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THE EFFECT OF TILLAGE AND WHEAT RESIDUE MANAGEMENT ON NITROGEN UPTAKE EFFICIENCY AND NITROGEN HARVEST INDEX IN WHEAT

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ABSTRACT

In order to evaluate the effects of tillage and wheat residue management on nitrogen uptake and distribution, nitrogen uptake efficiency, nitrogen use efficiency and nitrogen harvest index in wheat, a two-year field experiment was implemented as a split block experiment in a randomized complete block design with twenty treatments and three replicates at experimental site of Ferdowsi University of Mashhad, Iran in 2013 and 2014 growing seasons. Four different tillage practices namely, conventional tillage applied by mouldboard plough + disk, reduced tillage practices applied by sweep plough + disk and chisel plough + disk and conserved tillage applied by disk as vertical factor and five different crop residue applications (0, 25, 50, 75 and 100% wheat residue) as horizontal factor. According to the results, the lowest (2.58 %) and highest (2.77%) grain nitrogen percentage were observed when disk and chisel plough + disk were used, respectively. Employing chisel plough + disk led to the maximum nitrogen uptake efficiency and nitrogen use efficiency. Grain nitrogen percentage, nitrogen uptake efficiency and nitrogen use efficiency significantly increased with increasing wheat residue level. For instance, when wheat residue was applied at 75% ratio, nitrogen uptake efficiency increased by 61.2% compared with control treatment. According to the results it appears that application of wheat residue along with reduced tillage could improve nitrogen utilization efficiency, especially in arid and semi-arid regions.

Keywords: Nitrogen harvest index, Nitrogen uptake efficiency, Nitrogen use efficiency, Reduced tillage, Residue management, Wheat.

INTRODUCTION

Nitrogen is the most important of all major nutrients and plays a key role in photosynthesis, vegetative growth and protein synthesis in wheat (Salvagiotti et al., 2009). Accordingly, nitrogen fertilizers, whether applied as organic materials or as mineral nitrogen, are therefore a key element to gain maximum yield and improve final product quality in wheat production (Kazemzadeh and Peighambar Doust, 2013). Unfortunately, nitrogen fertilizers are often used more than optimized limit, which not only increase production costs but also create critical environmental problems (Guarda et al., 2004; Zheng et al., 2007). Nitrogen loss in wheat is not limited to field, a considerable amount of nitrogen loss occurs after harvest and during processing and consumption of the crop (Koocheki et al., 2012; Hu et al., 2014). It has been reported that increase in nitrogen loss is more likely when mineral fertilizers are used (Soltani et al., 2013). Therefore, choosing fertilizer type and proper fertilizer management could result in lower nitrogen loss (Soltani et al., 2013). Consequently, determining required nitrogen, particularly from organic sources to gain maximum economic yield and reduce nitrogen loss should be taken into account more than ever (Ankumah et al., 2003).

Nitrogen use efficiency is defined as kg of yield per kg consumed fertilizer which represents the ability of the crops to take available nitrogen and turn it to economic yield (Salvagiotti et al., 2009). Nitrogen use efficiency is defined by interactions between its components such as nitrogen uptake efficiency (quotient of plant nitrogen uptake and total crop nitrogen supply) and physiological nitrogen use efficiency (quotient of yield and uptake nitoegn) (Lea and Azevedo, 2006; Salvagiotti et al., 2009).

Increase in nitrogen use efficiency is one of the most important strategies for increasing agricultural production and reducing environmental pollution (Limon-Ortega et al., 2008; Koocheki et al., 2012). According to Moraghebi et al. (2011), grain yield, grain protein content and grain protein yield in wheat linearly increased with increasing nitrogen application, however, nitrogen use efficiency and physiological nitrogen use efficiency significantly decreased. In addition to nitrogen use efficiency, nitrogen harvest index (an indicator of the up-taking nitrogen transformed into the biomass of the usable plant organs) could help to understand the relationships between quality and nitrogen application (Salvagiotti et al., 2009; Koochei and Seyyedi, 2015).

