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Wheat Yield as Influenced by Nitrogen Rates, Sources and Tillage Systems

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Authors' contributions

This work was carried out in collaboration between all authors. Author MJB proposed the study, complimented the literature searches and analysis, translated and prepared it into a manuscript. Author MD conducted the experiments, collected the data, performed the statistical analysis and managed the literature searches and analysis of the study and prepared it as a MS thesis in Farsi in collaboration with authors MJB and SAK who supervised the experimentation as well. All authors read and approved the final manuscript.

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ABSTRACT

Conservation tillage systems present a challenge for integrating an efficient fertilizer program in wheat (*Triticum aestivum* L.) production. A 2-year (2011–2013) field experiment was conducted to evaluate wheat response to three tillage systems (conventional, reduced and no tillage) and four nitrogen (N) [(0, 60, 120, 180 kg ha^{-1}), and two nitroxin rates (0, 180 kg ha^{-1})] at School of Agriculture, Shiraz University, Shiraz, Iran. The experiment was conducted as a split plots arranged in randomized completely blocks design with three replications. Results showed that grain yield and most of the yield components were significantly influenced by tillage systems, N rates and sources. Nitroxin inoculation did not accomplish significant difference in grain yield, but it increased grain yield when it was applied with 180 kg urea ha^{-1} compared to no nitroxin treatment. The highest grain and biological yields were obtained when crop was sown under reduced tillage (RD) system combined with 180 kg ha^{-1} of nitroxin inoculation. Therefore, for sustained production of wheat in the region, integration of 180 kg ha^{-1} of nitroxin inoculation under RD system is recommended.

Keywords: Biological fertilizers; conservation tillage; nitrogen availability.

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ABBREVIATIONS

CT : Conventional Tillage
RD : Reduced Tillage
NT : No Tillage
N : Nitrogen

1. INTRODUCTION

Crop production heavily depend on soil N availability, and its application rate should be carefully managed in farm to be available through the growing season and not limiting the vegetative and reproductive growth of crop, while its loses is kept at minimum [1]. Excessive N application could result in a high soil nitrate concentration which may leach to groundwater. The best way to solve these problems is application of biological N fertilizers which could decrease the use of the chemical N fertilizer, prevent the depletion of soil organic matter and reduce environmental pollution [2].

Nitroxin is a biological N fertilizer containing *Azospirillum* and *Azotobacter*. Azospirillum belongs to family *Spirilaceae*, heterotrophic and associative in nature. Azotobacter belongs to family *Azotobacteriaceae*, aerobic, free living, and heterotrophic in nature and are present in neutral or alkaline soils. The number of Azotobacter rarely exceeds 105 g^{-1} of soil due to lack of organic matter and presence of antagonistic microorganisms in soil [3,4]. In addition to their N fixing ability, they also produce growth regulating substances [5].

Biofertilizers are microbial inoculants consisting of living cells of micro-organism like bacteria, algae and fungi alone or combinations which may help promoting crop growth by converting nutritionally important elements (N, P) from unavailable to available form through biological process such as N fixation and solubilization of rock phosphate [6,7,8]. Biological activities are markedly enhanced by microbial interactions in rhizosphere of plants. They are beneficial to the soil, as they enrich it with micro-organisms that help producing organic nutrients, which in turn help the soil to fight diseases. They also restore the depleted nutrients of the soil [6]. Hasanudin et al. [8] concluded that soil inoculation with azetobacter and organic matter increased soil N and P availability and finally grain yield of corn (*Zea mays* L.).

In conservation tillage, N rates have been generally, increased by as much as 25% to prevent yield limitations from short-term N immobilization [9,10]. Ebrahim and Aly [9] showed that wheat grain yield was higher under NT than CT even when the soil fertility was low. Bahrani et al. [11] found the highest irrigated corn yield under reduced than CT systems.

Tillage systems can affect soil components that are important to crop growth and N availability. The effect of any tillage system on maintaining adequate N rates in the soil system is therefore critical to the sustainability of crop production systems. The integration of appropriate tillage and N management systems for sustainable crop production thus presents a significant challenge.

The integration between tillage systems, N rates, and sources is an important issue from production, economical, and environmental perspectives. The purpose of this research was to evaluate the influence of different tillage systems and N rates and sources on grain yield and yield components of wheat in wheat-corn rotation in southern Iran where these crops are intensively grown under irrigation.

