Journal of the Saudi Society of Agricultural Sciences 19 (2020) 225–232

Contents lists available at ScienceDirect

Journal of the Saudi Society of Agricultural Sciences

journal homepage: www.sciencedirect.com

The impacts of tillage, fertilizer and residue managements on the soil properties and wheat production in a semi-arid region of Iran

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ARTICLE INFO

Article history:
Received 2 July 2018
Revised 28 August 2018
Accepted 29 October 2018
Available online 30 October 2018

Keywords:
Harvest index
Grain per ear
Soil moisture content

ABSTRACT

Conservation tillage systems and residue management as well as nitrogen application are the effective factors on soil properties and crop yield. This study investigated the influence of these factors on the soil properties and winter wheat yield in the warm, semi-arid region of Jahrom, in south of Iran. The variables were residue management, *i.e.* keeping (R1) and burning (R2) previous corn residue beside two tillage systems, *i.e.* chisel plowing (T1) and moldboard plowing (T2); and three levels of nitrogen application *i.e.*, F1 = 0 kg/ha, F2 = 100 kg/ha and F3 = 150 kg/ha. The result revealed that the highest total organic carbon and nitrogen content were obtained when chisel applied in the retained crop residue. But, soil BD was lower with moldboard plowing. It was indicated that chisel plowing can lead to highest yield when combined with retained residue and 150 kg/ha nitrogen.

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1. Introduction

Tillage intensity can affect physical and chemical properties of the soil. Careful soil management is essential to obtain sustainable agricultural production especially in drought-prone areas. More application of machineries in a tillage system will result in more soil compaction which in turn increases soil bulk density and decreases its air and water permeability. Additionally, it has been well documented that the compact soil hampers the downward growth of the crop roots. The soil with good physical quality will provide aeration and water as well as non-impeditive mechanical resistance for root proliferation.

Conservation tillage practices mitigate adverse effects of conventional tillage systems on the soil and crops while they provide yields similar to that of conventional tillage systems (Grabowski et al., 2014). The tillage systems don't enhance crop yield especially when the plant growth is limited by soil moisture (Seddaiu et al., 2016). Conservation tillage practices have helped farmers in the semi-arid Great Plains, USA, to intensify the frequency of cropping compared to the traditional crop–fallow system (Halvorson et al., 2001). Kabiri et al. (2015) reported that reduced tillage did not affect soil organic C and N content in a semi-arid calcixerepts. Moreover, many studies have confirmed that conservation tillage practices including chisel or disk also reduces soil losses compared to conventional tillage systems. A 22-year study in Australia showed that organic carbon and nitrogen content of the soil were declined with cultivation and burning stubble (Heenan et al., 2004). Soil fertility and quality including soil organic matter, microbial biomass, water infiltration capacity and soil water retention were improved by crop residue retention (Machado Pinheiro et al., 2015). A 6-year study in China indicated that soil properties were affected by tillage types; and bulk density and microbial counts were highly affected by tillage intensity (Luo et al., 2017). A study reported that soybean performed equally well in both conventional and reduced tillage systems while maize yield was lower than conventional tillage during the first five seasons of the study (Kihara et al., 2012).

Wheat (*Triticum aestivum* L.) is the third most commonly grown crop in the world and is annually grown on over 200 million ha. Wheat is also a staple crop in Iran. Many farmers in Iran burn the residue for on time seedbed preparation for the next crop. This practice reduces soil quality and fertility (Piggin et al., 2015). Crop residue management is essential to sustain soil properties over the years. Production of cereal in West Asia, including Iran, is characterized by burning or harvesting of stubbles, multiple cultivations,

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Peer review under responsibility of King Saud University.

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https://doi.org/10.1016/j.jssas.2018.10.001
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and delayed or late sowing and harvesting. Moldboard plowing is currently applied in around 65% of tillage practices although the agricultural extension services have tried to convince farmers to apply reduced tillage system by replacing moldboard plow with chisel plow to mitigate adverse effects of moldboard plowing. Conservation tillage practices, especially reduced tillage, have been introduced to Iranian farmers since 1999. Although moldboard plowing is prevalent in the southern regions of country, yet previous studies have carried out mainly on the north, west and central regions of Iran. Moldboard plowing is even worse in the regions like Jahrom. The most limiting factor is inadequate precipitation and high evapotranspiration rate of this area. Short growth period and temperature elevation during the grain filling stage are obstacles to obtain highest yield. No studies have been found on the wheat production in the warm, arid regions of the country, especially south and east of Iran. This study was conducted in Jahrom situated in south of Iran with warm climate and low annual precipitation. The main questions were that how tillage intensity, residue management and rate of nitrogen fertilizer affect the amount of wheat yield and sustainability production. We hypothesized that the optimum N rate for wheat would be affected by tillage system and residue availability. We also examined how wheat yield can be preserved with combining reduced tillage method and fertilizer and residue managements in the semi-arid region of Jahrom. Accordingly, wheat yield was analyzed under two tillage systems (conventional and reduced) and two crop residue managements (residue keeping and residue burning) with three nitrogen fertilizer rates (0, 100 and 150 kg/ha).

