Conservation tillage assessment for wheat cropping in the central Iran: energetic, economics and environmental aspects (Case Study: Isfahan Province)

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Abstract: Conservation tillage due to some properties such as reduction in time and energy required for seedbed preparation is going to be an unavoidable choice in the region with arid and semiarid climate. This short term research was conducted at Murchehkhort farms, central region of Iran to assess different tillage systems in terms of energetic, economics and environmental aspects. The study was planned as a completely randomized block design with three tillage treatments which replicated three times. The tillage treatments consisted of no-tillage (NT), direct drilling; reduced tillage (RT), chisel plow and roller packing as a combined machine followed by a light disking and drilling; and conventional tillage (CT), moldboard plow followed by two heavy harrow diskings and drilling. NT, compared to CT and RT used lower input energy and saved 0.26 and 1.23 GJ ha^{-1}, respectively. Contribution of tillage machinery in total energy consumption for NT, RT and CT treatments were 2.52, 3.18 and 4.32 GJ ha^{-1} or 8.3%, 10% and 14%, respectively. Energy efficiency was significantly higher for no-tillage but no significant difference was observed between CT and RT. NT yielded maximum wheat grain per unit of input energy by having energy productivity equal to 0.136 kg MJ^{-1}. Mean gross margin variation for no-tillage and reduced tillage treatments was equal to 113.28 and -0.56 USD ha^{-1}, respectively and the profit of NT was more than CT. No significant difference was observed between different treatments in terms of pesticide use but herbicide used per unit of crop yield was significantly different and a decreasing trend was observed for NT, RT and CT treatments, respectively. Finally, Short term investigation showed that no-tillage was the most efficient method in the region where has been studied, but with regards to some concerns including adverse environmental effects of higher quota of chemical inputs in conservation methods, high consumption of irrigation water and also the short duration of study, more research with longer period seems to be useful to obtain more reliable results.

Keywords: no-tillage, reduced tillage, energy efficiency, gross margin, herbicide

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1 Introduction

The economy has played a decisive role in acceptance rate of tillage system by growers. Profitability and riskiness of each tillage system are related to the input price as well as the efficiency of technology used in production process. The past decade has witnessed rapid changes in price of inputs especially fuel and chemical materials. From January 2001 to January 2011, the nominal price per liter for diesel, adjusted for farmers' excise tax exemptions, rose from US$ 0.018 to 0.136 as a result of the inflation and modification of subsides in Iran. Economy and environment issues are mutually dependent. Based on many reports, conservation systems have a lower fuel consumption (Bertocco et al., 2008; Khakbazan et al., 2012). The use of fossil fuels has a direct impact on emissions of greenhouse gases. Also, with respect to increasing trend to chemical control of weed in conservation systems achievement to a good

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compromise is necessary.

Agricultural activities serve as a system to produce bioenergy in the various forms such as human and livestock food and the amount of energy involved in crop production has increased significantly in the last century. Generally, energy inputs have classified in two main groups: direct and indirect using energy. Direct energy is directly consumed in the farm and comprises fuel, labor and electricity but indirect one refers to the energy embodied in all the input factors that are to be consumed in a production system and it includes machinery, fuel, fertilizers, herbicides, pesticides and material for plant propagation (Hernanz et al., 2014). It is important that the energy efficiency in crop production has been kept as high as possible and also with respect to aforementioned rose in input price, optimization of input usage seems to be unavoidable. Therefore, an important goal of researchers during the last decades has been to investigate the energy budget of various crops in order to present strategies to optimize and control all different forms of energy. One of these latter strategies was to reduce energy use by avoiding unnecessary tillage, labor and time which was required in field operations, and to improve soil water content and soil conservation. Therefore, promoting the shift from conventional tillage to conservation tillage system such as reduced tillage and no-tillage (NT) was an unavoidable choice. These two last tillage systems were considered as an immediate response to ensure a reduction in energy consumption and production costs (Sprague, 1986).

Despite the aforementioned advantageous for conservation tillage systems, some concerns such as more weed infection and less crop yield (Zentner et al., 2004), soil compaction and development of hardpan after repeated application of no-tillage (Akinyemi and Adedeji, 2004; López-Garrido et al., 2014) and poor establishment due to the lack of a seedbed preparation (Arvidsson et al., 2014), may be existed.