2. MATERIALS AND METHODS

2.1 Study Area

A two-year (2011–2013) field experiment was conducted at School of Agriculture, Shiraz University (358520 E, 408290 N, altitude 1810 m asl), Shiraz, Iran, on a silty loam fine, mixed mesic, Typic Calcixerpets soil with pH of 7.4, EC of 0.70 dS/m, total N and organic C contents of 0.40 and 0.61%, respectively. The region represents semi-arid climatic conditions with relatively warm summers and cold winters.

2.2 Experimental Procedure

The experiment was conducted as a split plot arranged in randomized completely blocks design with three replications. The treatments were three tillage systems [(conventional (CT), reduced (RT), and no tillage (NT)] as main plots, four N rates [(0, 60, 120, 180 kg ha^{-1}), as urea], and two nitroxin rates (0, 180 kg ha^{-1})] as subplots. Prior to the study, the whole experimental site was grown to irrigated corn (SC 704 cv.) under moldboard plow system in both years.

In CT treatment, moldboard plow disturbed soil to a 30 cm-depth followed by two vertical tillage with harrow disking. For RD treatment, soil was disturbed to a depth of 15– 20 cm using a chisel plow followed by a single harrow disking, with partial incorporation of crop residues. In NT treatment, the seeds were sown with pneumatic row planter.

Winter wheat (Shiraz cv.) was planted at a rate of 200 kg ha^{-1} using a penumatic planter in 4 x 4 m plots in 11 and 20 November of the first and second year, respectively. The wheat seeds were disinfected with carboxin (200 g per 100 kg seed) prior to planting. Nitrogen was broadcasted both at sowing and stem elongation times as urea (46% N). Bilogical fertilizer was inoculated nitroxin (mixture of N fixing bacteria including Azetobacter and Azosperilium with concentration of 10^8 live bacteria per g of inoculant (recommended by Aryamehr Inc.,Tehran) at two l ha^{-1} with seeds half at planting time and the other half sprayed at tillering stage. Phosphorus fertilizer was applied at sowing time as triple superphosphate (150 kg ha^{-1}). Plots were uniformly irrigated every 10 days and weeds were controlled with herbicide Total (30 g ha^{-1}) during both growing seasons.

2.3 Measurements

Crop emergence rate was measured by throwing a 1 m quadrate in each plot and count seedlings number a week after sowing. Twenty spikes were randomly selected from each plot, grains were separated from trash and counted, divided by 20 to calculate grains per spike. To determine 1000-grain weight, four samples of 100 clean grains were dried in oven to reach 14% moisture and weighed.

Biological yield was determined at harvest time when plants of 1 m^2 of each plot were cut at the stem base, dried in an oven at 72 C° for 24 hr and weighed. Then spikes were trashed to separate the grains and weighed for grain yield. Three leaves were randomly selected from each plant at grain feeling stage and their chlorophyll contents (first, middle and final parts) were measured by portable chlorophyll meter (SPAD 502).

2.4 Statistical Analysis

Data were statistically analyzed for each year by SAS 9.1 and M STAT C [12] software. Means were separated by Duncan's Multiple Range Test at $p \leq 0.05$.

3. RESULTS AND DISCUSSION

Results showed that the highest grain yield was obtained with the highest nitroxin rate with no significant difference with the highest urea rate in first year, but the difference was notable in second year indicating the enhancing effect of nitroxin in yield increase (Table 1) as shown in other plants [13,14,15,16, 17].

Rotor and Delima, [18] indicated that biological fertilizers cannot alone increase seed yield of crop comparable to chemical fertilizers and they can provide only half of the N requirements of crop. Ghazavi (19) also reported that biological fertilizers had only enhancing and complementary effects on yield increase and could not replace chemical fertilizers. However, Farnia and Hasanpoor (20) reported that yield of wheat increased with urea more than biological fertilizers.

