Conservation tillage assessment for wheat cropping in the central Iran: soil properties, irrigation water use efficiency and crop yield aspects (case study: Isfahan Province)

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Abstract: Isfahan province in the center of Iran is mostly arid and semi-arid that causes some limitation in grain production. Recently, a contrast between conventional tillage and contemporary conservation tillage systems such as no-tillage and reduced tillage exists. The objectives of the study were to evaluate the effect of different tillage methods on soil properties, irrigation water use efficiency and crop yield of irrigated wheat followed by corn. Field experiment was conducted as a randomized complete block design with three treatments and three replications. Treatments consisted of no-tillage (NT), reduced tillage (RT) and conventional tillage (CT). Results showed significant effects of tillage method on seed germination and plant density, but no difference was observed for crop yield. In terms of moisture content and soil electrical conductivity tillage methods had no significant difference. No-tillage has the lowest residue turnover and also carbon to nitrogen ratio (C:N). Minimum and maximum irrigation water use efficiency (IWUE) respectively was found for reduced and conventional tillage, although conventional tillage and no-tillage had no significant difference. Generally, performance of conservation methods was beyond the common opinion and these methods consequently can be a suitable alternative for conventional method, of course by consideration to some modification.

Keywords: no-tillage, reduced tillage, crop yield, IWUE, C:N

Citation: Taki, O., S. Aliasgarian, and A. Javadi. 2019. Conservation tillage assessment for wheat cropping in the central Iran: soil properties, irrigation water use efficiency and crop yield aspects (case study: Isfahan Province). Agricultural Engineering International: CIGR Journal, 21(1): 51–57.

1 Introduction

Isfahan province in the center of Iran is mostly arid and semi-arid (based on Koppen Climate classification system) that cause to some limitation in grain production. Winter wheat is an important, well-adapted grain crop in this area and usually has grown in rotation with corn. Wheat seeding begins in November's beginning and continues for about a month. Depending on field condition, previous corn residue might be treated mechanically or might be removed from the field to improve sowing quality. Recently, a contrast between conventional tillage (CT) and contemporary conservation tillage systems such as no-tillage (NT) and reduced tillage (RT) exists and conservation systems are taken into consideration in terms of economic, energy and environmental aspects.

In such climate, due to little residue stubble mulch to protect the soils, mechanical loosening of soil is often beneficial and will be followed by better porosity and infiltration; and decreased runoff and erosion. However, these beneficial effects are short-lived and disappear by the end of the first cropping cycle (FAO, 1995). CT

Received date: 2016-09-08 **Accepted date:** 2019-01-18

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affects the chemical properties of the soil by inversion the soil layers as well as by incorporation of the crop residues into deeper layers of the soil profile. CT promotes a loss of soil organic carbon, and an increase in CO_2 emission to the atmosphere (Al-Kaisi and Yin, 2005).

Conservation tillage is defined as any tillage and planting system that at least leaves 30% of crop residue on the soil surface after planting (Uri et al., 1998). The effectiveness of conservation tillage depends on the soil type, crop requirements, rainfall probability, and soil water storage capacity (Díaz-Zorita et al., 2004; Hemmat and Eskandari, 2004; Hou et al., 2012). Although positive results of conservation tillage on water use efficiency and grain yield were reported in some research (Hemmat and Eskandari, 2004; Wang et al., 2007; Qing et al., 2009; Huang et al., 2012) but negative (Taa et al., 2004; Sharma et al., 2011) and no significant result (Malhi et al., 2006; Berhe et al., 2013) is also reported. Morell et al. (2011) reported that conservation tillage result is related to the precipitation quantity and despite its better performance in dry year; no significant effect is observed in wet year. Enhancement of infiltration and reduction in evaporation (Díaz-Zorita et al., 2004); runoff and erosion control, decreasing in organic matter oxidation, improvement of environmental quality and soil productivity (Sullivan et al., 2008); and reducing cost and increasing benefit (Smart and Bradford, 1996) are reported as benefits of conservation tillage. Compaction and development of hardpan (Akinyemi and Adedeji, 2004) and poor establishment due to the lack of a seedbed (Arvidsson et al., 2014) are reported as adverse effects of conservation tillage in long period.