In Iran most researches related to conservation tillage have been separately considered in special aspects such as soil properties and crop yield components (Hemmat and Taki, 2001; Javadi et al., 2009; Abdollahi et al., 2015) and energy indices (Tabatabaeefar et al., 2009), but economical and environmental aspects are less accounted. The objective of the present study was short term investigation of aforementioned conservation tillage systems in terms of energetic, economical and environmental aspects.

2 Material and methods

2.1 Site description

The research was conducted in Murchehkhort farms, central region of Iran in 2011- 2012. The site is located at Isfahan province, latitude 33°5'N, longitude 51°29'E, and at an altitude of 1669 m. Approximately, 96% of annual precipitation occurs through November to May with mean annual precipitation of 124.9 mm. The mean monthly maximum and minimum temperature are 28°C (July) and 1°C (January), respectively with annual mean of 11.2°C. According to the USDA soil classification, soil texture was belong to Sandy clay loam class (59.9% sand, 16.7% silt and 29% clay) and pH, EC, organic carbon and total nitrogen were 7.8, 0.28 dS m^{-1}, 0.28% and 0.03%, respectively. Previous crop was silage corn (Double-cross 790) with 35 ton ha^{-1} mean yield that was cultivated in rotation with wheat for three years under no-tillage condition.

2.2 Experimental detail

The experiment was based a completely randomized block design with three tillage treatments which has been replicated three times. Figure 1 shows layout of the experimental design.

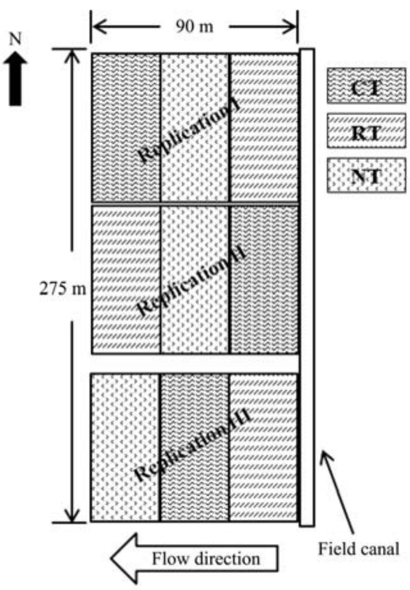


Figure 1 Layout of the experimental design

At early November 2011, treatments were applied that consisted of no-tillage (NT): direct drilling with Sfoggia planter, reduced tillage (RT): chisel plow and roller packing as a combined machine followed by a light disking and drilling with TAKA grain planter; and Conventional tillage (CT): moldboard plow followed by two heavy harrow diskings to ensure the full incorporation of the crop residue and drilling. Characteristics of implement that has been used in experiment are shown in Table 1.

Table 1 Characteristics of implement used in the experiment

Implement	Properties	Connection type	Working width, cm	Working depth, cm
Combine (John Deere 1055)	-	Self-propelled	365	-
Tractor (Massey Ferguson 285)	2540 kg- 75 hp- 4WD	-	-	-
Tractor (New Holland 6090)	5850 kg- 165 hp- 4WD	-	-	-
Direct drill planter (Sfoggia)	13 rows - double disc furrow opener	Pulled	250	9- 12
Chisel packer (Agromaster)	9 tines- Toothed roller	Mounted	225	15
Grain driller (TAKA)	21 rows- disk furrow opener	Mounted	250	3- 6
Moldboard plow	3 shares- reversible	Mounted	90	30
Heavy duty offset disk	24 disks (51 cm diameter)	Pulled	250	10- 15
Light duty disk	36 disks (35 cm diameter)	Mounted	225	8- 10
Furrower	-	Mounted	120	-
Ridger	-	Mounted	120	-
Sprayer	-	Mounted	800	-

Wheat (cv. Mahdavi) was drilled at a rate of 450 seeds m^{-2}. Crop harvesting was done in middle July 2012. Statistical analysis was done by SPSS package (Version 16.0, SPSS, Inc., Chicago, IL); the least significant difference test was used to mean comparisons at P<0.01 level of significance.

2.3 Energy indices

The energetic indices were considered including input energy (E_i), output energy (E_o), energy efficiency (*EE*), net energy gain (*NEG*) and energy productivity (*EP*). *EE* has been defined as the ratio of output to input energy. Difference among the output and input energy has been presented as the *NEG*. *EP* is produced crop per unit of consumed energy.