2. Material and methods

2.1. Site characteristics and experimental designs

A field experiment was conducted in two years (autumn-winter 2013 and spring 2014 followed by autumn-winter 2014 and spring 2015) at Jahrom University research farm whose soil specifications are listed in Table 1. Jahrom is located in south of Fars province within 28°30′00″N and 53°33′38″E. The mean, minimum and maximum annual temperatures of the region are 20.8 °C, 11 °C and 44 °C, respectively. The mean annual precipitation of Fars province is around 400–600 mm/year, but in the warm climate of Jahrom (south of Fars) it reaches to 100 mm/year.

The experiments were established in a block strip split plot design including $2 \times 2 \times 3$ factors, *i.e.* 12 treatments with four replicate blocks. The factors included two tillage methods: T1: two passes of chisel plow combined with roller + grain drill planter, and T2: moldboard plow + disk harrow + grain drill planter; two residue management systems: R1: keeping previous corn residue, and R2: burning previous corn residue and three levels of fertilizer application: F1: 0 kg/ha, F2: 100 kg/ha and F3: 150 kg/ha.

Farm machinery operations were completed by October 15th. 150 kg/ha wheat grain was planted on October 15th at 12.5-cm row spacing, and harvested at 30 May. Irrigation was conducted 6 times during the growing season. Urea, as an N source, was applied three times: (at the time of cultivation, stem elongation and booting stages). The two-way interaction effect of tillage and N source on the soil and crop was considered in this study due to its effect is important from crop production perspective. Few experiments have investigated the interactions between differing tillage systems and N fertilizer sources.

Burning crop residue is a common practice in Iran and also in Jahrom. Thus, it was essential to be considered in this study. The treatment with no crop residue can't be considered as a conservation method. The systems using moldboard plow were not regarded as conservation systems as they totally invert the soil surface and reveal a bare soil surface. The analysis showed that more than 30% corn residue was remained on the soil surface after two passes of chiseling. Accordingly, all the treatments including T1R1 were considered as conservation and all the treatments including T2R2 were conventional systems.

The plot dimensions were 4×20 m and the measured variables in each plot were from soil and wheat plant. The soil variables were: soil bulk density, soil nitrogen content, total organic carbon (TOC) and soil moisture content (SMC). The wheat crop variables were: the rate of seed emergence, wheat grain yield, thousand kernel weight, nitrogen use efficiency (NUE) and harvest index (HI) or ratio of grain yield to above ground biomass measured at the harvesting.

2.2. Crop samplings

A 0.5-m^2 quadrat was used for collection of plant samples from each plot. The samples were taken at different wheat growing stages including tillering and maturity (ca. 35 and 180 days after planting, respectively). Wheat plants within each quadrat were harvested by hand. All the plant samples were oven-dried for 48 h at 75 °C and then weighted to obtain their dry biomass weights. Wheat yield and its components were measured at maturity. All the collected data were statistically analyzed using SPSS 21 software.

The emergence rate index (ERI) can be determined by Eq. (1) (Erbach, 1982):

$$\sum_{n-1}^{x} \frac{EMG_n - EMG_{n-1}}{DAP_n} \tag{1}$$

where n is the n^{th} emergence observation, EMG_n shows the percentage of planted seeds which emerged on the day of the n^{th} emergence observation, EMG_{n-1} denoted the percentage of planted seeds which emerged on the day of the $(n-1)^{th}$ emergence observation, which will be equal to 0 when n = 1. DAP_n is the number of days after planting when the n^{th} emergence observation was taken. The counting of emergences stopped when no new crop was observed.

The harvest index (HI) is the ratio of yield to total plant biomass (Piggin et al., 2015):

$$\frac{Grain\ \ yield(\frac{kg}{ha})}{Biomass(\frac{kg}{ha})} \tag{2}$$

Table 1
Soil specification of the research farm in two years of the study.

Year	Depth (m)	PH	EC (mmhos/cm)	Silt (%)	Clay (%)	Loam (%)	Soil texture	Bulk density	Total organic carbon (g/kg)	N (g/kg)	P (ppm)	K (ppm)	Soil moisture content (%)
2013–2014	0–0.1	7.4	1.60	51	22	27	SL	1.25	1.51	0.16	8.8	190	12.5
	0.1–0.2	7.5	1.62	47	21	32	SL	1.34	1.33	0.12	8.3	176	12.8
	0.2–0.3	7.5	1.62	46	21	33	SL	1.47	1.15	0.10	7.4	170	13.4
2014–2015	0–0.1	7.2	1.64	50	22	27	SL	1.25	1.35	0.11	8.5	182	12.9
	0.1–0.2	7.4	1.63	46	20	31	SL	1.33	1.24	0.10	8.1	166	13.6
	0.2–0.3	7.5	1.62	46	20	33	SL	1.43	1.19	0.10	7.8	169	13.9

Shoots plus roots can be considered as the plant biomass, but above-ground biomass is more common as the exact root mass is so difficult to measure.