Therefore, selecting between the different tillage methods must be done based on comprehensive studies with respect to technical, economic and environmental aspects. The objective of the study was to evaluate the considered tillage methods in terms of aforementioned aspects for irrigated wheat followed by corn. Effects of the tillage method on soil properties, irrigation water use efficiency and crop yield are presented.

2 Material and methods

2.1 Description of the study area

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 (Figure 1). 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. Soils of the area are predominantly Sandy clay loam (Table 1). The mean monthly daily relative humidity ranges from 14% (September) to 57% (January) with monthly mean of 30%. The monthly bright sunshine ranges from 206 h (December) to 372.7 h (June) with monthly mean of 282.3 h. Previous crop was silage corn (Double-cross 790) with 35 ton ha^{-1} mean yield.

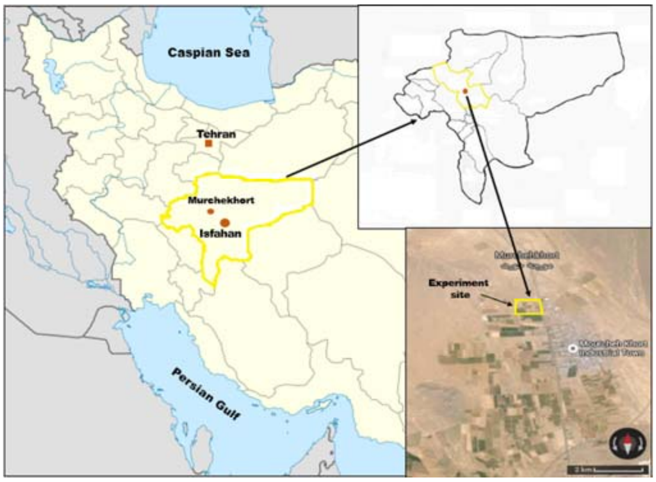

Figure 1 Map of the experiment location (Murchehkhort, Isfahan, Iran- November 2011)

Table 1 Electrical conductivity (ds $m^{-1}\times 10^3$), acidity (pH), total nitrogen (%), organic carbon (%), soil component (%) and texture class of soil profile in various depth (cm)Measured in Murchehkhort, Iran- November 2011 (*n*= 21)

Depth	EC	Acidity	TN	OC	Sand	Silt	Clay	Texture class
0-10	3.2	7.8	0.03	0.22	55	16	29	Sandy clay loam
10-20	2.8	7.8	0.03	0.3	59	14	27	Sandy clay loam
20-30	2.4	7.7	0.04	0.31	49	20	31	Sandy clay loam

2.2 Experimental design

The experimental design was a randomized complete block design with three treatments and three replications. Treatments consisted of NT: direct drilling with Sffogia planter, RT: chiseling to the depth of 15 cm and roller packing as a combined machine following with a light disking to the depth of 8-10 and drilling with TAKA grain planter; and CT: moldboard plowing to the depth of 30 cm accompanied by two heavy disks harrowing to the depth of 10-15 cm to ensure the full incorporation of the crop residue and drilling. Figure 2 shows layout of the experimental design. To avoiding compaction of the tilled plots by tractor maneuvering, 5 m spacing between replication II and III was maintained. Statistical analysis was done by SPSS package (version 16.0, SPSS, Inc., Chicago, IL); The Duncan multiple range test was applied to compare treatments at P<0.01 level of significance.