Machinery specification for different field operation was adopted from ASABE standard D497.4 FEB03 (ASABE, 2003a) which is shown in Table 2. To determine the fuel consumption, the fuel tank of the tractor was filled full before the operation and after the operation; the fuel consumption was determined by measuring the amount of the fuel added to the tank. Soil moisture content of 15% (mean of field capacity and wilting point) was considered as an index to determine irrigation time. Irrigation water was measured using a Washington State College (WSC) flume (Burton, 2009). Transportation distance was approximately 70 km. Energy equivalent for various inputs of the production system are presented in Table 3. Energy equivalent of wheat grain and chaff was assumed to be equal to 14.48 and 9.25 MJ kg^{-1}, respectively (Tabatabaeefar et al., 2009). Input and output energy was calculated with considering energy equivalent for each item.

Table 2 Machinery specification for different field operation

Machinery	Mass, kg			Overall life, h			Speed, km h^{-1}	Field eff.
	Tract.	Imp.	Self P.	Tract.	Imp.	Self P.		
Tractor + mouldboard plough	2540	800		12000	2000		4.5	0.85
Tractor + heavy disc harrow	5850	2500		12000	2000		7	0.85
Tractor + grain driller	2540	550		12000	1500		6	0.68
Tractor + chisel packer	2540	460		12000	2000		4	0.78
Tractor + light disk	2540	1050		12000	2000		7	0.85
Tractor + direct drill	5850	3530		12000	1500		6	0.66
Furrower	2540	120		12000	2000		4.5	0.86
Ridger	2540	190		12000	2000		4.5	8.2
Tractor + sprayer	2540	146		12000	1500		5.5	0.63
Combine harvester			16500			3000	3	0.58

Note: eff.: Efficiency; Tract.: Tractor; Imp.: Implement; P.: Propelled.

Table 3 Energy equivalent for input and output of agricultural production system

Energy inputs	Unit	Energy equivalent	Reference
Nitrogen	MJ kg^{-1}	47.1	(Karkacier and Gokalp Goktolga, 2005)
P_2O_5	MJ kg^{-1}	15.8	(Karkacier and Gokalp Goktolga, 2005)
Potassium	MJ kg^{-1}	11.15	(Mohammadi et al., 2008)
Herbicide	MJ kg^{-1}	238	(Karkacier and Gokalp Goktolga, 2005)
Pesticide	MJ kg^{-1}	101.2	(Karkacier and Gokalp Goktolga, 2005)
Seed	MJ kg^{-1}	17.6	(Ghiyasi et al., 2008)
Human labor	MJ h^{-1}	1.96	(Tabatabaeefar et al., 2009)
Tractor	MJ kg^{-1}	93.61	(Kaltschmitt et al., 1997)
Combine	MJ kg^{-1}	87.63	(Karkacier and Gokalp Goktolga, 2005)
Machinery	MJ kg^{-1}	62.7	(Chaudhary et al., 2006)
Diesel fuel	MJ l^{-1}	56.31	(Mohammadi et al., 2008)
Electricity	MJ kW h^{-1}	11.93	(Pathak and Bining, 1985)
Irrigation water	MJ m^{-3}	1.02	(Mohammadi et al., 2008)
Transportation	MJ km^{-1} t^{-1}	4.5	(Tabatabaeefar et al., 2009)

2.4 Economical evaluation

Gross margin variation (*GMV*) method was used to determine the most profitable tillage treatment. Gross margin has been defined as revenue minus the variable cost. *GMV* was calculated by Equation (1) and (2).

$$GM_i = Tr_i - TVC_i \tag{1}$$

$$GMV_i = GM_i - GM_0 \tag{2}$$

where, *GM*, *Tr* and *TVC* are gross margin, total revenue and total variable cost, respectively. ΔGM is difference between the corresponded *GM* to each treatment and control treatment (GM_0, CT considered as the control treatment). The *i* index shows treatment number (0: CT; 1: RT; and 2: NT).

