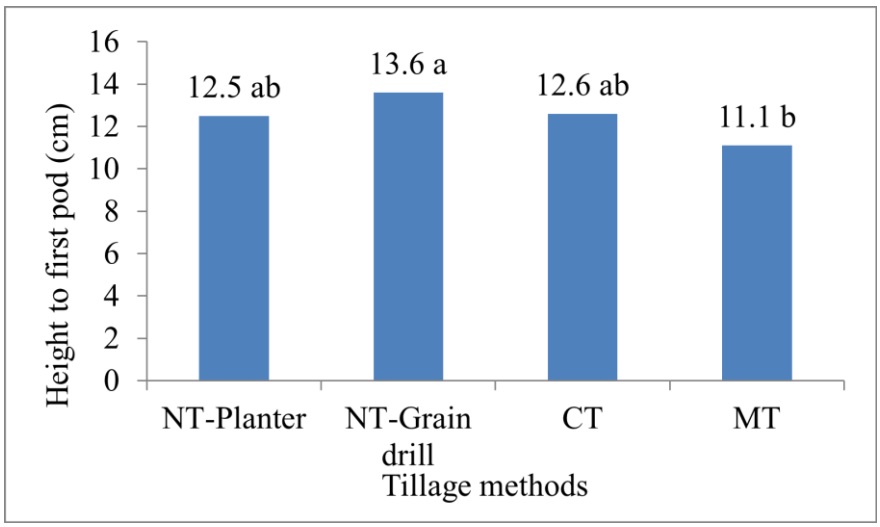
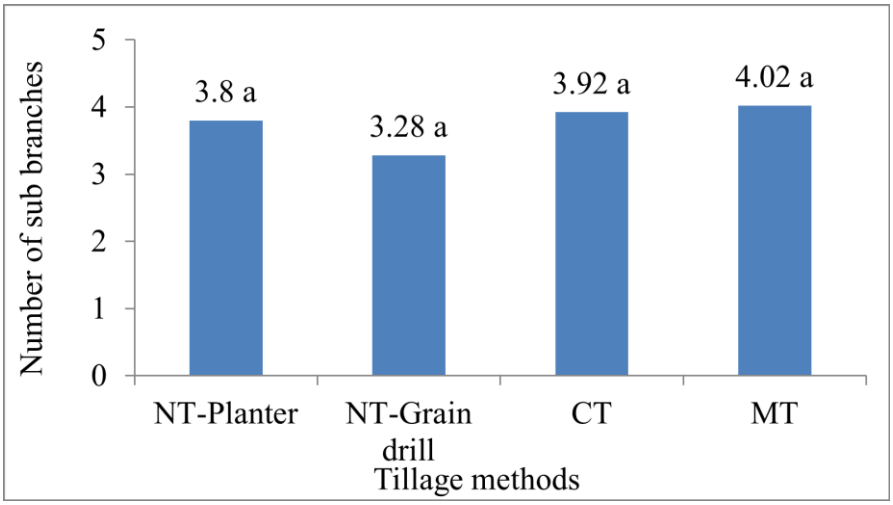


Figure 3 Mean comparison of height to first pod, CV.= 7.6% in year 2012



(c) (d)

Figure 4 Mean comparison of number of sub branches, CV.= 15.6% in year 2012

The results of variance analysis of yield and yield components for year 2013 are shown in Table 5. As it is shown in the table the grain yield and harvest index of soybean obtained using different tillage methods are significantly different at probability level of 5%. Whereas the other measured parameters including plant height, number of pod per plant, 1000-grain weight and above ground dry matter are not significantly different.

The results of mean comparison of yield and yield components parameters measured in year 2013 are shown in Table 6. NT-Planter with yield of 3617 kg ha^{-1} had the highest yield whereas CT method had the lowest yield of 3054 kg ha^{-1}. Our results confirm previous data on the effect of conservation tillage methods on soybean yield (Thiagalingam et al., 1991; Dibert et al., 1989; Grabau and Pfeiffer, 1990; Wagger and Denton, 1989a; Opara, 2015; Farooq et al., 2011). However, the highest value of number of pod per plant, above ground dry matter and harvest index belongs to NT-Planter.