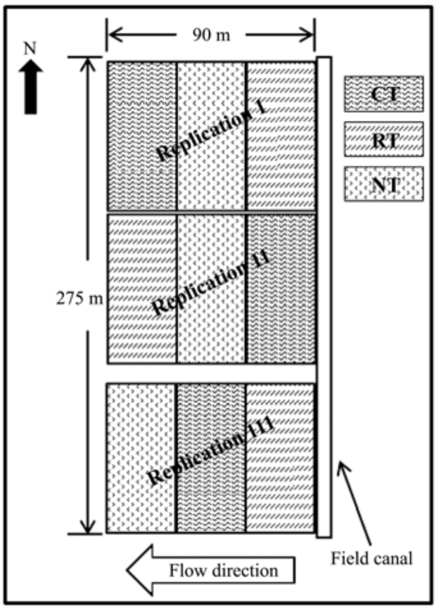

Figure 2 Layout of the experimental design (CT: conventional tillage, RT: reduced tillage, NT: no-tillage)

2.3 Implementation of experiment

At early November 2011 irrigation was done and treatments were applied after reaching the soil moisture to desirable level (16%-18% based on dry weight). Approximately 3000 kg ha^{-1} corn residue was estimated on the field surface before operation. Wheat (cv. Mahdavi) was drilled 6 cm deep at a rate of 450 seeds m^{-2}. Required amount of fertilizer was determined according to the primary soil test including 260 kg ha^{-1} urea, 200 kg ha^{-1} triple super-phosphate and 50 kg ha^{-1} potassium nitrate. Half of nitrogen and the total of phosphorus and potassium fertilizers were applied as ammonium nitrate, triple super-phosphate and potassium nitrate during the planting (NT) or the secondary tillage (RT and CT), respectively. Upon completion of planting and preparation of plots first flooding irrigation and 12 days later next irrigation was done. Half of nitrogen was applied in the tillering stage of wheat growth (March 2012). Also based on soil experiment, 15 and 20 kg ha^{-1} nitrogen as urea was allocated to NT and RT, respectively. 2,4-Dichlorophenoxyacetic acid (2-4-D) at a rate of 2 kg ha^{-1} was applied in middle April to control broadleaf in all treatments. Additionally, to control narrow leaf in NT, puma super (fenoxaprop-p-ethyl) at a rate of 2 kg ha^{-1} was applied. Crop harvesting was done in middle July 2012.

2.4 Water, soil and plant measurement

2.4.1 Soil properties

In order to measure moisture content, soil sampling was conducted before tillage and also several stages during the growth season at 0-10, 10-20 and 20-30 cm soil depth. For each individual plot, Five samples were collected a day before each irrigation (nine irrigation stages) and were dried in an electrical oven at 105°C for a 16 h (Gardner et al., 2001). Soil moisture content (MC) was computed by the formula:

$$MC = \frac{M_w - M_d}{M_w} \times 100$$

where, MC, M_w and M_d is the moisture content (%), the wet soil mass (g) and the dry soil mass (g), respectively.

Carbon to nitrogen ratio (C:N) is an important index to evaluation of soil fertility and also estimation of potential decomposition rate. Sampling depth of 0-30 cm as the root penetration range (sampling in 10 cm thick soil layers) was considered to C:N ratio determination. Samples were collected in three phases including before tillage operation (November, 2011), tillering stage of wheat growth (March, 2012) and after crop harvesting (July, 2012). Soil organic carbon (SOC) concentration was determined using a wet combustion method (Nelson and Sommers, 1996) and total nitrogen (TN) by the Kjeldahl digestion method (Gallaher et al., 1976). Finally, conversion of SOC to soil organic matter (SOM) was done by multiplying SOC by 1.724 (Staney and Yerima, 1992). Electrical conductivity (EC) usually has used as an indicator of the total dissolved salts concentration in the soil and was determined by the water extract method (Dahnke and Whitney, 1988).

Residue inversion (RI) defines as the amount of residue mixed with soil due to tillage operation. Plant residue on the soil surface was collected before and after the operation and RI was obtained by the formula:

$$RI = \frac{M_a - M_b}{M_a} \times 100$$

where, RI, M_a and M_b is the residue inversion (%), the mass of dried plant residue before tillage (kg), and the mass of dried plant residue after tillage (kg), respectively. For each individual plot ten samples were randomly gathered using the square frame with 1×1 m dimensions.