The biomass yield including grain and chaff was used to determine revenue. Variable costs are those costs that vary directly in proportion to the extent of operation area including costs related to fuel, oil, repair and maintenance, irrigation, chemicals, labor and seed. Fuel cost was determined based on measured fuel consumption for each treatment and oil cost was calculated as 15% of total fuel cost. According to the ASABE standard EP496.2 FEB03 repair and maintenance cost was calculated by Equation (3).

$$C_{rm} = (RF1)P\left[\frac{h}{1000}\right]^{(PF2)} \tag{3}$$

C_{rm} is accumulated repair and maintenance cost (USD), *RF*1 and *RF*2 are repair and maintenance factor, *P* is purchase price of machine (USD) and *h* is accumulated use of machine. To reflect inflation effects, purchase price was modified by multiplied by $(1+i)^n$, where *i* is the average inflation rate and n is the age of the machine (ASABE, 2003b). Other variable costs were calculated with respect to related price and usage.

2.5 Environmental survey

Based on the primary soil test, the amount of fertilizer was determined. Half of nitrogen and the whole of phosphorus and phosphate fertilizers were applied as ammonium nitrate, triple super-phosphate and Potassium nitrate (130, 200 and 50 kg ha^{-1}, respectively) with seed (NT) or during the secondary tillage (RT and CT). The other half of nitrogen was applied in the tillering stage of wheat growth. Also based on secondary soil experiment, 15 and 20 kg ha^{-1} nitrogen as urea was allocated to NT and RT, respectively. *2-4-D* at a rate of 2 kg ha^{-1} was applied in middle April to control broadleaf in all treatment. Additionally, to control narrow leaf in NT, puma super (water emulsion containing 69 g L^{-1} fenoxaprop-p-ethyl) at a rate of 2 kg ha^{-1} was applied. Utilization of chemical inputs per crop unit was compared for treatments as an environmental Index.

3 Results and discussion

3.1 Energy prospect

Despite the statistically significant difference between input energy for treatments (p<0.01), output energy was almost similar. NT Compared to CT and RT used lower input energy and saved 0.26 and 1.23 GJ ha^{-1}, respectively. Contribution of tillage machinery in total energy consumption for NT, RT and CT treatments was 2.52, 3.18 and 4.32 GJ ha^{-1} or 8.3%, 10% and 14%, respectively. Fuel consumption in tillage operation for CT, RT and NT was 38.48, 21.07 and 3.74 L ha^{-1}, respectively. Due to direct drilling of seed, lack of primary tillage and limited secondary tillage, NT led to least fuel consumption. Fuel consumption related to other machinery operation was comparatively similar for treatments. Considering the tillage and planting operation, RT and NT in comparison to CT led to 40% and 74% reduction in fuel consumption. Sanchez-Giron et al. (2007) observed 23% and 62% lower fuel consumption for RT and NT than CT, respectively. This reduction resulted in 27% and 49% saving in total fuel consumption for RT and NT than CT, respectively. Fuel consumption for different operation is shown in Figure 2.

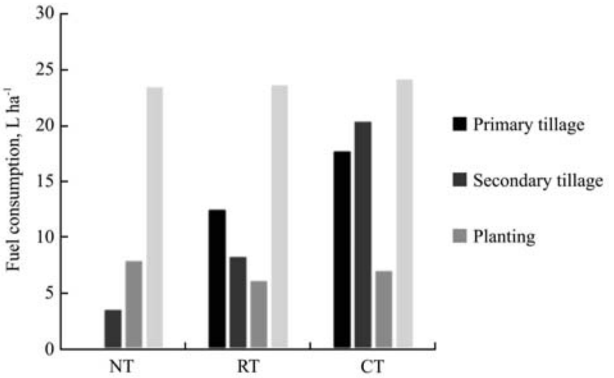


Figure 2 Fuel consumption in different parts of cultivation for experiment treatments

Figure 3 shows the total energy consumption and the percentage distribution associated with the inputs. In all methods, the most consuming input was irrigation with 12.85, 13.99 and 14.17 GJ for CT, RT and NT, respectively. Irrigation, fertilizer and fuel respectively with overall average of 44.0%, 32.2% and 7.9 % had maximum, and labor with 1.6% had minimum values of energy consumption. Hernánz et al. (1995) reported similar results in a long-term evaluation of conservation tillage systems for cereal and legume production. The energy consumed by the seeds had an average percentage of 7.8%. This is a relatively high value since commercial seed was used. If part of the crop had been used for seed production the energy impact of this input would have been lower.