Table 5 Mean squares of yield and yield components in year 2013

Source of variation	df	Plant height	Number of pod per plant	1000 – grain weight, gr	Grain yield, kg ha^{-1}	Above ground dry matter, kg ha^{-1}	Harvest index
Replication	3	61.7**	151^{ns}	6.31^{ns}	252302^{ns}	1207270^{ns}	1.17^{ns}
Tillage	2	1.75^{ns}	90.6^{ns}	14.6^{ns}	319856*	639924^{ns}	9.4*
Error	6	4.1	95.2	14.1	56844	274532	1.81
CV. (%)		3.3	13.4	2.1	7.12	16.2	3.5

ns: not significant * , **: significant at level of 5% and 1%, respectively, F test

Table 6 Mean comparison of yield and yield components in year 2013

Treatment	Plant height	Number of pod per plant	1000 – grain weight, gr	Grain yield, kg ha^{-1}	Above ground dry matter, kg ha^{-1}	Harvest Index, %
NT-Planter	60.2^{a}	75^{a}	182^{a}	3617^{a}	9077^{a}	39.8^{a}
CT	61.2^{a}	65^{a}	178^{a}	3054^{b}	8730^{a}	38.7^{ab}
MT	60.0^{a}	70^{a}	179^{a}	3377^{ab}	8280^{a}	36.8^{b}

Mean follows by the same letters in a column are not significantly different at level of 5% by LSD test

The results of means comparison of some phenological characteristics for different tillage methods in year 2013 are shown in Figures 5, 6, 7 & 8. As can be seen from Figure 6, the number of days to flowering is significantly different at probability level of 5% between NT-Planter and other tillage methods. The number of days to maturity of NT methods is significantly different compared to CT and MT. The mean of number of days to maturity for NT-Planter, 135 days, is smaller than that of CT and MT. Three days sooner is taken for soybean to be matured in NT-Planter than CT and MT with the coefficient of variation of 0.41%. The same results obtained in year 2102. However, there is no significant difference between CT and MT for the number of days to maturity the same as the results in year 2012. However, there is no significant difference for the value of height to first pod of all tillage methods at probability level of 5% and included in the same group. The value of sub branches is not significantly different and put in the same group in all tillage systems.