2.3. Soil samplings

The chemical material used in the experiments of soil samplings were provided from Merck Co. and double distilled deionized water was used in all solutions. Electrolytic conductivity (EC) and pH of the soil were measured using standard instruments of Lutron, pH-208 and Lutron, CD-4306, respectively. The soil texture determination and its particle size analysis were conducted using standard ASTM 152H-Type hydrometer. Soil bulk density, soil nitrogen (N), phosphorous (P), potassium (K) and total organic carbon (TOC) contents were evaluated in the soil depth ranges of 0–0.1 m, 0.1–0.2 m and 0.2–0.3 m. The samples were manually collected using core samplers (metal sleeves 4.1 cm in diameter and 5 cm in depth) or a small spade. In order to estimate TOC, common Walkley-Black method was applied (Walkley and Black, 1934). Soil moisture content (SMC, %) was gravimetrically determined at the flowering stage of winter wheat in each of the two study years from 0 to 30-cm soil depth. Soil samples were oven-dried at 105 °C to reach to constant weight for calculating the SMC. To determine soil bulk density (BD), the samples were oven-dried for 24 h at 105 °C. This parameter was calculated by Eq. (3):

$$BD = \frac{W_d}{V} \tag{3}$$

where BD is soil bulk density (g cm^{-3}), W_d represents sample dry weight (g), and V denotes sample total volume (cm^3). Soil nitrogen content was determined by standard Kjeldahl method (Bremner, 1960). Available phosphorous of the soil was measured by Olsen procedure (Olsen, 1954) and potassium was determined by flame photometry method (Brown and Lilleland, 1946).

3. Results and discussion

3.1. Weather condition

The experimental site monthly rainfall and temperature during the two years of study are shown in Fig. 1. The temperatures of the two growing seasons were very similar in most of the months. The average temperatures were 17.9 °C and 18.7 °C for the first and second year of the study. However, rainfall rates varied a lot in some months, *i.e.* January, March and November. The average rainfalls were 21.3 and 29.9 mm/year for 2013–2014 and 2014–2015, respectively. The monthly variation may affect wheat grain yield and other parameters accordingly.

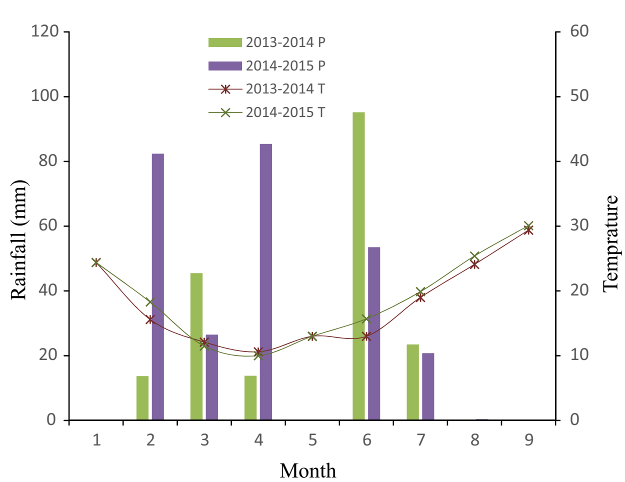

Fig. 1. Monthly rainfall and temperature of two years of the study.

3.2. Soil physical properties

Combination of chisel plowing and keeping residue slightly increased SMC, TOC and nitrogen content for most of the increments between 0 and 30-cm depth (Fig. 2). Average values of soil

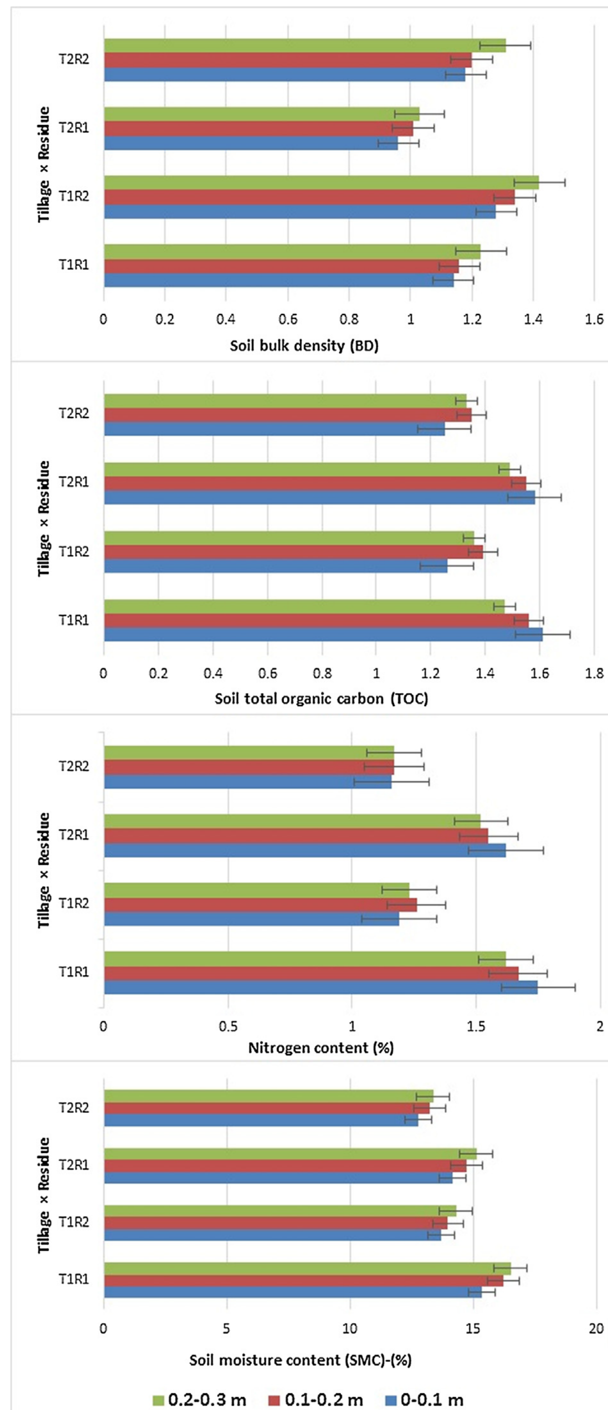

Fig. 2. Effect of tillage × residue on soil properties at 0–0.3 m soil depth.

physical properties are listed in Table A1 (in appendix) for the two years of study. The data of the second year are not repeated here as they are close to the first year (below ±1% difference). In general, the best agronomic conditions, *i.e.* higher TOC, SMC and nitrogen content were observed when chisel applied in retained crop residue. But, soil BD was lower with moldboard plowing.