Conservation tillage, which is based on zero or reduced tillage practices, and maintaining crop residues on soil surface, play a critical role in improving soil fertilization (Ghuman and Sur, 2001; Rezvani Moghaddam et al., 2013; Faligowska and Szukała, 2015) by increasing soil organic matter and nutrients availability, especially nitrogen (De Gryze et al., 2005; Liu et al., 2006; Singh and Haile, 2007). Furthermore, considering the positive effects of crop residue in stimulating microbial activity, improving soil structure and permeability and reducing water erosion (De Gryze et al., 2005; Monzon et al., 2006; Bastian et al., 2009), it seems that application of crop residue would improve nitrogen uptake efficiency and nitrogen use efficiency through increasing nitrogen availability and reducing nitrogen leaching. In this context, it has been reported that application of mushroom waste medium could increase growth characteristics, yield and nitrogen uptake by wheat (Seyyedi and Rezvani Moghaddam, 2011).

The aim the current study was to evaluate the effects of tillage and wheat residue management on nitrogen uptake and distribution, nitrogen uptake efficiency, nitrogen use efficiency and nitrogen harvest index in wheat.

MATERIALS AND METHODS

The experiments were carried out during 2013 and 2014 growing seasons as a split block experiment in a randomized complete block design with twenty treatments and three replicates at experimental site of Ferdowsi University of Mashhad, Iran. The average monthly rainfall and temperature are given in Table 3.

Prior to the experiment, soil samples were randomly collected across the field from 0-30 cm depth to determine physical and chemical properties. The results are given in Table 4.

The experimental treatments consisted of twenty combinations of two factors: four different tillage practices namely, conventional tillage applied by mouldboard plough + disk, two reduced tillage practices applied by sweep plough + disk and chisel plough + disk and conserved tillage applied by disk as vertical factor and five different crop residue applications (0, 25, 50, 75 and 100% wheat residue) as horizontal factor.

In the first year, the required amount of wheat residue (5250 kg ha^{-1}) was determined based on the straw and stubble produced by local farmers (Table 5). The wheat residue were imported to the field and incorporated into the soil at the depth of 30 cm just after performing tillage practices on 21st of May. In the second year, the amount of applied wheat residue was determined based on the produced straw and stubble from the first year and then incorporated into the soil on June 20th as mentioned above.

Each experimental plot was 3 × 3 m consisted of 6 rows spaced 0.5 m apart. One m distance between the blocks and between each plot was considered to prevent lateral water movement and other interferences.

Winter wheat (*Triticum aestivum* c.v Cascogen) seeds were sown on 11th and 16th of November in the first and second year, respectively. The plant density of 200 plants per m^2 was selected. The furrow irrigation was performed immediately after seed sowing. Polyethylene pipelines and a water counters were installed to control irrigation water. During crop growth period no chemical fertilizer, herbicide or pesticide were applied. Weeds were removed manually.

At maturity stage, when all the plants turned yellow (20th of June in 2013 and 23rd of June in 2014) the crop was harvested and grain yield and biological yield were determined. In addition, nitrogen uptake efficiency, nitrogen used efficiency and nitrogen harvest index were calculated using following equations:

Equation 1: Grain nitrogen content (g m^{-2}) = Grain weight (g m^{-2}) × Grain nitrogen percentage

Equitation 2: Plant nitrogen content (g m^{-2}) = Plant weight (g m^{-2}) × Plant nitrogen percentage

Equation 3: Nitrogen uptake efficiency (%) = Plant nitrogen content/Soil nitrogen content × 100

Equation 4: Nitrogen use efficiency (g grain g nitrogen in the soil) = Grain yield/ Soil nitrogen content

Equation 5: Nitrogen harvest index (%) = Grain nitrogen content/ Plant nitrogen content × 100

Nitrogen percentage in different part of plant was determined using micro-kjeldahl method (AOAC, 2000).

Four soil samples were collected from each plot using an auger. The data were obtained by averaging out four obtained data for each plot. Soil nitrogen content was calculated based on the soil nitrogen content before initiating the experiment and added nitrogen due to wheat residue per unit area.