Mean of energy indices for different treatments is presented in Table 4. Due to lower *Ei* for NT and also no significant difference in terms of *Eo* between treatments, energy efficiency (*EE*) was significantly higher for no-tillage but no significant difference was observed for CT and RT (p>0.05). Therefore, NT obviously had higher potential to utilization of inputs in order to produce wheat crop. Highest net energy gain (*NEG*) was belonged to NT although difference among the NT and CT was statistically no significant. It means that NT resulted in more output energy, wheat yield, relative to its input energy compared to other treatments. NT yielded maximum wheat grain per unit of input energy by having energy productivity (*EP*) equal to 0.136 kg MJ^{-1}. Meanwhile, CT and RT had comparatively similar *EP*. Conversely, it inferred that NT consumed minimum energy to producing unit of crop. Tabatabaeefar et al. (2009) reported significant difference of no-tillage and conventional tillage in terms of *EP* in wheat production, while *EP* values for moldboard plow, chisel plow and no-tillage treatments were equal to 0.085, 0.098 and 0.114 kg MJ^{-1}, respectively. Also in comparison of conservation and conventional systems Kosutic et al. (2005) observed similar results for consumed energy.

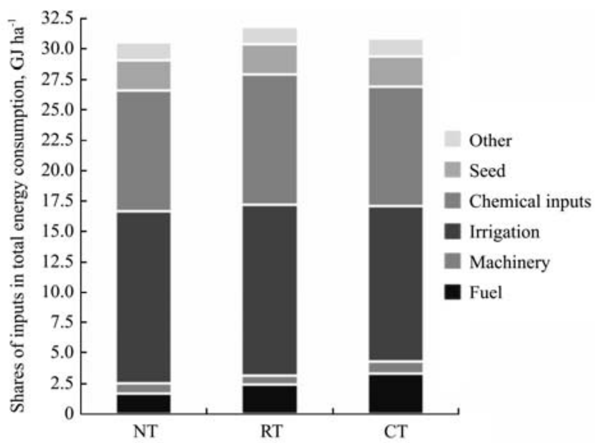


Figure 3 Share of various inputs in total energy consumption for different treatments

Table 4 Mean of energy indices for different treatments

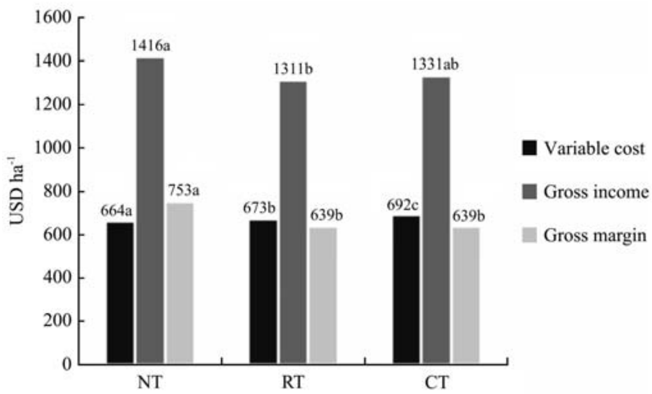
Treatment	E_i, MJ	E_o, MJ	EE	NEG, MJ	EP, kg MJ^{-1}
Conventional tillage	30884 a	97943	1.70 b	67059 ab	0.126 b
Reduced tillage	31775 b	96552	1.63 b	64777 b	0.121 b
No-tillage	30549 a	10385	1.83 a	73304 a	0.136 a

Note: Means followed by various letters are significantly different (Duncan 5%).

3.2 Economical evaluation

Mean gross margin variation (*GMV*) for no-tillage and reduced tillage treatments was equal to 113.28 and –0.56 USD ha^{-1}, respectively. Considering the sign of

GMV for trial treatments, only NT was more profitable than CT. RT has the least value of gross margin. In terms of variable cost, treatments had significant difference (p < 0.05) and CT had maximum value of cost. CT with respect to other treatments had similar value of gross income but difference of RT and NT was statistically significant. Minimum and maximum value of gross income was obtained for RT and NT, respectively. Values of gross margin belonged to CT and RT were similar but NT had significantly different value (Figure 4). CT with approximately 3% higher cost than NT and RT had highest value of total cost. Net income for NT, RT and CT respectively was equal to 747, 638 and 639 USD ha^{-1}. Similar results are reported by many researchers in semiarid regions (Hernánz et al., 1995; Sanchez-Giron et al., 2007; Khakbazan et al., 2012).