Table 1. Effect of tillage systems, urea and/or nitroxin rates on wheat grain yield for two years (kg ha^{-1})

Tillage system	Urea or nitroxin rates (kg ha^{-1})							
	0	**60**	**120**	**180**	**240**	**N0**	**N180**	**Mean**
2011-2012								
CT	1992hij	2184ghi	2642bcd	3139bcd	2707def	1603j	3264j	2504A
RT	1596i	2757ef	2603efg	3349b	2942be	2269fi	4070a	2755A
NT	825k	1852ij	1921ij	2479eh	2512eh	1007k	2750cf	1907B
Mean	1472D	2165C	2389C	2989B	2720B	1627D	3361A	
2012-2013								
CT	1986ghi	2595fg	2925ef	367bcd	4029ab	1835hi	3921abc	2995A
RT	2219ghi	2397fg	3450cde	3525bcd	39225abc	2373fgh	4289a	3168A
NT	1738ghi	1975ghi	2743ef	3147de	3524bcd	1807i	3641bcd	2654B
Mean	1981D	2322C	3040CB	3449B	3826A	2005D	3950A	

Means with similar small and capital letters (columns and rows) are not significantly different (Duncan 5%). CT, conventional tillage; RT, reduced tillage; NT, No tillage; N, nitroxin

Wheat grain yield was significantly affected by tillage systems, N rates and sources and their interactions with the highest grain yield was obtained under RT system accompanied by 180 kg ha^{-1} nitroxin application in second year with no significant difference with CT system (Table 1). Grain yield increased with increased urea rates in both years across the tillage systems. Nitroxin also increased yield in both years with no significant difference with the highest urea rate. Changing the tillage from CT to NT systems reduced grain yield by 23.9% and 16.9% in first and second year, respectively. However, the highest biological yield was obtained under CT system accompanied by 180 kg ha^{-1} of nitroxin application in first year. Biological yield was significantly affected by tillage systems and the highest grain yield was achieved under RT with no significant difference with CT system in second year (Table 2) and it significantly decreased from CT to NT systems by 6.9% and 9.2% in first and second year, respectively.

Winter wheat yield depression under conservation tillage systems compared to conventional practices has also been reported due to residues accumulation [21], low growth due to lower soil temperatures during the first stages of the growing seasons [22], or N immobilization [23] or phytotoxin accumulation by crop residues [24]. However, Camara et al. [23] concluded that the effect of N depended on yearly rainfall of the region, but N, generally increased grain yield. However Papendick, and Miller [25], Payne et al. [26], Mrabet et al. [27], Hemmat and Eskandari [28], and Alijani et al. [29] found higher grain yield of wheat under RT than CT systems. Norwood et al. [30] found the highest grain yield of wheat after corn under RT system due to higher spikes per m^2 and thereby grains per spike. Kwaw-Mensah and Al-Kaisi [31] reported that the interaction between tillage systems and N rate for corn were more frequent with chemical N fertilizer, where most growth stages showed a favorable response to tillage and N rates, especially with N rates between 85 and 170 kg ha^{-1} with chisel plow and strip tillage systems.

The interaction between tillage systems and N rates and sources is not well documented. A long-term tillage study with spring wheat using conventional, minimum and no tillage along with three N rates (0, 22, and 45 kg N ha^{-1}) showed the highest response of wheat yield to N under conventional and minimum tillage systems for all N rates in years when precipitation was high [32]. Azarpur et al. [33] found high seed yield of faba bean (*Vicia faba* L.) under CT combined with 25 kg N application and nitroxin inoculation.

Table 2. Effect of treatments on wheat biological yield and 1000-grain weight for two years

Treatment	Biological yield (kg ha^{-1})	1000-grain weight (g)
2011-2012		
Urea or nitroxin (kg ha^{-1})		
0	5522f	22.3c
60	8470d	23.9c
120	8611d	24.3b
180	9933c	26.7b
240	10311b	27.8a
N0	103116	23.7c
N180	7090	29.1a
Tillage system		
CT	8638b	24.9b
RT	9434a	27.0a
NT	8043c	24.4b
2012-13		
0	8000c	26.6c
60	8483c	29.7b
120	9600b	29.6b
180	10113b	30.6ab
240	10523a	32.3a
N0	8055c	26.8c
N180	10486a	32.1a
Tillage system		
CT	9430a	29.3b
RT	9570a	31.4a
NT	8970a	28.4b