The result of ANOVA including main effects and interactions of the different treatments for two years of the study are summarized in Table 2. Significant differences were observed between treatments with and without residue, between tillage systems and between fertilizer applications in the soil depth of 0–0.1 m. The detailed Dunkan analysis showed that F1, F2 and F3 had significantly different effects on the TOC of soil in the depth of 0–0.1 m (Table 2).

Two-way interaction of tillage × residue (T × R) had also significant effect on TOC of upper soil layer (0–0.1 m) in both years. None of tillage, residue and fertilizer showed significant differences on TOC in soils deeper than 0.2–0.3 m. The two-way interaction effect of R × F on TOC in the shallow depth (0–0.1 m) was significant (Table 2), meaning that rate of applied nitrogen may change rate of soil residue and consequently, TOC at this depth.

Soil nitrogen content was affected by tillage intensity, residue management and nitrogen application from surface to 0.2 m depth, but no significant influence was observed in deep soil (0.2–0.3 m). Tillage had no significant effect on TOC in depth of 0.1–0.2 m in the second year of the study. The two-way interaction of T × R showed significant effect (0.95 probability level) on the nitrogen content and SMC of 0.2–0.3 m soil depth. The two-way interaction of R × F influenced the amount of BD, TOC and nitrogen content in the shallow soil of 0–0.1 m, but had no impacts on the mentioned variables of deeper soils up to 0.3 m in both years of the study. Similarly, the three-way interaction of T × R × F exhibited no significant impact on BD, TOC, SMC and soil nitrogen content in both years.

3.3. Crop properties and grain yield

It was observed that different tillage (Fig. A1 in appendix) and residue managements (Fig. A2 in appendix) led to similar wheat crop properties, different rates of nitrogen fertilizer however significantly changed the crop properties (Fig. A3 in appendix). For instance, compared to F1, F3 increased grain yield by 65% while T1 slightly increased grain yield by 4% compared to T2. The crop properties showed more profound variation by co-application of the managerial variables, *i.e.* tillage, residue and nitrogen (Fig. 3). Table 3 reveals that emergence rate index (ERI) and wheat density were mainly affected by tillage methods in both years of the study while tillage had significant effect on the biological yield only at the first year of the study. Dunkan analysis indicated that three levels of fertilizer application have different effects on wheat density; but, similar effect on ERI (Table 3).

Although we found significant effect of tillage on the ERI, the average values revealed that all the treatments led to almost similar ERI and wheat plant density (Fig. 3). Only the data of the second year of the study are shown in Fig. 3 since they were similar to the first year (difference less than 1%). The only parameter that showed higher variation between year 1 and 2 of the study was biological yield (4% difference). Both tillage method and fertilizer application rate have significant effects on wheat grain and biological yields. Fig. A1 shows around 25 g/m^2 more average grain yield in T1 as compared with T2.

Table 2
Analyses of variance of soil physical properties for two years of the study (F values are reported).