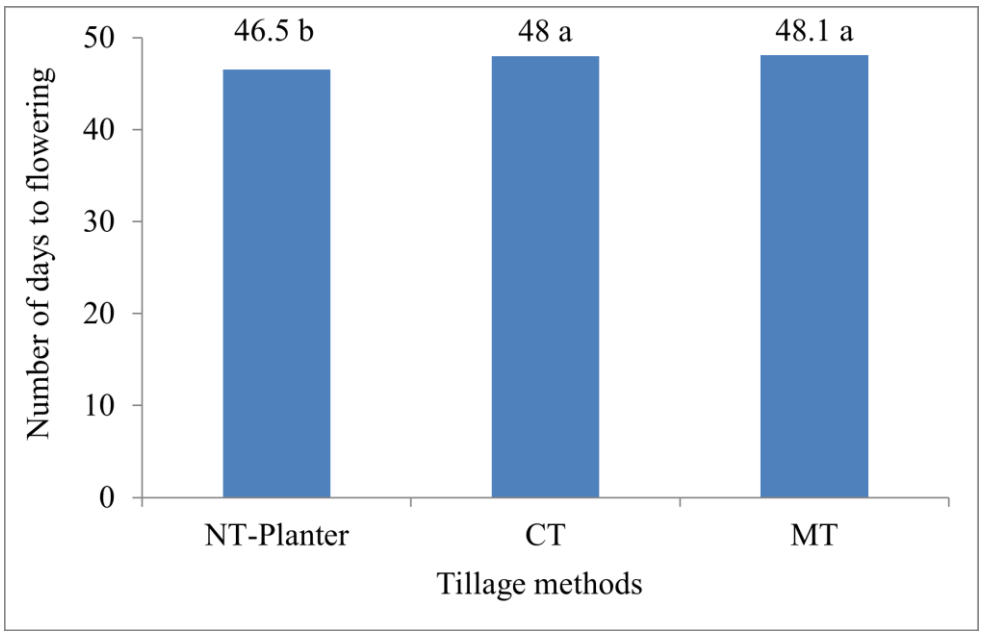


Figure 5 Mean comparison of number of days to flowering, CV. = 1.57% in year 2013