All data were subjected to analysis of variance (ANOVA) using SAS software (version 9.3). When an F test indicated statistical significance at $P < 0.01$ or $P < 0.05$, the protected least significant difference test (protected LSD) was used to separate the means of main effect.

RESULTS AND DISCUSSION

Nitrogen percentage in different parts of wheat

The results indicated that grain, straw and root nitrogen percentage was significantly affected by tillage practices and crop residue levels. However, interaction between tillage practices and crop residue levels was not statistically significant on these parameters (Table 1). In addition, the main effect of year, interaction between year and tillage practices and interaction between year and crop residue levels were not significant (Table 1).

According to the results, chisel plough + disk treatment was more effective in increasing grain, straw and root nitrogen content compared with the other tillage practices (Table 2). For example, chisel plough + disk treatment increased nitrogen percentage in grain and straw by 7.4 and 14%, respectively, compared with mouldboard plough + disk treatment (Table 2). From the results, grain, straw and root nitrogen percentage increased with increasing wheat residue rate (Table 2). However, there was no significant difference between 75 and 100% wheat residue treatments in terms of grain, straw and root nitrogen percentage (Table 2). For instance, grain nitrogen percentage increased by 32% due to application of 75% wheat residue treatment compared with control treatment (Table 2).

Generally, increases in soil aggregate stability, soil water content and organic matter and nutrients are the main benefits of conservation tillage (Hobbs et al., 2008; Thierfelder and Wall, 2010; Farooq et al., 2011). Hence, the combination of these benefits can lead to increase in nitrogen uptake by plants through increasing nitrogen availability and stimulating plant growth. On the other hand, since chisel plough does not turn the soil, so water and nutrients loss as well as soil structure disturbance would be at a minimum compared with mouldboard plough (Azim Zadeh et al., 2002; Mazaheri and Majnon Hoseini, 2007). Accordingly, increase in nitrogen uptake in wheat might be due to improved soil quality in terms of nutrients availability and lower nitrogen loss.

Nitrogen uptake in different parts of wheat

From the results given in Table 1, the main effects of tillage practice and wheat residue levels were found to be significant on grain, straw and plant nitrogen content. Moreover, except for plant nitrogen content, none of these parameters were affected by interaction between tillage practices and wheat residue levels (Table 1). Furthermore, the main effect of year, interaction between year and tillage practices and interaction between year and crop residue levels were not significant (Table 1).

The results revealed that the highest and lowest grain, straw and plant nitrogen content were observed when chisel plough + disk and disk practices were applied, respectively (Table 2). In comparison with mouldboard plough + disk, grain, straw and plant nitrogen content was significantly higher when chisel plough + disk practice was applied. Similar to nitrogen percentage, nitrogen content in grain, straw, root and plant significantly increased with increasing wheat residue levels up to 75%. The lowest nitrogen content was observed in control treatment (Table 2). The maximum absorbed nitrogen in wheat plants (30.4 g m^{-2}) was obtained when chisel plough + disk was accompanied 75% of with wheat residue (Figure 1).

In general, nutrient availability due to gradual mineralization of organic nitrogen during growing season is known as the most important advantages of crop residues application, (Azadshahraki et al., 2011; Li et al., 2015). Hence, according to equations 1 and 2, increase in nitrogen uptake per unit area, not only can be affected by nitrogen uptake by plants, but also might be due to more vegetative growth and seed weight per unit area. In this regard, increase in leaf area index and dry matter production in barley due to wheat residue application has been documented by Sadeghi and Kazemeini (2011).