SOV	DF	BD1	BD2	BD3	TOC1	TOC2	TOC3	N content 1	N content 2	N content 3	SMC	SMC	SMC
		0–0.1 m	0.1–0.2 m	0.2–0.3 m	0–0.1 m	0.1–0.2 m	0.2–0.3 m	0–0.1 m	0.1–0.2 m	0.2–0.3 m	0.1–0.3 m	0.1–0.3 m	0.1–0.3 m
2013–2014													
Block	3	4.833	8.209	0.799	1.962	0.422	4.524	2.515	0.461	0.691	1.623	1.326	0.721
Tillage (T)	1	60.500**	3788.604**	5.061*	4.905**	3.712	0.300	954.147**	758.427**	0.776	78.284**	67.231**	5.281*
Error (T)	3	0.833	14.626**	1.621	0.264	0.994	0.556	6.834	2.764	1.573	1.227	1.305	1.631
Residue management (R)	1	666.125**	5195.901**	4.051	27.058**	360.085*	7.500	1246.233**	1056.034*	2.026	19.335**	17.128**	4.210*
Error (R)	3	2.792	10.231	4.425	0.307	1.040	0.780	4.834	2.573	2.259	0.521	0.385	0.402
T × R	1	36.125*	406.187**	10.220	3.631*	7.531**	0.012	132.515**	138.067**	3.864*	2.441*	2.246*	2.623*
Error (T × R)	3	2.792	8.912**	1.472	0.363	0.194	0.396	2.479	2.584	0.838	2.343	2.040	2.234
Fertilizer application (F)	2	15.594**	4.385*	0.939	3.448*	2.928	1.488	3.083*	5.419*	1.245	0.335	0.428	0.352
T × F	2	0.219	4.253	2.285	0.170	0.931	0.336	1.610	0.329	1.135	0.267	0.241	0.162
R × F	2	4.156*	1.418	4.556	0.393*	1.149	0.192	1.831	2.301	0.786	1.018	1.213	1.257
T × R × F	2	0.031	0.099	1.304	2.748	2.519	0.768	0.083	2.334	0.639	0.746	0.683	0.672
Error (F)	24	–	–	–	–	–	–	–	–	–	–	–	–
2014–2015													
Block	3	4.321	7.322	0.587	2.025	0.471	4.735	2.322	0.633	0.431	1.702	1.654	0.689
Tillage (T)	1	58.254**	3708.256**	5.211*	4.731**	3.902	0.237	903.226**	0.427	1.019	79.225**	69.113**	5.146*
Error (T)	3	0.756	14.302**	1.872	0.337	0.843	0.731	6.541	1.993	1.804	1.032	1.095	1.118
Residue management (R)	1	651.112**	5183.438**	4.121	26.126**	346.122*	6.784	1167.041**	1134.127*	1.839	21.337**	19.152*	5.106*
Error (R)	3	2.761	9.602	4.342	0.354	1.242	0.631	4.522	2.671	2.438	0.336	0.389	0.291
T × R	1	34.054*	388.472**	9.788	3.601*	6.155**	0.032	128.351**	126.122**	3.637*	2.138*	2.147*	2.420*
Error (T × R)	3	2.541	8.761**	1.532	0.459	1.126	0.251	2.672	2.769	1.151	2.121	2.092	2.234
Fertilizer application (F)	2	15.326**	4.548*	1.226	3.546*	3.106	1.670	3.295*	5.012*	1.482	0.368	0.421	0.254
T × F	2	0.213	4.170	2.457	0.209	1.251	0.189	1.780	0.561	1.225	0.291	0.237	0.278
R × F	2	4.147*	1.385	4.369	0.430*	1.115	0.135	1.539	2.779	0.931	1.122	1.138	1.140
T × R × F	2	0.027	0.312	1.423	2.836	2.658	0.566	0.122	2.129	0.779	0.836	0.792	0.856
Error (F)	24	–	–	–	–	–	–	–	–	–	–	–	–

* BD is soil bulk density, TOC is soil organic carbon and SMC is Soil moisture content.
** Significance at 0.01 level of probability.

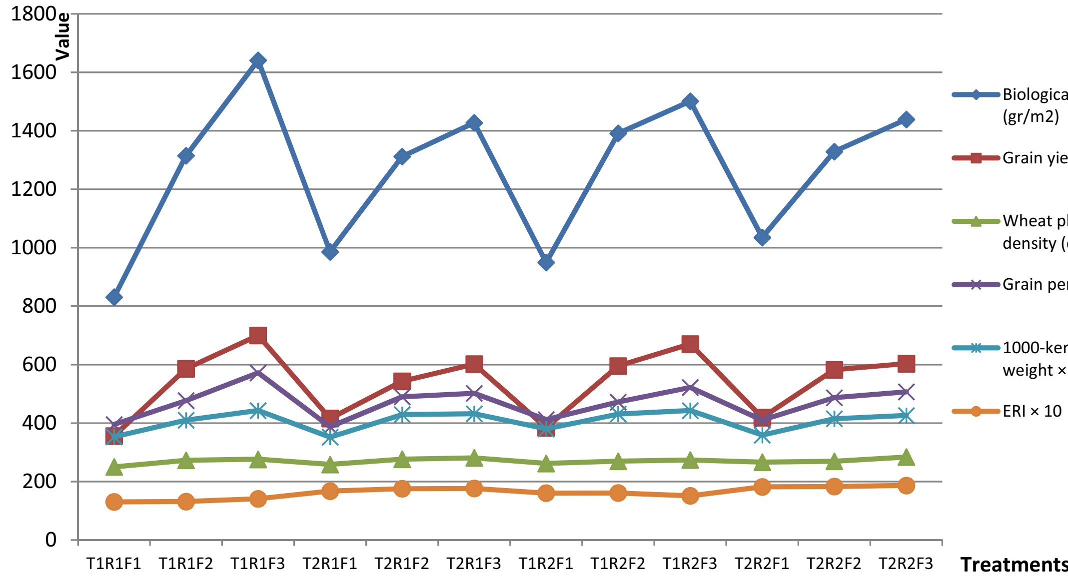

Fig. 3. Wheat crop properties under different treatments.

Table 3
Analyses of variance of wheat crop properties and grain yield for two years of study (F values are reported).