2.4.2 Irrigation water use efficiency

Irrigation water was measured using a Washington State College (WSC) flume. Soil moisture content of 15% (mean of field capacity and wilting point) was considered as an index to irrigation requirement. Finally, irrigation water use efficiency (IWUE) was calculated as the amount of crop yield (kg) per unit of consumed water (m^3 ha^{-1}).

2.4.3 Crop yield

Crop yield parameters included seed emergence, plant density and wheat yield (harvested grain and biomass). Seed emergence (E) is defined as the percentage of seeds emerged at the end of the trial period (25 d) and was computed as the number of emerged seed (P) divided by product of the planted seed number (S) to the germination (G) using the formula:

$$E = \frac{P}{S \times G} \times 100$$

where, S was computed as the ratio of the amount of seed planted per unit of area to thousand weight of seed. Plant density (number of plants per m^2) was determined by using a 1×0.5 m sampling frame and counting the number of plant before the Tillering stage. After the eliminating of marginal lands, wheat plants were harvested at ground level from 1 m^2 of each plot to find out grain and biomass yields.

3 Results and discussion

3.1 Crop yield

Despite the significant difference between treatments in terms of the seed emergence and plant density (p< 0.01), no significant difference was observed for grain and biomass yield. NT in comparison to CT has 16.3% lower seed emergence (Table 2) that might be due to inappropriate seedbed in NT condition. Existence of residue on the bed and lack of tillage affect the planter performance in NT treatment. Similar results have been reported by some investigators (Arshad et al., 1994; Malhi et al., 2006).

Table 2 Seed emergence (%), plant density, grain yield (1000 kg ha^{-1} ×) and biomass yield (1000 kg ha^{-1}) of different treatments measured in Murchehkhort, Iran for the period 2011- 2012

Treatment	Seed emergence	Plant density	Grain yield	Biomass yield
NT	51.43±2.01b	228.3±24.3c	4.15±0.39a	9.30±0.67a
RT	55.89±3.60ab	250.3±13.7b	3.83±0.31a	8.65±0.76a
CT	61.47±1.69a	272.0±20.4a	3.88±0.35a	8.78±0.71a

Note: Means followed by similar letters are not significantly different (p<0.01).

Also, some results showed better yield of conservation tillage, NT and RT, (Hernánz et al., 1995; Hemmat and Eskandari, 2004; Su et al., 2007) and vice versa (Sharma et al., 2011). This diversity in result might be originated from difference in some factors such as trial time range, climate and environmental condition and trial Implementation.

3.2 Soil properties

No difference was observed among the tillage methods in terms of MC in whole soil profile (Table 3). The highest value of MC in the surface layer was seen for NT and was lowest for CT as shown in Figure 3. Although in all treatments soil profile showed higher MC with increase in depth but increment in CT plots were higher that it can be related to probably limited soil porosity and infiltration for conservation tillage in arid and semi-arid tropics due to shallow plowing and fewer soil inversion (FAO, 1995). Similar trends have been reported by (Huang et al., 2012). Fengyun et al. (2011) reported lower MC in upper profile than subsoil and higher MC for NT related to CT. Residue on the Soil shielded surface from solar radiation and reduced air movement just above the soil surface (Van Donk and Klocke, 2012). Therefore, residue on the soil surface seems to act as a barrier against the evaporation and water losses. While CT by inversion the soil leads to the decrease of the soil bulk density, increase of the soil porosity(FAO, 1995)and hence improves the soil water holding capacity in lower layers (Figure 3). Plant residue due to having higher absorption capability compared to soil (approximately four times higher than clay soil) contributes to higher soil water storage (Arshad et al., 1999; Romaneckas et al., 2009). Intensity of residue inversion (RI) was significantly influenced by tillage methods (p<0.01) and as predictable, the RT contributes to 62% lower residue inversion compared to the CT

(Table 3). Lack of the large hunk due to using the combine tiller in RT eliminates the need to use heavy duty disk and resulting in maintaining more residue on the surface.

