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Nitrogen and irrigation water management in corn (*Zea mays*) under no-tillage and conventional tillage systems

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ABSTRACT

Organic carbon and irrigation water scarcity are two major limiting factors in corn (*Zea mays* L.) production of Fars province which is located in the south of Iran. Soil tillage systems can affect the nitrogen and water utilization. In 2015-2017, by using the strip-split plot design and two line-source sprinkler irrigation systems, effects of 0, 90, 180, and 270 $kg.ha^{-1}$ of pure nitrogen and 6400, 7500, 8550, and 9600 $m^3.ha^{-1}$ of irrigation water in conventional, and no-tillage systems were investigated. Results showed that conventional tillage system had high WUE and foliage yield than no-tillage systems. Based on the obtained results, in the terms of dry foliage yield, combined application of 8550 $m^3.ha^{-1}$ irrigation water and 90 kg $N.ha^{-1}$ (I2N90 treatment) are introduced as the superior treatments in both of two tillage systems. While, in terms of WUE, combined application of 8550 $m^3.ha^{-1}$ irrigation water and 90 kg $N.ha^{-1}$ (I2N90 treatment) in conventional tillage and combined application of 7500 $m^3.ha^{-1}$ irrigation water and 135 kg $N.ha^{-1}$ (I3N135 treatment) in no-tillage systems are introduced as the superior treatments.

Key words: Conservation tillage, Irrigation, Maize, Nitrogen, WUE

Fars province located in the south of Iran and based on Koppen Climate classification system has mostly arid and semi-arid climate (Nasseri *et al.* 2017). Corn (*Zea mays* L.) is one of the most important crops cultivated in Fars province but its production in this province is limited by water and nitrogen. Austin (2011) reported that drought and nutrient deficiency are the main factors effect on crop production in arid and semi-arid areas. Conservation tillage practices by enhancing soil fertility, reducing seasonal evapotranspiration and conserving more soil water can effect on crop yields (Lampurlanes *et al.* 2016). Lenka *et al.* (2012) reported that tillage practices by affecting on the soil macro pores characteristics influenced soil moisture conservation and distribution. Tillage also by affecting on water infiltration can affect nitrate-N concentration, water contents, aeration, available of organic carbon, soil temperature, infiltration and evapotranspiration processes (Shao *et al.* 2016). The crop residues in conservation tillage are the direct sources of organic carbon. Decomposition of crop residues in conservation tillage is an effective practice that can improve soil properties and support crop production (Wang *et al.* 2015). A large number of studies have shown that conservation tillage practices have produced favorable benefits, including improved soil organic contents as well as increased crop yield and water use efficiency (Mazzoncini *et al.* 2016). Singh *et al.* (2016) believed that conservation tillage practices improved soil physical status like soil density, soil porosity, field capacity. In contrast, some limitations such limited root growth due to soil compaction in the no-tillage system, can lead to reduced contact between the crop roots and the soil in the root zone, and may decrease plant water and nutrients absorption (Zhang *et al.* 2004). The dominant factors affecting crop production in south of Iran are low amounts of rainfall and of low amounts of organic carbon in agronomic soils. As soil tillage systems can affect the nitrogen and water utilization, the objective of this research was to study conventional and no-tillage systems effects on irrigation water use efficiency and yield of corn and determine optimum amounts of irrigation water and nitrogen rates in two tillage systems.

MATERIALS AND METHODS

This field study was conducted at Fars, Iran (29˚77′N and 52˚72′E) for two years from July 2015 to October 2017 on a fine, carbonatic, termic, Typic Haploxerepts soil. The site (1170 m altitude) with the temperature averages 16.5°C and an average annual rainfall of 308 mm has a semiarid

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Table 1 Means of some soil physical and chemical characteristics at the experimental field

Ec	pH	T.N.V.	O.C.	P	K	Mn	Fe	Zn	Fc	PWP	BD	Texture
($dS.m^{-1}$)		($g.100g^{-1}$)				($mg.kg^{-1}$)			(%)		($g.cm^{-3}$)	
1.31	8.1	32.0	0.60	8.5	224	7.7	5.0	0.66	21	11	1.6	SiClL