SOV	DF	ERI	Wheat density(crop/m^2)	Grain yield(g/m^2)	Biological yield (g/m^2)	HI	1000-kernel weight (g)	Grain per ear
2013–2014								
Block	3	1.551	1.128	0.867	0.382	1.115	0.724	3.110
Tillage (T)	1	82.284**	4.166*	5.480*	2.852*	1.309	3.981	2.859**
Error (T)	3	1.223	0.266	0.079	3.571	1.171	0.168	1.824
Residue management (R)	1	22.449**	0.448	2.924*	1.445	0.169	2.066	0.098
Error (R)	3	0.478	1.860	1.377	1.331	2.122	0.710	0.255
T × R	1	2.952*	0.032	0.436	0.042	0.219	7.192**	2.451
Error (T × R)	3	2.674	0.006	0.188	0.153	0.124	1.388	1.478
Fertilizer application (F)	2	0.397	19.970*	276.587**	324.844**	1.006	140.021**	120.945**
T × F	2	0.255	0.483	17.578**	17.111**	0.129	1.377	6.176**
R × F	2	1.015	2.976*	1.651	6.003**	1.088	2.157	3.416**
T × R × F	2	0.834	0.365	1.057	3.936**	0.891	1.162	1.651
Error (F)	24	–	–	–	–	–	–	–
2014–2015								
Block	3	1.423	1.163	0.782	0.430	1.121	0.651	3.009
Tillage (T)	1	79.113**	4.236*	5.304*	0.432	1.268	4.103	2.447**
Error (T)	3	1.016	0.278	0.110	3.237	1.185	0.225	1.667
Residue management (R)	1	21.403**	0.375	2.738*	1.226	0.139	2.230	0.118
Error (R)	3	0.431	1.732	1.504	1.569	2.154	0.657	0.335
T × R	1	2.637*	0.051	0.371	0.083	0.437	6.852**	2.557
Error (T × R)	3	2.254	0.025	0.225	0.324	0.309	1.241	1.669
Fertilizer application (F)	2	0.361	21.112*	263.204**	298.921**	0.886	138.113**	117.551**
T × F	2	0.279	0.372	17.056**	16.134**	0.225	1.521	6.378**
R × F	2	1.116	2.730*	1.431	5.782**	1.234	2.362	3.056**
T × R × F	2	0.806	0.422	1.116	3.338**	0.906	0.906	1.779
Error (F)	24	–	–	–	–	–	–	–

HI: Harvest index; ERI: Emergence rate index.
** Significance at 0.01 level of probability.

4. Discussion

4.1. Impact of tillage, residue and nitrogen managements on physical properties of soil

BD value was increased from top to bottom of the soil layers in both years. In the first layer (0–0.1 m) all the considered variables, *i.e.* tillage systems, residue management and nitrogen application had significant effects on BD. Some previous studies have clarified that tillage type has no impact on BD (Shirani et al., 2002). But, some have found the significant influence of tillage intensity on BD in deeper soil layers up to 0.2–0.3 m (Mosaddeghi et al., 2009). Our result is not consistent with the result of the latter study. Our result is also similar to a study conducted in China where BD was increased with increasing soil depth while it was influenced by tillage practices related to tillage depth (Mu et al., 2016). The impact of crop residue on the deeper soils (0.2–0.3 m) was not considerable since some residues accumulated on the top (0–0.1 m) or medium soil layer (0.1–0.2 m). All in all, the treatments including chisel plowing and keeping residue lowered BD.

Our data revealed that the two-way interaction of F × R had significant effect on TOC of soil layer only at depth of 0–0.1 m. It means that combination of different levels of nitrogen application and residue managements had different impacts on TOC which could be mainly due to decomposition effects of nitrogen fertilizer on the organic materials and crop residue. The top layer was more affected because of higher temperature this layer. Malhi et al., (2011) pointed out that keeping straw significantly increased TOC of soil at 0–5 and 0–15 cm depths. Some researchers observed that nitrogen application increased soil TOC especially when combined with keeping crop residue (Kumar and Yadav, 2001; Yang et al., 2004). In the medium depth of 0.2–0.3 m, the only significant effect of residue management was on TOC although the significance of two-way interaction of $T \times R$ showed that type of tillage can change the effect of residue management on TOC (Table 3). The insignificant effect of two-way interaction of $T \times F$ on TOC clarified that tillage intensity combined with nitrogen consumption may not significantly change TOC in the soil depths of 0–0.1 m, 0.1–0.2 m and 0.2–0.3 m. Although the two-way interaction of $T \times F$ was not statistically significant, the effect of tillage can't be ignored as chisel plowing led to slightly higher TOC than moldboard plowing at deeper soil layers (Fig. 2).

Table A1 (in appendix) revealed that, averaged overall soil depths and nitrogen content under chisel plowing was around 9.1% higher than moldboard plowing. Chisel plowing in China saved 7.6% more nitrogen than moldboard plowing (Mu et al., 2016). Detailed data showed that upper soil layer (0–0.1 m) had higher nitrogen than deeper soils when the residue was kept (Fig. 2). But, in the burned residue treatments, the nitrogen content slightly increased from top to bottom. Statistical analyses revealed that two-way interaction of $T \times R$ had significant effects on the soil nitrogen content in all soil increments from top to bottom. This is not totally in agreement with the result of a study by Du et al. (2010) in which they reported that no-till and rotary tillage with maize residue increased total N concentration in the top soil layer, but did not increase total N storage with maize residue return in the soil profile. Kristensen et al. (2003) mentioned the microbial pool as the main source of labile N which may be released by tillage. Overall, combination of changes in tillage type, residue management and nitrogen application should be done more carefully since their combination may significantly change BD, TOC and soil nitrogen content.

The effects of residue on the SMC of deep soil layers were more obvious than BD changes. The availability of soil water during the critical flowering stage of crops is essential to improve the grain yields. The SMC at the critical flowering stage of wheat was measured in this study. It was observed that chisel plowing along with keeping residue led to higher SMC particularly at deeper soils which was important in this warm region of Iran (Fig. 2). The effect of chisel plowing, as a deeper tillage method than conventional ones, on reserving the moisture may be due to lower soil disturbance and enlarging the profile water storage by increasing soil porosity (Berheet et al., 2012) besides the availability of crop residue to absorb water. The two-way interaction of $T \times R$ influenced SMC at different soil depth; meaning that SMC was affected mainly by tillage and residue managements rather than fertilizer application.