Table 3 Moisture content (%), residue inversion (%), organic matter (%), organic carbon (%), total nitrogen (%), carbon to nitrogen ratio (C:N ratio) and electrical conductivity (ds m^{-1}) of different treatments measured in Murchehkhort, Iran for the period 2011- 2012

Treatment	MC	RI	OM	OC	TN	C:N ratio	EC
NT	15.53 ± 2.02^{a}	9.48 ± 2.21^{a}	0.52 ± 0.02^{b}	0.30 ± 0.01^{b}	0.048 ± 0.00^{b}	6.14 ± 0.61^{a}	2.98 ± 0.41^{a}
RT	15.45 ± 2.26^{a}	34.83 ± 5.03^{b}	0.64 ± 0.02^{a}	0.36 ± 0.01^{a}	0.043 ± 0.04^{b}	8.51 ± 0.85^{b}	3.29 ± 0.46^{a}
CT	15.55 ± 2.11^{a}	91.93 ± 12.87^{c}	0.61 ± 0.08^{a}	0.35 ± 0.01^{a}	0.056 ± 0.01^{a}	6.20 ± 0.49^{a}	3.52 ± 0.50^{a}

Note: Means followed by similar letters are not significantly different (p<0.01).

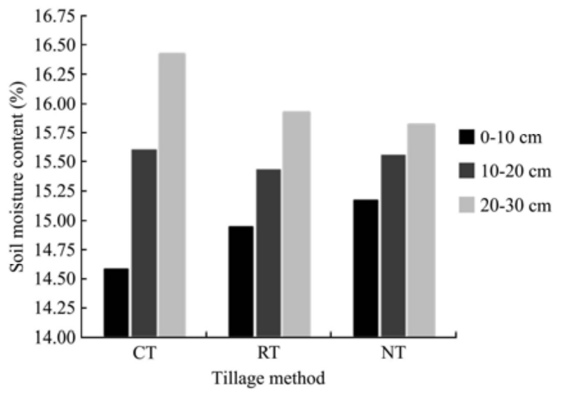

Figure 3 Moisture content (mass %) of soil profile under the different tillage methods measured in Murchehkhort, Iran for the periods 2011- 2012 (CT: conventional tillage, RT: reduced tillage, NT: no-tillage)

Tillage methods have significant effect on OM, OC and TN. Maximum and minimum of OM and also OC was observed in RT and NT respectively, while CT and RT had no significant difference. RT and CT have minimum and maximum of TN, respectively (Table 3). Despite the more consumption of nitrogen fertilizer for conservation treatments (RT and NT), the related total nitrogen was significantly lower than CT treatment. This difference can be result of relatively higher biomass yield for conservation treatments or more losses of nitrogen due to denitrification under conservation treatments. Unlike the NT and RT treatment with highest amount of OC in surface layer (0-10 cm), OC was concentrated in the lowest layer (20-30 cm) for the CT treatment (Table 4).

The C:N ratios of CT and NT methods was similar but RT with ratio of 8.51 had significant higher C:N ratio than to other methods (p<0.01). The ratio of C:N indicates the rate of decomposition of organic matter and this results in the release (mineralization) or immobilization of soil nitrogen and the dividing line between immobilization and release of N is about 20:1 (Swangjang, 2015). Also The change of soil C:N could lead to significant declines in carbon storage (Aitkenhead and McDowell, 2000). Therefore, C:N ratio for all treatment was lower than threshold ratio (20:1) and N mineralization for all treatments are expected.