During decomposition of crop residue with high carbon to nitrogen ratio, soil nitrogen is consumed by microorganisms, which might result in reduced availability of nitrogen for the plants (Foroughifar and Poor-Kasmani, 2002; Ruffo and Bollero, 2003). In the current study, wheat reside were applied before seed sowing in summer, therefore increase in dry matter production and nitrogen uptake was mainly due to gradual release of elements from the decomposed wheat residue and microorganisms. As mentioned earlier, reduction soil disturbance, wind and water erosion and nutrients loss, which are the main benefits of conservation tillage (Farooq et al., 2011), can lead to increase plant growth, grain yield and nitrogen uptake per unit area. In other words, retaining crop residue not only improves physical and chemical properties of soil, but also promotes soil biological activity thought increasing microorganisms population, as a result, more nutrients will be available for the plants during growing season (Shams Abadi and Rafiee, 2007; Salehi et al., 2011). Similar results have been reported by Ozpinar and Cay (2066) who stated that reduced tillage plays a pivotal role in increasing soil organic matter and nitrogen. Increase in wheat grain yield on account of chisel plough compare with mouldboard has been reported by the other researchers (Shams Abadi and Rafiee, 2007; Mohammadi et al., 2009).

Nitrogen uptake and nitrogen use efficiency

Nitrogen uptake and nitrogen use efficiency significantly affected by tillage practice and wheat residue levels (Table 1). The interaction between tillage practices and wheat residue levels was significant on nitrogen uptake efficiency (Table 1). The main effect of year, interaction between year and tillage practices and interaction between year and crop residue levels were not significant on nitrogen uptake and nitrogen use efficiency (Table 1).

The maximum nitrogen uptake efficiency (64.21 g grain per g nitrogen) and nitrogen use efficiency (17.48 g grain per g nitrogen) were related to chisel plough + disk tillage practice (Table 2). For instance, nitrogen uptake and nitrogen use efficiency increased by 20.7 and 16.1% due to chisel plough + disk tillage practice compared with mouldboard plough + disk tillage practice (Table 2). Nitrogen uptake and nitrogen use efficiency both increased with increasing wheat residue application up to 75% and then slightly decreased by applying 100% wheat residue treatment, however this reduction was not statistically significant (Table 2). In addition, the maximum nitrogen uptake efficiency (78.52%) was related to chisel plough + disk tillage practice along with 75% wheat residue treatment (Figure 2).

Table 1. Analysis of variance (mean of squares) on wheat characteristics affected by tillage practices and wheat reside levels.

S.O.V	DF	N percentage in seed	N percentage in residue	N percentage in root	N content in seed	N content in residue	N content in root	N content in total plant	N uptake efficiency	N use efficiency	N harvest index
Year (Y)	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y in Block	4	-	-	-	-	-	-	-	-	-	-
Tillage (T)	3	**	**	**	**	**	NS	**	**	**	NS
Y × T	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × T in Block	12	-	-	-	-	-	-	-	-	-	-
Levels of residue (S)	4	**	**	**	**	**	**	**	**	**	NS
Y × S	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T × S	12	NS	NS	NS	NS	NS	NS	*	*	NS	NS
Y × T × S	12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error	64	-	-	-	-	-	-	-	-	-	-

*, ** and ns: significant at the 0.05 and 0.01 levels of probability and no significant, respectively.

Table 2. Main effects of tillage practices and wheat residue levels on different wheat characteristics.

Experimental treatments	N percentage in seed	N percentage in residue	N percentage in root	N content in seed (g. m^{-2})	N content in residue (g. m^{-2})	N content in root (g. m^{-2})	N content in total plant (g. m^{-2})	N uptake efficiency (%)	N use efficiency (%)	N harvest index (%)
Tillage										
Disk (D)	2.58	0.43	0.45	12.79	4.03	1.07	17.90	47.22	12.97	70.99
Sweep + D	2.57	0.42	0.45	15.60	4.03	1.09	20.72	54.65	15.86	74.75
Mouldboard + D	2.58	0.43	0.45	15.08	4.25	1.12	20.46	53.19	15.06	72.93
Chisel + D	2.77	0.49	0.47	18.77	4.78	1.15	24.70	64.21	17.48	75.74
LSD= 0.05	*0.087*	*0.036*	*0.004*	*1.523*	*0.517*	*0.108*	*1.343*	*3.482*	*1.388*	*6.221*
Levels of residue (%)										
0	2.19	0.36	0.41	11.26	3.20	0.91	15.37	41.34	13.85	73.06
25	2.44	0.43	0.43	12.82	3.84	0.98	17.64	46.87	13.91	72.17
50	2.72	0.47	0.46	15.27	4.75	1.19	21.20	55.63	14.67	71.54
75	2.89	0.48	0.49	19.88	4.68	1.19	25.75	66.79	17.82	76.67
100	2.89	0.48	0.49	18.57	4.91	1.27	24.75	63.44	16.46	74.57
LSD= 0.05	*0.097*	*0.041*	*0.004*	*1.702*	*0.578*	*0.120*	*1.501*	*3.893*	*1.551*	*6.602*
Year										
First	2.62	0.44	0.46	15.29	4.21	1.08	20.58	54.28	15.20	73.70
Second	2.62	0.44	0.46	15.83	4.34	1.14	21.31	55.36	15.48	73.51
LSD= 0.05	*0.062*	*0.026*	*0.003*	*1.077*	*0.365*	*0.076*	*0.950*	*2.462*	*0.981*	*3.278*