Means with similar small letters in each treatment are not significantly different (Duncan 5%).
CT, conventional tillage; RT, reduced tillage; NT, No tillage; N, nitroxin

The highest wheat 1000-grain weight (Table 2), grains per spike (Table 3) and tillers per m^2 (Table 4) were obtained under RT system accompanied by 240 ha^{-1} of urea application and180 kg ha^{-1} nitroxin inoculation, respectively in second year with no significant difference with 180 kg urea ha^{-1} . Increased urea rates increased 1000-grain weight, but it was insignificant under CT and NT systems in first year. 1000-grain weight was higher in RT than other systems in both years. Changing tillage from CT to NT systems reduced grains per spike in first year, but it was insignificant compared to RT, while in second year, there was no significant difference between CT and NT systems.

Table 3. Effect of tillage systems, urea and/or nitroxin rates on grains per spike

Tillage system	Urea or nitroxin rates (kg ha^{-1})							
	0	60	120	180	240	N0	N180	Mean
2011-2012								
CT	23.3gh	38.3cde	40.3cd	44.1c	54.0b	28.2egh	55.7ab	4.05A
RT	23.0h	38.7cde	42.0c	54.7b	9.7 0ab	30.0efg	30.efg	44.0A
NT	23.0h	28.3fgh	32.0efg	38.3cd	43.0c	25.7gh	60.0a	33.7B
2012-2013								
CT	26.3mn	30.7n	36.0gh	50.8cd	56.0bc	40.jjn	58.7ab	41.3B
RT	27.0mn	40.0ei	45.ef	58.5ab	62.7ab	37.0fi	63.0a	47.6A
NT	24.0n	29.3kn	40.0ei	50.0cd	41.4cd	28.7mn	51.7cd	38.8B
Mean	25.8E	35.0D	40.3C	53.5B	55.4AB	32.0D	57.8A	

Means with similar small and capital letters (columns and rows) are not significantly different (Duncan 5%). CT, conventional tillage; RT, reduced tillage; NT, No tillage; N, nitroxin

The highest grains per spike was achieved under RT system and 180 kg urea ha^{-1} accompanied with nitroxin application in second year (Table 3). Changing the tillage from CT to NT systems significantly reduced grains per spike in first year with no significant difference with RT system. Therefore, it seems that changing the tillage system cannot compensate crop N requirement. Inoculation with nitroxin did not bring about significant difference in wheat grains per spike in second year, but it increased them by 48% compared to no nitroxin treatment when it was accompanied by 180 kg urea ha^{-1}**.** However, Reiger et al. [34] showed that tillage systems did not have a significant effect on grains per spikes of wheat grown after corn. Sherifi and Haghnia [35] also found that nitroxin cannot solely affect wheat grains per spike.

Tillers per m^2 was significantly influenced by tillage systems and N sources with the highest in RT system accompanied by 240 kg urea ha^{-1} in second year with no significant difference with180 kg ha^{-1} of nitroxin inoculation (Table 4). Increased urea rates significantly increased tillers per m^2 and the effect of higher nitroxin rates on tillers number were pronounced more than urea. RT system had generally higher tillers per m^2 compared to other tillage systems in both years as indicated by Reiger et al. [34].

The highest crop emergence rate (CER) was obtained from RT system and 240 kg urea ha^{-1} in both years with no significant difference with 180 kg ha^{-1} of nitroxin inoculation in first year (Table 5). CER increased with increased urea and nitroxin rates in both years, but higher nitroxin rates had higher CER than the highest urea rate in second year.Tillage systems had a significant effect on CER with the lowest in NT in second year. Presence of crop residues on untilled soil often lead to poor crop stablishment and reduce CER, particularly in heavy soils [24]. There was no significant difference between CT and RT systems for CER.