Table 2 Results of chemical analysis of water used for field irrigation

pH	EC	HCO_3^-	Cl^-	HBO_3^-	SO_4^{--}	Total anion	Mg^{++}	Ca^{++}	Na^+	Total cation	SAR
	$dS.m^{-1}$					($meq.l^{-1}$)					
8.0	0.48	2.3	1.1	-	1.1	4.5	1.0	2.2	1.8	5.0	0.62

climate. Each year, soil samples were collected from surface horizon (0 - 30cm) of the soil. In soil samples, particle-size distribution determined by hydrometer method (Gee and Bauder 1986), TNV was determined by neutralization with HCl (Loeppert and Suarez 1996) and organic carbon were determined by Walkley Black method (Nelson and Sommers 1996). Available Zn, Fe, Mn, and Cu were determined by DTPA extraction (Lindsay and Norvell 1978), phosphorus were determined by sodium bicarbonate extraction (Olsen *et al.* 1954) and potassium were determined by NH_4OAc-K extraction.

The field experiment was established as a strip split-split plot design with 3 replicates for a total of 192 plots. The main plots (48 m × 48 m) were conventional tillage (CT) and no-tillage (NT). Subplots (24m × 48 m) were 0, 90, 135, and 180 kg. N ha^{-1} as urea and sub-subplots (12 m × 48 m) were set at 9600 (I1), 8550 (I2), 7500 (I3), and 6400 (I4) $m^3.ha^{-1}$ during the growing season.

In both two years, tillage treatments were conducted after the harvest of previous wheat crops according to the designed patterns. No tillage operations were carried out in the no-tillage system and a moldboard plow, a disk harrow, and a leveler were employed for the conventional tillage. A seed drill was used for all two tillage systems to plant corn (sc.704).

The irrigation treatments were applied using two line-source sprinkler irrigation systems (Hanks *et al.* 1976). For this purpose, 8 Nelson F33 sprinklers with about 12 m sprinkling radius at a distance of 6 m from each other were mounted on risers of 150 cm height installed on a 75 mm polyethylene pipeline. As the sprinkling radius was 12 m, 4 treatments (I_1 to I_4) were located 0-3, 3-6, 6-9, and 9-12 m apart on both sides of the main pipeline and perpendicular to it. Therefore, each plot was 3*3 m^2. The amount of irrigation water was calculated through measuring soil moisture in treatment I_1 one day before irrigation using the following equation [1]:

$$I = [(\theta_F - \theta)\rho_b.\ D]/100 \quad (1)$$

where, I is the depth of irrigation water (cm), θ_F is the gravimetric soil moisture content at field capacity (%), θ is the available gravimetric soil moisture (cm), ρ_b the soil bulk density ($g.cm^{-3}$), and D is the effective root depth (30 cm). The irrigation interval was 8 days and the volume of irrigation water was measured by a flow meter using a catch can. The total water collected in each catch can was then determined during the growing season. Water use efficiency (WUE) was determined using the following equation (Zhao *et al.* 2019):

$$\text{WUE} = \text{Yield } (kg.ha^{-1}) / \text{ water used } (m^3.ha^{-1}) \quad (2)$$

The amount of nitrogen required for each treatment plot

Table 3 Main effects of various tillage systems on the different parameters

Tillage treatment	Plant height (cm)	Stem diameter (mm)	No. of plants.m^{-2}	Fresh yield ($t.ha^{-1}$)	Dry yield ($t.ha^{-1}$)	Soil OC ($g.100g^{-1}$)	Foliage N uptake (kg. ha^{-1})	WUE ($kg.m^{-3}.ha^{-1}$)
2014-2015								
conventional tillage (CT)	248	20.7	8.89	63.875	38.906	0.883	448	4.93
No tillage (NT)	223	26.2	7.84	50.292	29.146	1.147	332	3.69
2015-2016								
conventional tillage (CT)	248	20.1	8.07	57.521	39.659	0.893	432	4.96
No tillage (NT)	246	19.4	7.73	54.667	34.884	1.104	370	4.42
2014-2016								
conventional tillage (CT)	248 a	20.38 b	8.48 a	60.698 a	39.283 a	0.888 b	440 a	4.95 a
No tillage (NT)	234 b	22.80 a	7.79 b	52.479 b	32.015 b	1.126 a	351 b	4.06 b
Anova								
	8843^{**}	280^{**}	23.0^{**}	3242^{**}	2535^{**}	0.04^{*}	377454^{**}	37.91^{**}