4.2. Impact of tillage, residue and nitrogen managements on wheat crop properties

Table 3 displays that tillage type (T) had significant impacts on the most wheat properties, but both residue management (R) and two-way interaction of $T \times R$ significantly affected only ERI, grain yield and thousand-kernel weight. The significant effect of two-way interaction of tillage and residue managements reflects that their impacts on the crop properties were not independent. Fallahi and Raoufat (2008) found no difference between tillage methods in terms of ERI. However, Mu et al. (2016) stated that combination of chisel plowing and retained residue give the highest wheat and maize grain yields compared to the moldboard plowing and retained/removed residue. Another study by Wang et al. (2012) revealed that, compared to conventional tillage, deep plowing resulted in 13–16% higher yield in winter wheat in northern China. Tillage depth may affect the residue location, and thus influence the depth distribution of N (Puget and Lal, 2005). Our data in Fig. 2 and Table A1 confirmed that nitrogen content of soil was higher under chisel plowing. Furthermore, the significant contribution of chiseling in yield can be explained by greater water availability compared to conventional tillage (Mu et al., 2016) since SMC was higher under this tillage method (Fig. 2). Although the second year received higher rainfall, no significant difference was found on the wheat yield of the two years of study. It was also reported that higher straw on the soil surface increased the number of moist soil days (Unger, 1978). Several studies on different crops have reported that residue removal reduced the yield compared to residue keeping (Hazarika et al., 2009; Bahrani et al., 2007). Accordingly, it can be concluded that combination of conservation tillage and keeping the residue may lead to higher yield especially in warm climates.

Fig. 3 indicates that the highest wheat crop properties, *i.e.* biological and grain yields, crop density, grain per ear, ERI and thousand-kernel weight were obtained when T1 was combined with R1 and F3 (treatment T1R1F3) at both years of the study. However, the maximum points revealed that when T2 was combined with R1 or T1 was combined with R2 we had higher outputs in comparison with other combinations only if F3 was used (see T1R2F3, T2R1F3). Conversely, the minimum outputs were obtained if the combinations of T2 and R1 or T1 and R2 were used with F1 (see T1R2F1, T2R1F1). This confirms importance of the level of applied nitrogen fertilizer in combination of different tillage and residue management systems. Our results are consistent with Halvorson et al. (1999) study in which they reported that application of 50–100 kg/ha nitrogen alleviated the deleterious effect of reduced tillage systems and resulted in higher wheat yield compared to conventional tillage system. However, another study stated that wheat grain yield was lower in no-tillage system compared to conventional tillage systems while wheat grain was not altered by N fertilization (Rieger et al., 2008).

The significant effect of two-way interaction of $T \times R$ on the thousand-kernel weight when the main effects of T and R were not significant indicated that tillage intensity and residue management had no independent impact on this factor. However, Fig. 3 shows that highest thousand-kernel weight was obtained from T1 compared to T2; while R1 and R2 and F2 and F3 had similar impacts on the thousand-kernel weight. Nitrogen application had significant effect on the thousand-kernel weight at 0.01 level of significance (Table 3). This is consistent with the studies by Warraich et al. (2002) and Zheng et al. (2016) in which fertilizer rate influenced the quality of wheat grain.

No significant impact was found on HI meaning that the proportion of wheat grain to wheat biomass was slightly affected by tillage, residue or fertilizer managements. However, T2, R1 and F2 led to higher wheat HI. The rate of nitrogen fertilizer can influence the thousand-kernel weight. The two-way interaction effects of fertilizer with tillage method ($T \times F$) and residue management ($R \times F$) were significant on the number of grain per ear. Since residue management alone had no significant impact on this factor, consideration of combined effects are essential for sustainable agricultural practices. Nitrogen application (F) and two-way interaction of $R \times F$ could influence wheat density significantly in both years of the study. It indicates that although the main effect (sole effect) of residue management was not significant on the wheat density, it can change the density of wheat when combined with nitrogen application.

5. Conclusion

Scientific crop management is essential especially in dry and warm areas. This study was conducted to investigate the impacts of different tillage, residue and nitrogen management systems on soil and crop properties in two years. The significance of this study will be highlighted when we notice that little information is available on the suitable wheat production practices on the warm climate of Iran. Moldboard plowing and burning previous residue had unfavorable impacts on the wheat properties although all the impacts were not statistically significant. Application of 100 or 150 kg/ha nitrogen can assist in reducing adverse effects of conventional tillage system. The best results were obtained from chisel plowing system (T1), keeping residue (R1) and 150 kg/ha nitrogen (F3). Considering combinational effects, the highest and the lowest grain yield were obtained from T1R1F3 and T1R1F1, respectively. Nonetheless, the statistical analyses revealed that most two-way interactions had significant impact on the wheat properties meaning that the combination of tillage, residue and nitrogen should be carefully applied in the warm condition of Jahrom.