Table 4. Effect of tillage systems, urea and/or nitroxin rates on tillers per m^2

Tillage system	Urea or nitroxin rates (kg ha^{-1})						
	0	60	120	180	240	N0	N180
2011-2012							
CT	4.7ij	7.0ef	6.7rfg	7.3de	9.3bc	5.0hij	10.0ab
RT	5.3hij	7.3de	6.0fgh	8.3cd	10.7a	5.7ghi	11.0a
NT	4.3j	5.7ghi	5.7ghi	7.3de	7.3de	4.3j	7.3de
Mean	4.8D	6.7C	6.1C	7.7B	9.1A	5.0D	9.4A
2012-2013							
CT	5.3i	6.3ghi	7.0fgh	7.7efg	11.0bc	5.7hi	11.0bc
RT	5.7hi	7.0efg	8.3def	9.7cd	13.0a	7.7efg	12.3ab
NT	5.1i	6.0ghi	6.7ghi	8.7de	9.7cd	7.3efg	10.7c
Mean	5.1D	6.7CD	7.3C	8.7B	11.2A	6.9CD	11.3A

Means with similar small and capital letters (columns and rows) are not significantly different (Duncan 5%). CT, conventional tillage; RT, reduced tillage; NT, No tillage; N, nitroxin

Table 5. Effect of tillage systems, urea and/or nitroxin rates on crop emergence rate (%)

Tillage system	Urea or nitroxin rates (kg ha^{-1})							
	0	**60**	**120**	**180**	**240**	**N0**	**N180**	**Mean**
2011- 2012								
CT	37.1k	59.5h	63.0fi	75.9cf	81.9abc	73.0abc	78.7bcd	67.0A
RT	43.3jk	44.3ei	70.6cg	90.73ab	94.5a	60.9ghi	91.3a	70.8A
NT	39.1k	51.1ijk	53.hij	66.5dh	73.1be	42.4jk	69.1cg	56.4B
Mean	39.9A	51.6 C	62.3 AB	77. 0A	83.1 A	58.7 C	69.7 B	
2012-2013								
CTl	41.1i	58.def	63.6cf	62.1cf	82.7ab	69.1efg	68.7cd	63.7A
RT	40.0hi	55.1efg	64.0cd	66.0cd	86.1a	52.0fgh	83.1ab	63.8A
NT	33.3i	42.9hi	44.7ghi	55.2ef	57.3def	35.9i	64.5cde	47.7B
Mean	38.1D	52.3C	57.6C	61.1B	75.3A	53.3C	72.0 A	

Means with similar small and capital letters (columns and rows) are not significantly different (Duncan 5%). CT, conventional tillage; RT, reduced tillage; NT, No tillage; N, nitroxin

Table 6. Effect of tillage systems, urea and/or nitroxin rates on leaf chlorophyll content (SPAD) in 2012 – 2013

Tillage system	Urea or nitroxin (kg ha^{-1})							
	0	**60**	**120**	**180**	**240**	**N 0**	**N180**	**Mean**
CT	42.3i	36.1ghi	39.1be	41.3abc	41.3abc	36.1fi	40.8be	38.2A
RT	35.8ghi	37.5eh	37.9iefg	40.7bcd	41.7ab	35.9ghi	40.8bc	38.6A
NT	33.6i	36.0ghi	37.9def	38.9cf	40.8bc	35.1hi	39.7be	37.3A
Mean	34.6E	36.5D	38.3C	39.5BC	41.1A	35.7E	40.4AB	

Means with similar small and capital letters (columns and rows) are not significantly different (Duncan 5%). CT, conventional tillage; RT, reduced tillage; NT, No tillage; N, nitroxin

Tillage systems did not significantly change leaf chlorophyll content (LCC) which is similar to Abdolahi [36] in corn and Bronson et al. [37] in cotton (*Gossypium hirsutum* L.). The highest LCC was obtained under RT system accompanied by 240 kg urea ha^{-1} (Table 6). Increased urea rates, generally increased LCC with no significant difference between different fertilizer sources.

4. CONCLUSIONS

Results of these experiments showed that wheat grain and biological yields, 1000-grain weight, grains per spike and tillers per m^2 were significantly affected by tillage systems, N rates and sources, their interactions and years. The highest grain yield, grains per spike, tillers per m^2 and CER were obtained under RT system combined with 180 kg ha^{-1} of nitroxin inoculation. Nitroxin inoculation did not accomplish significant difference in wheat grains per spike in second year, but it increased them compared to no nitroxin treatment when it was accompanied by 180 kg urea ha^{-1}. There was no significant difference for crop emergence rate under CT and RT systems. Therefore, integration of 180 kg ha^{-1} of nitroxin inoculation under RT system is recommended for sustained production of wheat in the region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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