Table 3. Some meteorological data for the two growing seasons.

Month	Precipitation (mm)		Average temperature (°C)	
	2013–2014	2014–2015	2013–2014	2014–2015
November	3.30	42.50	9.83	7.28
December	7.30	11.30	3.73	5.95
January	6.00	21.90	4.93	5.06
February	1.40	54.70	1.69	7.77
March	85.10	41.10	9.21	8.39
April	34.40	7.60	17.01	17.94
May	27.40	24.10	22.82	23.02
June	3.70	0.00	27.26	28.35
Total	168.60	203.20	-	
Average	-	-	12.06	12.97

Table 4. Some of physical and chemical properties of field soil in the experiment.

Soil texture	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	OC (%)	pH	EC (dS m^{-1})
Silty-loam	17.41	8.43	142.31	0.43	8.24	1.09

Table 5. Some nutrient content in wheat residue used in the experiment.

OC (%)	Total N (%)	Total P (%)	Total K (%)
35.02	0.47	0.27	0.62

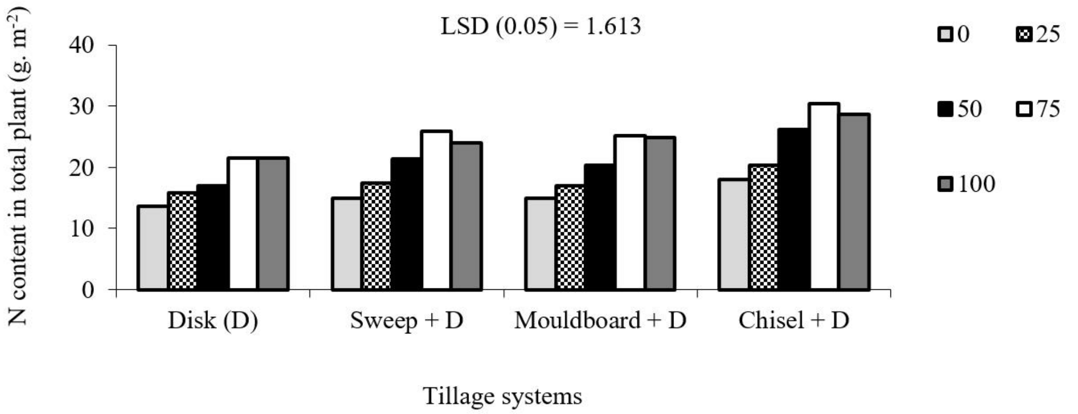

Figure 1. Interaction between tillage practices and wheat residue on plant nitrogen content.