Similar letters in each column represent insignificant differences between the two treatments related to the parameter**.**

Table 4 Combined effects of irrigation-tillage, nitrogen- tillage and irrigation-nitrogen-tillage on the yield contributing characters

	Plant height (cm)		Stem diameter (mm)		No. of plants .m^{-2}		Fresh yield (t.ha^{-1})		Dry yield (t.ha^{-1})		OC post harvesting (g.100g^{-1})		Foliage N uptake (kg.ha^{-1})		WUE (kg.m^{-3}.ha^{-1})	
	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT
Irrigation																
I1	261 a	238 b	20.98a	23.35 a	8.40 a	7.75 a	64.417ab	53.396 b	40.817b	33.031 b	0.835 b	1.15 a	470 a	354 b	4.25 c	3.43 b
I2	259 a	243 a	20.96a	24.02 a	8.70 a	7.56 a	68.458a	56.417 a	40.817b	34.994 a	0.953 a	1.07 a	487 a	392 a	5.41 a	4.15 a
I3	248 b	236 a	20.29ab	23.69 a	8.48 a	7.63 a	62.188b	53.521 b	40.608b	32.277 b	0.943 a	1.13a	457 a	359 b	5.41 a	4.31 a
I4	224 c	222 c	19.29b	20.13 b	8.33 a	8.21 a	47.729c	46.583 c	30.167c	27.758 c	0.822 b	1.15a	346 b	297 c	4.71 b	4.34 a
Nitrogen																
N0	239 b	229 a	19.52 b	21.4 a	8.56ab	7.90 a	56.313b	49.646 a	37.425b	29.706 b	0.862 a	1.06 b	393 b	294 b	4.70 b	3.77 b
N90	254 a	237 a	20.65 ab	23.1 a	8.21b	7.79 a	62.104a	53.354 a	40.077a	32.823 a	0.899 a	1.12 ab	118 a	360 a	5.05 a	4.16 a
N135	254 a	237 a	21.50 a	23.3 a	8.38ab	7.63 a	63.229a	53.896 a	40.100a	33.152 a	0.894 a	1.17 a	466 a	384 a	5.01 a	4.18 a
N180	245 b	235 a	19.85 ab	23.4 a	8.77a	7.83 a	61.146a	53.021 a	39.529ab	32.379ab	0.898 a	1.15 a	453 a	366 a	5.02 a	4.12 a
*I * N* T*																
I1N0	245cd	232be	20.00ae	21.75cg	8.42a	7.75 a	58.417c	50.417be	39.658cd	29.042def	0.791e	1.07cd	415cg	318cde	4.13ef	3.02 f
I1N90	368a	240ab	21.42abc	23.08ae	8.00a	7.92 a	63.000bc	52.083be	38.300d	32.758bcd	0.825de	1.12ad	433bf	342be	3.99f	3.41 ef
I1N135	266a	235ad	21.58ab	23.75ae	8.58a	7.75 a	69.750ab	54.917ad	43.450ad	34.100abc	0.857cde	1.21ab	525a	387bc	4.53def	3.55de
I1N180	267a	244a	20.92ad	24.83ab	8.58a	7.58 a	66.500abc	56.167abc	41.858bcd	36.225ab	0.865be	1.21ab	507ab	370bcd	4.36def	3.77cde
I2N0	251bc	240abc	19.33de	21.75dh	8.67a	7.83 a	61.417bc	54.417ad	41.675bcd	32.967bcd	0.942abc	1.07cd	446ae	339be	4.89be	3.86be
I2N90	260ab	244a	21.33abc	24.08ad	8.58a	7.58 a	72.750a	56.083abc	48.783a	35.675ab	0.975a	1.08cd	523a	400 b	5.73a	4.20abc
I2N135	267a	244a	22.08a	25.08ab	8.50a	7.67 a	70.750ab	61.417a	46.208ab	38.408 a	0.967ab	1.06cd	487ad	470 a	5.43abc	4.51a
I2N180	258ab	243a	21.08ad	25.50 a	9.08a	7.17 a	68.917ab	53.750 be	45.492abc	32.967bcd	0.930abc	1.07cd	489ad	371bcd	5.58ab	4.04ad
I3N0	235def	230cde	19.92ae	22.67 bf	8.25a	7.58 a	57.833c	51.167be	38.567d	30.333cf	0.923ad	1.07cd	410dg	281ef	5.14ad	4.04 ad
I3N90	258ab	240abc	21.00ad	24.17abc	8.33a	7.25 a	63.500bc	57.083ab	41.600bcd	33.933bc	0.972a	1.12ad	467ad	380bc	5.54ab	4.52 a
I3N135	258ab	238ad	21.17ad	23.75ae	8.58a	7.50 a	65.417abc	52.583 be	41.358bcd	31.925be	0.945abc	1.21ab	500abc	375bcd	5.51ab	4.26abc
I3N180	240de	234ad	19.8cde	24.17abc	8.75a	8.17 a	62.000bc	53.250 be	40.908bcd	32.617bcd	0.930abc	1.10ad	487ad	400b	5.45ab	4.39ab
I4N0	224fg	216f	18.83de	20.00gh	8.92a	841 a	47.583d	42.583 f	29.800e	26.525 f	0.792 e	1.02d	30h	241 f	4.66cf	4.14abc
I4N90	230ef	223ef	18.83de	21.17fh	7.92a	8.41 a	49.167d	48.167def	31.625e	28.925bef	0.825 de	1.17abc	370fg	320bcd	4.94ad	4.52a
I4N135	224fg	229de	21.17ad	20.42fgh	7.83a	7.58 a	47.000d	46.667ef	29.383e	28.175ef	0.807e	1.21ab	349gh	304def	4.59def	4.40ab
I4N180	216g	218f	18.33e	18.92h	8.67a	8.41 a	47.167 d	48.917cf	29.858e	27.408f	0.865be	1.22a	363fgh	324cde	4.66cf	4.28abc
Anova																
Irrigation	7243**	1970**	15.1*	77.9**	0.65^{ns}	2.04^{ns}	1956**	418**	1010**	225**	0.115**	0.04^{ns}	97750**	39530**	7.76**	4.25**
Nitrogen	1271**	305^{ns}	18.7^{ns}	19.^{3ns}	1.41^{ns}	0.32^{ns}	223**	89^{ns}	38^{ns}	59^{ns}	0.007^{ns}	0.06*	24605*	36887**	0.63^{ns}	0.91^{ns}
I *N	243**	71^{ns}	2.6^{ns}	6.4^{ns}	0.50^{ns}	0.74^{ns}	45 ^{ns}	37^{ns}	21^{ns}	19^{ns}	0.004^{ns}	0.02^{ns}	4389^{ns}	4550^{ns}	0.28^{ns}	0.18^{ns}