Note: Means followed by similar letters are not significantly different (Duncan 5%).

Figure 4 Variable cost, gross income and gross margin of various treatments

In all treatments, highest value of cost was attributed to machinery cost with averagely 23.9% of total production cost. In spite of lower machinery operation for NT, due to high price of direct drill planter and related tractor, corresponded cost was higher than other treatments. In conservation treatments, irrespective of the machinery cost, irrigation had maximum amount of production cost (Figure 5). Maximum cost of chemical inputs was belonged to NT treatment with 110.2 USD ha^{-1} and in comparison to NT, 7.4% and 11.9% lower cost was observed for RT and CT, respectively. Although pesticide and herbicide costs belonged to NT was 48.9% higher than other treatments but minimum consumed cost in all treatment was related to these.

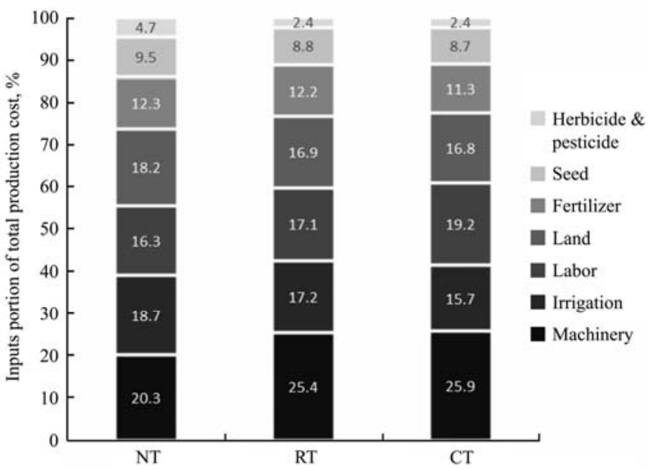


Figure 5 Share of various inputs in total production cost of different treatments

3.3 Environmental aspect

Tillage methods only in terms of urea consumption had significant difference and for other fertilizer were statistically similar (p>0.05). Despite the higher consumption of nitrogen for NT when it compared to CT treatment, due to higher crop yield for NT, no significant difference was observed between the NT and CT regarding the fertilizer used per unit of crop yield. RT treatment had highest value of proportional urea usage (Table 5). No significant difference was observed for different treatments in terms of pesticide use but herbicide used per unit of crop yield was significantly different and a decreasing trend was observed for NT, RT and CT treatments, respectively. It has inferred that CT acts as a mechanical method to fight with weeds and finally leads to decrease in herbicide consumption during the crop growth.

Table 5 Mean indexed value of used chemical inputs per unit of crop yield related to conventional tillage as a reference

Treatment	Urea	Super phosphate triple	Potassium nitrate	Pesticide	Herbicide
Conventional tillage	-	-	-	-	-
Reduced tillage	$0.9\times10^{-2*}$	0.1×10^{-2}	0.02×10^{-2}	0.1×10^{-2}	0.1×10^{-2}
No-tillage	-0.4×10^{-2}	-0.3×10^{-2}	-0.08×10^{-2}	-0.1×10^{-2}	$4.5\times10^{-2*}$

Note: Mean indexed value with significant difference with reference (Duncan 5%).

4 Conclusion

No-tillage treatment compared to other treatments has led to significantly lower fuel consumption. According to the limited resources and increasing price of petroleum, conservation system will become the first priority of farmers in the future. Highest value of crop yield per unit of consumed energy and also maximum energy efficiency has belonged to no-tillage. Therefore with considering the energy aspect, no-tillage relative to conventional and reduced tillage obviously has a notable advantage. No-tillage compared to other treatments has better economic situation and led to more profit. Also based on proved knowledge, conservation systems have other benefits such as better moisture content of soil and improving microorganism activity, decreasing soil erosion and reducing of deep soil compaction. On the other hand, maximum amount of fertilizer, herbicide and pesticide were used in conservation treatments and to protection soil, water and atmosphere, and environmental consideration should be taken into account. Therefore, Short term result of this research showed that in general no-tillage has better performance than other methods but some modification are needed especially in irrigation technique, to enhance the efficiency of irrigation, and also extensive study on probability of water and soil pollution due to more usage of chemical inputs seems to be useful. However, to obtain the more trustworthy outcome and to predict long term effects of conservation tillage practice, long term research is necessary.

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