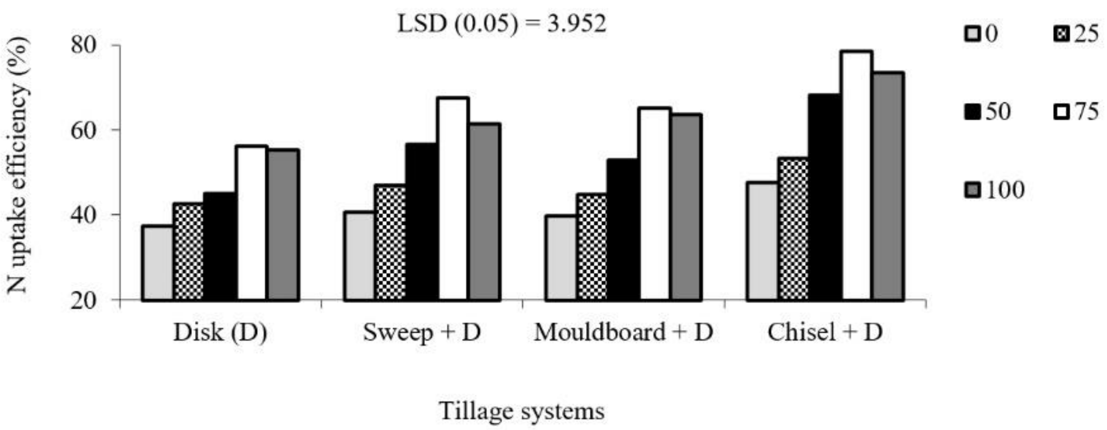

Figure 2. Interaction between tillage practices and wheat residue on nitrogen uptake efficiency.

As mentioned before, increase in nutrient availability is the most outstanding benefits of reduced tillage along with retaining crop residue. According to equations 3 and 4, increase in nitrogen availability or increase in grain yield per unit area can result in increase in nitrogen uptake and nitrogen use efficiency (Yolcu and Cetin, 2015). On the other hand, due to positive relationships between total nitrogen content in plant and nitrogen uptake efficiency (Figure 3) as well as between nitrogen uptake efficiency and nitrogen use efficiency (Figure 4), it seems that factors can result in increase in nitrogen uptake, in turn, lead to an increased grain yield for each consumed nitrogen unit.

Nitrogen harvest index

Nitrogen harvest index was not affected by year, interaction between year and tillage practices as well as interaction between year and wheat residue levels (Table 1). It appears that nitrogen harvest index is controlled by genetic factors than environmental conditions or agronomic practices (Salvagiotti et al., 2009).

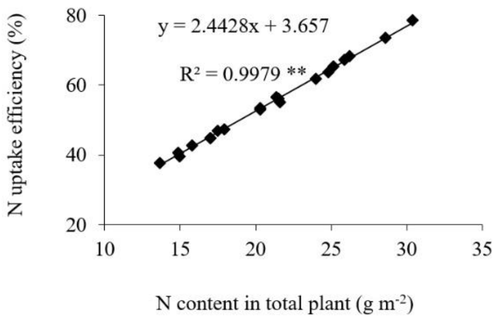

Figure 3. Relationships between nitrogen content in plant and nitrogen uptake efficiency.

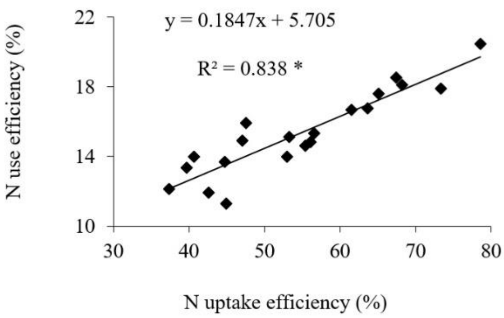

Figure 4. Relationships between nitrogen uptake efficiency and nitrogen use efficiency.

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CONCLUSIONS

According to the results, it can be concluded that reduced tillage using chisel plough and disk plays a key role in improving nitrogen uptake and nitrogen use efficiency. Hence, application of wheat residue and reduced tillage are recommended to increase suitability in wheat production in arid and semi-arid regions. In addition, the results indicated that more application of wheat residue (100% wheat residue) not only had no positive effect on nitrogen uptake, but also decreased nitrogen uptake and nitrogen use efficiency. Therefore, in order to increase nitrogen use efficiency and to reduce production costs and environmental pollution, suitable amount of wheat residue should be applied.

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