Similar letters in each column of irrigation, Nitrogen and Irrigation*Nitrogen, represent insignificant differences between the two treatments related to the parameter.

in each tillage system was applied to the soil at planting time, at V3 stage, and at V10 stage. Based on the soil test results, triple superphosphate and zinc phosphate were uniformly applied to each treatment plots at 200 and 40 $kg.ha^{-1}$, respectively.

In the harvesting time, plant height, stem diameter and numbers of plants in square meter, soil organic carbon and wet foliage yields of each plot were measured. The wet foliage were dried at 65-70°C to find out dry foliage yield. In dry foliage, concentration and uptake of N, P, K and Zn were measured. Measured parameters as well as water use efficiency was evaluated with SAS version 9.2 (analysis of variance). When main effects were significant, the means were compared by using Duncan's multiple range tests.

RESULTS AND DISCUSSION

Tillage had a significant effect on the plant height, stem diameter, number of $plant.m^{-2}$, fresh and dry yield, N uptake by foliage and soil organic carbon after harvesting (Table 3). As the mean plants height and number of plants per square meter were significantly higher in CT than NT (by 5.6% and 8.1%, respectively), the fresh and dry foliage yield was higher in CT than in NT by 13.5 and 24.8% (Table 3). This result is in accordance with Zhang *et al.* (2018) and Ziaeian *et al.* (2019) who reported that the corn yield in conventional tillage was more than no-tillage. Based on Jin *et al.* (2017) reports deep ploughing in conventional tillage can decrease subsoil density, thereby increase soil water storage and crop yield. Van den Putte *et al.* (2010) believed that limited root growth due to soil compaction in the no-tillage system, can lead to reduced contact between the crop roots and the soil in the root zone, and may decrease plant water and nutrients absorption. In contrast with our results, Rani *et al.* (2019) reported that there were no statistical differences between conservation and conventional tillages in terms of grain yield. Singh *et al.* (2016) also believed that conservation tillage improved soil physical status like soil density, soil porosity and field capacity and Chen *et al.* (2015) reported that conservation tillage practices could capture rainfall effectively and could improve soil water and then improved crop yield.