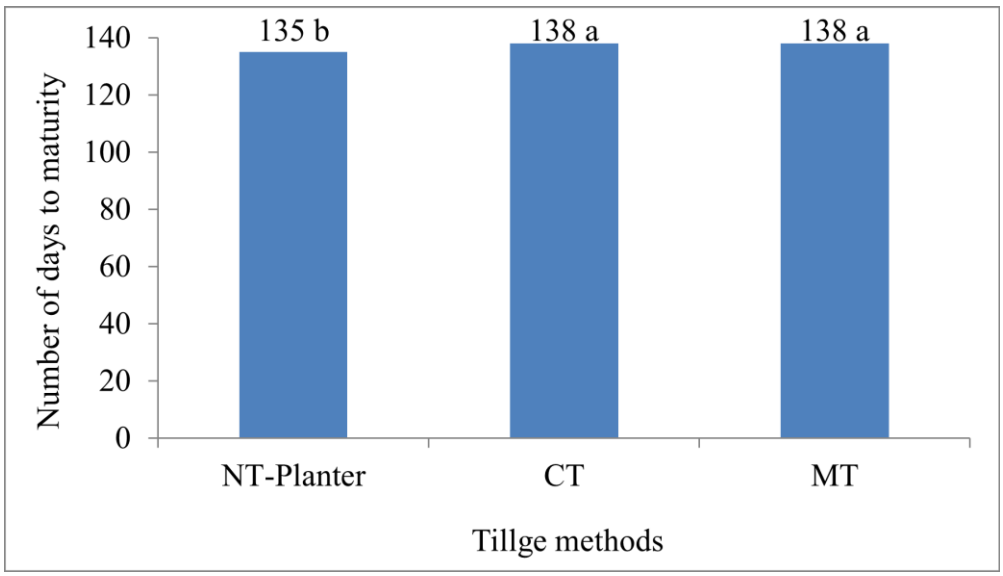


Figure 6 Mean comparison of number of days to maturity, CV. = 0.41% in year 2013

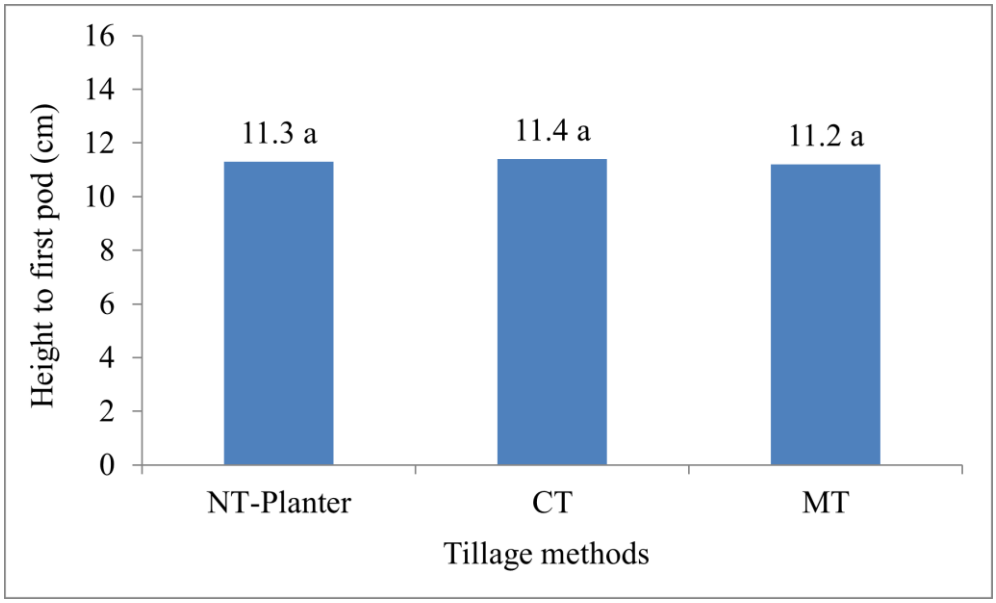


Figure 7 Mean comparison of height to first pod, CV.= 5.5% in year 2013

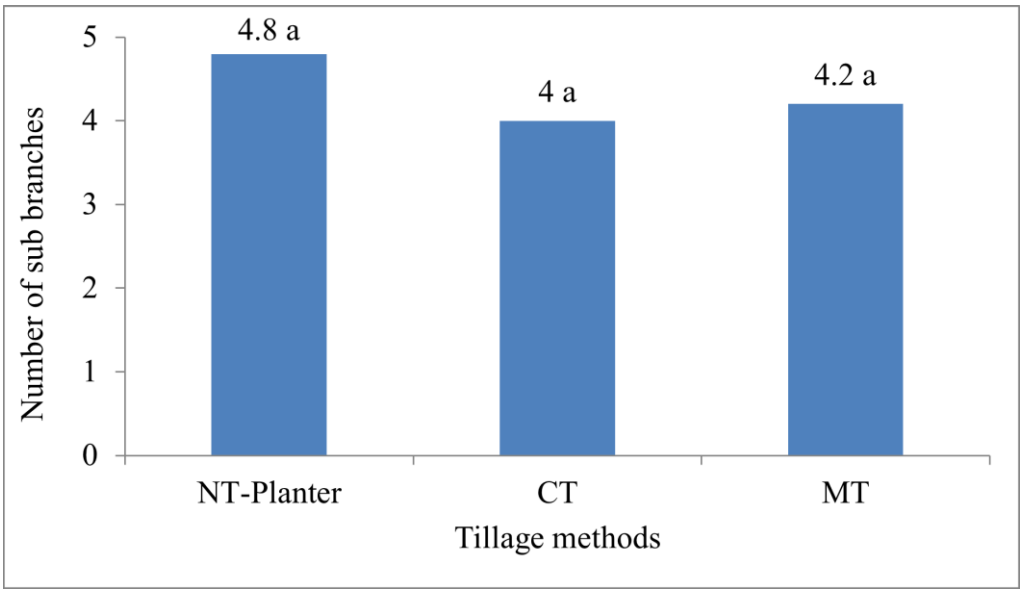


Figure 8 Mean comparison of number of sub branches, CV.= 6.3% in year 2013

As an overall discussion, numerous studies have been carried out to assess the impact of conservation tillage on crop yield. Many of them suggested increase in yield (Haggblade and Tembo, 2003; Mazvimavi and Twomlow, 2009; Thiagalingam et al., 1991; Dibert et al., 1989; Grabau and Pfeiffer, 1990; Wagger and Denton, 1989a; Opara, 2015; Liu et al., 2013; Farooq et al., 2011) as the present study shown the same results. Some of them stated decrease in yield (Wang et al., 2007; Su et al., 2007; Xie et al., 2008) in the use of conservation tillage systems. However, the effect of conservation tillage systems on the yield and yield components of different crops should be studied for a long period of time with considering the conditions of soil and climate and appropriate use of tillage machines. Some previous works did not indicate any differences in crop yield on the influence of conservation tillage on soybean and grain sorghum in dryland conditions in the first three years of experiments. Whereas after the next thirteen years greater yield was observed in no-till systems (Jasa et al., 1999).