Table 4 Organic matter (%), organic carbon (%), total nitrogen (%), carbon to nitrogen ratio and electrical conductivity (ds m^{-1}) of treatments in soil profile measured in Murchehkhort, Iran for the period 2011- 2012

Sampling depth	Treatment	OM	OC	TN	C:N ratio	EC
NT	0-10	0.471	0.45	0.050	9	3.30
	10-20	0.588	0.21	0.040	5.25	3.03
	20-30	0.709	0.23	0.055	4.18	2.36
RT	0-10	0.718	0.55	0.040	13.75	3.53
	10-20	0.791	0.33	0.045	7.33	3.27
	20-30	0.951	0.20	0.045	4.44	3.07
CT	0-10	0.605	0.30	0.055	5.46	3.76
	10-20	0.718	0.30	0.055	5.46	3.60
	20-30	0.885	0.46	0.060	7.67	3.21

Although maximum and minimum of EC were respectively belonged to CT and NT but no significant difference was observed between treatments (Table 3). In the surface layer of soil, normally higher EC is expected for NT because fertilizer is only applied to the topsoil at planting while tillage operation in CT incorporates fertilizer into lower soil layer. However, results obtained in this study show higher soil EC for CT (Table 4). These phenomena can be described by some processes including discontinuity in the soil and limited water infiltration into deeper layers due to existence of plough pan under the CT (Huggins and Reganold, 2008) or more effective leaching of salt due to better water infiltration under conservation tillage especially NT (Shipitalo et al., 2000).

3.3 Irrigation water use efficiency

Conservation tillage treatments due to lack of leveling and more existence of residue on the surface have lower rate of water movement on the soil surface and more water consumption in comparison to conventional tillage.

Therefore partly significant effect was observed for tillage methods in terms of water consumption and IWUE (p<0.01). Low rate of water movement in NT and RT increased the non-uniformity of water infiltration through the plot. RT has minimum amount of IWUE and no significant difference was observed between NT and CT in Table 5.

RT in comparison to CT and NT produced 9.4% and 6.4% lower crop per unit of consumed water, respectively (Table 5). Jin et al. (2009) studied the effect of tillage methods and residue cover on IWUE in an annual double cropping system and reported 6.5%-36.1% higher IWUE for conservation methods than CT. Also some other researcher reported higher IWUE for NT than CT and RT (Su et al., 2007; Feng et al., 2011).

Table 5 Water consumption (m^3 ha^{-1}) and irrigation water use efficiency (IWUE) (kg m^{-3}) of different treatments measured in Murchehkhort, Iran for the period 2011- 2012

Treatment	Water consumption	IWUE
NT	11575±291^{b}	0.358±0.03^{a}
RT	11432±138^{b}	0.335±0.03^{b}
CT	10501±171^{a}	0.370±0.04^{a}

Note: Means followed by similar letters are not significantly different (p<0.01).

4 Conclusion

Overall moisture content of whole soil profile was not significantly affected by conservation tillage, but different distribution pattern was observed under the different treatment. Conservation treatments effectively have maintained the moisture in the surface layer compared to other treatment. This additional moisture is a major advantage at the first stage of plant growth especially in dry zones. C:N ratio for conventional and no-tillage methods was approximately similar but reduced tillage was accompanied by significant increase in C:N ratio. Low C:N ratio in CT and NT improves soil microorganism activity and facilitates the mineralization process of organic matter and finally contributes in providing nutrients needed by plant. Also minimizing of residue inversion prevents from losses of the organic matter due to the excessive decomposition. Despite the higher level of IWUE for CT, no significant difference has been observed with NT. Lower level of IWUE in NT due to the higher amount of water consumption could be improved by modifying the irrigation technique and enhancing the efficiency of irrigation. Short term result of this research showed that against the common opinion of farmers, transition from conventional to conservation systems not only has not decreased the yield but also has similar or even better results. However, to obtain the trustworthy outcome and to predict long term effects of conservation tillage practice long term research is necessary.

Acknowledgements

The authors sincerely appreciate the full support of the Agricultural Engineering Research Institute of Iran (AERI) and for cooperating and advising in implementation of project.

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