Tillage also had a significant effect on water use efficiency. On the average over two experimental years, WUE was higher in CT than in NT by 18.0% (Table 3). Overall, conventional tillage system with average yield 39283 $kg.ha^{-1}$ and WUE average 4.95 $kg.m^{-3}.ha^{-1}$ was significantly superior to no-tillage system by average yield 32015 $kg.ha^{-1}$ and average WUE of 4.06 $kg.m^{-3}.ha^{-1}$ (Table 3).Various tillage can increase soil water content (Sharma *et al.* 2011). There are sufficient pore spaces in conventional tillage which causes a better development of the tap root (Van den Putte *et al.* 2010). Another possible explanation for WUE in conventional tillage is that deep ploughing can decrease subsoil density, thereby increase soil water storage and crop yield (Jin *et al.* 2017). In contrast, conventional tillage may have negative effects on water productivity and yield (Alletto *et al.* 2011). It has been shown that WP can be improved by conservation tillage system such as no-tillage and reduced tillage systems and these systems are more useful and more effective in reducing soil erosion (Mohammadi 2012, Safari *et al.* 2013). Shao *et al.* (2016) reported that conventional tillage without straw mulching, which is widely used in semi-arid region, remarkably increased soil water loss via evaporation.

Combined effects of irrigation water, nitrogen and tillage systems on the yield contributing characters are presented in Table 4. In general, the amounts of plants height, number of plants per square meter, yield and WUE in CT were higher than NT in the same treatments so that in I2N180 treatment, amounts of plant height and number of plants per square meter, fresh and dry foliage yield and WUE in conventional tillage were higher than to no-tillage system by 8.6, 9.8, 13.2, 16.9 and 16.9 %, respectively. It has been reported that yield is a function of photosynthesis rate. Water stress resulting in reduced photosynthesis. Reduced photosynthesis reduces yield (Mafakheri *et al.* 2010). Drought stress reduces stomata conductance and net photosynthesis, shortens plant growth and ultimately reduces yield (Rajjala *et al.* 2009). Nitrogen application also had significant effects on yield and WUE. Azizian and Sepaskhah (2014) reported that nitrogen by influencing on cell division and by helping absorption of other nutrients increased plant growth. Subedi *et al.* (2007) reported that application of sufficient nitrogen leads to increased root growth and improved capability to absorb water from the deeper soil layers under drought conditions.

Conclusion

Tillage systems affected the irrigation and nitrogen application rates, yield and water use efficiency (WUE). The maximum dry foliage yield in conventional (CT) and in no-tillage systems (NT) (48783 and 38405 $kg.ha^{-1}$, respectively) were obtained from combined application of 8550 $m^{-3}.ha^{-1}$ irrigation water and 90 kg $N.ha^{-1}$(I2N90) and combined application of 8550 $m^{-3}.ha^{-1}$ irrigation water and 135 kg $N.ha^{-1}$ (I2N135) treatments, respectively, which are recommendable in the same conditions. The maximum WUE in CT (5730 $kg.m^{-3}.ha^{-1}$) were obtained from I2N90 treatment and in NT (4520 $kg.m^{-3}.ha^{-1}$) were obtained from combined application of 7500 $m^{-3}.ha^{-1}$ irrigation water and 90 kg $N.ha^{-1}$ (I3N90) or combined application of 6400 $m^{-3}.ha^{-1}$ irrigation water and 90 kg $N.ha^{-1}$ (I4N90) treatments. In general, combined application of 90 kg $N.ha^{-1}$, and 8550 $m^{-3}.ha^{-1}$ of irrigation water and combined application of 135 kg $N.ha^{-1}$ and 7500 $m^{-3}.ha^{-1}$ irrigation water are introduced as the superior treatment in conventional tillage and in no-tillage systems, respectively.

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