For farmers, maximizing yield and managing risk is a complex challenge that is unlikely to be solved by a single approach. There are three specific major challenges: increasing yield potential (the maximum yield for a given genotype under optimal conditions), protecting yield potential, and increasing resource use efficiency to ensure sustainability. Improved crop management practices will undoubtedly increase yield in the future. The biggest gains will come from combinations of improved crops and improved agronomical practices (Fan et al., 2012). Conservation agriculture is by no means a low output agriculture and allows yields comparable with modern intensive agriculture but in a sustainable way. Yields tend to increase over the years with yield variations decreasing. However, for the farmer, conservation tillage is mostly attractive because it allows a reduction of the production costs, reduction of time and labor, particularly at times of peak demand such as land preparation and planting and in mechanized systems it reduces the costs of investment and maintenance of machinery in the long term.

4 Conclusions

A study was conducted to evaluate the effect of conservation tillage methods on yield and yield components of soybean. The results of two year experiments showed that in year 2012, no-till grain drill with mean yield of 3612 kg ha^{-1} had the highest yield while the treatment minimum till with chisel packer and planting had the lowest yield of 2794 kg ha^{-1}. In year 2013, no-till with planter had the highest yield of 3617 kg ha^{-1} whereas conventional tillage method had the lowest yield of 3054 kg ha^{-1}. Phenological characteristics gave the good response to conservation tillage systems especially to no tillage systems. Moreover, it should be pointed out that the same response was seen in yield and yield components of soybean for no tillage systems. In overall, long term use of conservation tillage systems should be noticed to reach the higher yield of different crops. However some other important factors such as appropriate use of conservation tillage machines and conditions of soil and climate could be also considered.

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References

Busari, M. A., S. S. Kukal, A. Haur, R. Bhatt, and A. A. Dulazi. 2015. Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3(2): 119-129.

Conservation Tillage Information Center (CTIC). 2015. Tillage type definitions. USA. [Internet]. [Cited 2015 July 14]; Available from: http://www.ctic.purdue.edu/resourcedisplay/322/.

Dibert, E. J., M. Bigercyo, and R. A. Olson. 1979. Utilization of N15 fertilizer by nodulating and nonnodulating soybean isolines. *Agronomy Journal*, 71(5): 715-723.

Farooq, M., K. C. Flower, K. Jabran, A. Wahid, and K. H. M. Siddique. 2011. Crop yield and weed management in rainfed conservation agriculture. *Soil & Tillage Research*, 117(6): 172-183.

Fan, M., J. Shen, L. Yuan, R. Jiang, X. Chen, and W. J. Davies. 2012. Improving crop productivity and resource efficiency to ensure food security and environmental quality in China. *Journal of Experimental Botany*, 63(1): 13-24.

Grabau, L. J., and T.W. Pfeiffer. 1990. Management effect on harvest losses and yield of double-crop soybean. *Agronomy Journal*. 82(4): 715-718.

Haggblade, S., and G. Tembo. 2003. Early evidence on conservation farming. International Workshop on Reconciling Rural Poverty and Resource Conservation: Identifying Relationships and Remedies. Cornell University, Ithaca, NY.

Jasa, P. J., R. D. Grisso, C. C. Hunter, and E. C. Dickey. 1999. Conservation tillage influences on grain yield in a dryland soybean/grain sorghum rotation. ASAE/CSAE-SCGR Annual International Meeting Sponsored by

ASAE/CSAE-SCGR, Paper No. 99-1085. Toronto, Ontario Canada.

Liu, X., J. Jin, S. J. Herbertb, Q. Zhang, and G. Wang. 2005. Yield components, dry matter, LAI and LAD of soybeans in Northeast China. *Field Crop Research*, 93(1): 85-93.