The current study lacks the benefits of long-term experiments to identify the full impacts of conservation tillage and crop residue managements after long period of time. Currently, some farmers use no tillage system for cotton production in the studied region. It is suggested that future studies should be conducted to investigate long-term effects of different treatments including no-tillage system on the wheat/cotton crop and soil properties. Currently, there is no wheat variety appropriate to this warm region of Iran. Improving some varieties with higher yield which are tolerant to warm climate and water deficiency seems essential to enhance the sustainability of local grain production. Investigating into the effect of wheat tillage and fertilizer consumption on the weed type and density is also suggested for future studies.

Acknowledgement

The authors acknowledge the funding support from Jahrom University.

Appendix

See Figs. A1–A3, Table A1.

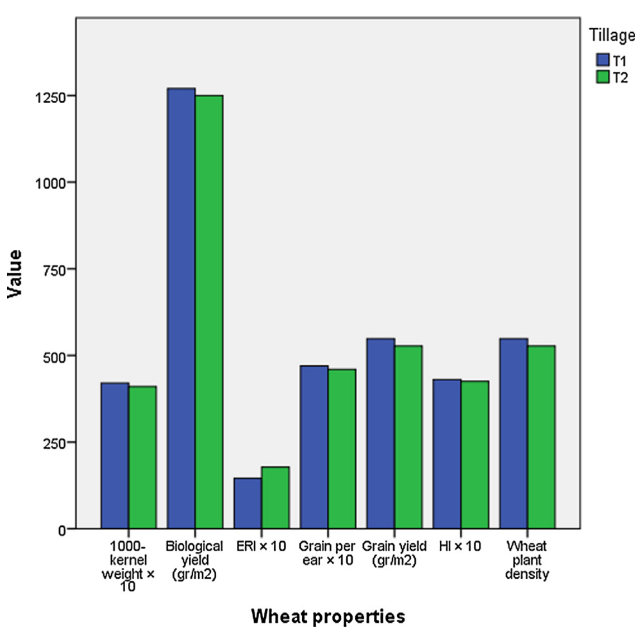

Fig. A1. Wheat properties considering tillage management for the second year of the study (below 5% difference between the first and second year of the study).

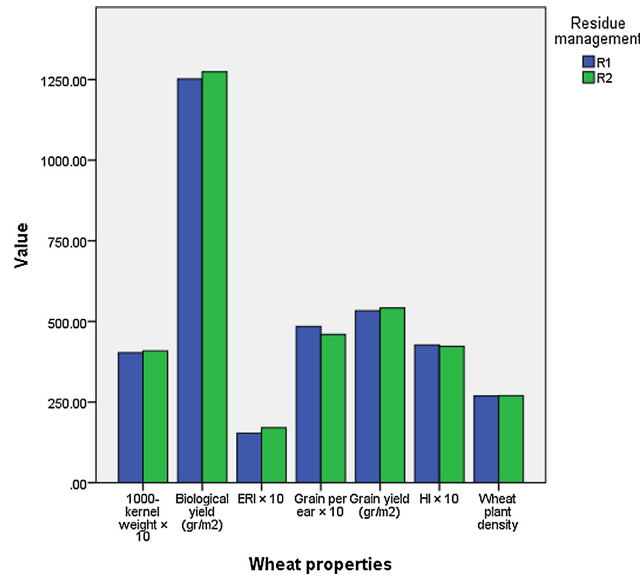

Fig. A2. Wheat properties considering residue management for the second year of the study (below 5% difference between the first and second year of the study).

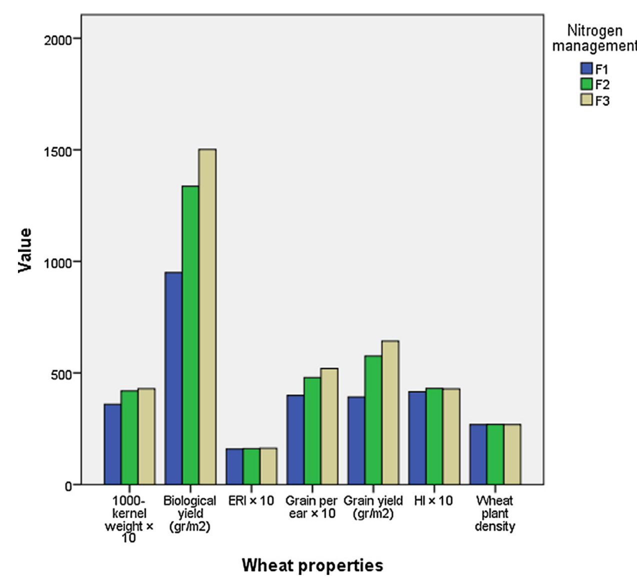

Fig. A3. Wheat properties considering nitrogen management for the second year of the study (below 5% difference between the first and second year of the study).

Table A1
Average values of soil properties for two tillage practices (T) and two residue management methods (R) (Average soil depth of 0–0.3 m).

	Tillage systems	Residue management	
		Keeping residue (R1)	Burning residue (R2)
BD (g/cm^3)	Chisel plowing (T1)	1.17	1.38
	Moldboard plowing (T2)	1.03	1.21
TOC (g/kg)	Chisel plowing (T1)	1.54	1.34
	Moldboard plowing (T2)	1.49	1.31
Nitrogen content (g/kg)	Chisel plowing (T1)	1.73	1.24
	Moldboard plowing (T2)	1.58	1.17
SMC (%)	Chisel plowing (T1)	15.61	13.80
	Moldboard plowing (T2)	14.21	12.75

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