Liu, B., X. B. Liu, C. Wang, Y. S. Li, J. Jin, and S. J. Herbert. 2010. Soybean yield and yield component distribution across the main axis in response to light enrichment and shading under different densities. *Plant Soil and Environment*, 56(8): 384-392.

Liu, Y., Y. Sui, D. Gu, X. Wen, Y. Chen, C. Li., and Y. Liao. 2013. Effects of conservation tillage on grain filling and hormonal changes in wheat under simulated rainfall conditions. *Field Crop Research*, 144(144): 43-51.

Mashingaidze, N., C. Madakadze, S. Twomlowb, J. Nyamangara, and L. Hove. 2012. Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. *Soil & Tillage Research*, 124(4): 102-110.

Mazvimavi, K., and S. Twomlow. 2009. Socioeconomic and institutional factors influencing the adoption of conservation farming by vulnerable households in Zimbabwe. *Agricultural Systems*, 101(1-2): 20-29.

Opara, O.A. 2015. FAO Book, Soil tillage in Africa, Needs and Challenges: Chapter 8, Conservation tillage for increased crop production.

Romero, V. M., L. L. Bellido, and R. J. L. Bellido. 2011. Faba bean root growth in a Vertisol: Tillage effects. *Field Crop Research*, 120(3): 338-344.

Serraj, R., and K. H. M. Siddique. 2012. Conservation agriculture in dry areas. *Field Crop Research*, 132: 1-6.

Smika, D. E., and P. W. Unger. 1986. Effect of surface residues on soil water storage. *Advances in Soil Science*, 5: 111-138.

Stipecevic, B., D. Jug, I. Jug, I. Zugec, M. Stosic, and D. Kolar. 2009. Influence of different soil tillage systems on soybean yield and yield components. *Tarim Makilanari Bilimi Dergisi (Journal of Agricultural Machinery Science)*,5(3): 263-267.

Su, Z.Y., J. S. Zhang, W. L. Wu, D. X. Cai, J. J. Lv, G. H. Jiang, J. Huang, J. Gao, R. Hartmann, and D. Gabriels. 2007. Effect of conservation tillage practices on winter wheat water use efficiency and crop yield on the Loess Planteau, China. *Agricultural Water Management*, 87(3): 307-314.

Thiagalingam, K., N. Gould, and P. Watson. 1991. Effect of tillage on rainfed maize and soybean yield and the nitrogen fertilizer requirements for maize. *Soil & Tillage Research*, 19(1): 47-54.

Unger, P. W., G. W. Langdale, and R. I. Papendick. 1988. Role of crop residues - improving water conservation and use. In: Cropping Strategies for Efficient Use of Water and Nitrogen. W. L. Hargrove (ed.) pp. 69-100. American Society of Agronomy Special Publication, No.51

Wagger, M. G., and H. P. Denton. 1989a. Tillage effects on grain yield in wheat-soybean- corn crops rotation. *Agronomy Journal*, 79(6): 952-956.

Wagger, M., and H. Denton. 1989b. Tillage effects on grain yields in wheat, double crop soybean and corn rotation. *Agronomy Journal*, 81(3): 493-498.

Wang, X. B., D. X. Cai, W. B. Hoogmoed, O. Oenema, and U. D. Perdok. 2007. Developments in conservation tillage in rainfed regions of North China. *Soil & Tillage Research*, 93(1): 239-250.

Wilhelm, W., and C. Wortmann. 2004. Tillage and rotation interactions for corn and soybean grain yields as affected by precipitation and air temperature. *Agronomy Journal*, 96(2): 425-432.

Xie, R. Z., S. K. Li, Y. Z. Jin, X. J. Li, Q. X. Tang, K. R. Wang, and S. J. Gao. 2008. The trends of crop yield responses to conservation tillage in China. *Sci. Agric. Sin.*, 41(2): 397-404.