Nitrogen use efficiency in winter cereals under optimum nitrogen fertilizer rates

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ABSTRACT

An experiment was arranged in factorial randomized complete block design with three replications at Gonbad Kavous University, Iran. Winter cereal (bread wheat, durum wheat, two rowed barley, six rowed barley, hull less barley, triticale and oat) were evaluated at zero and optimum nitrogen fertilizer rates. The result showed that cereal × nitrogen interaction was not significant on nitrogen utilization efficiency, nitrogen uptake efficiency and nitrogen use efficiency, nitrogen harvest index, nitrogen content and grain protein. Nitrogen fertilizer application affect nitrogen uptake and nitrogen use efficiency. The average of cereal nitrogen utilization efficiency was 31.03 kg.kg⁻¹. Cereal differed significantly in grain nitrogen content. The maximum and minimum nitrogen uptake was obtained in hull less barley (57%) and oat (27%) respectively. Mean Protein percent in cereal varied from 9.38 to 12.37.

Key words: Cereal, Nitrogen uptake, Nitrogen use efficiency, Grain, Yield.

Introduction

Growth and yield of plants affected by deficient or extreme amount of the essential nutrients (Ting-Hui et al., 2006). Nitrogen is known as an essential element from vegetative stage to physiological maturity (Rafiq et al., 2010; Ali, 2011) and one of the main inputs of wheat agriculture with expecting optimum yield. Nowadays, the use of nitrogen fertilizers is increasing continuously. According to the research conducted by Good and Beatty (2011), the total nitrogen application estimated 5.8 million tons in 1987 and will rise to approximately 6.151 million tons in 2050. Nitrogen use efficiency (NUE) has been defined as grain production per unit of available nitrogen while includes nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE). Nitrogen utilization efficiency constitution of two main parts: nitrogen harvest index and biomass production efficiency (Murrinen et al., 2006; Rahimizadeh et al., 2010). Nitrogen use efficiency (NUE) for cereal varies from 29% to 42% in developed and developing countries respectively. The rest remains in residue and loses with de-nitrification, volatilization, and leaching.

Nitrogen increases leaf area, tiller formation and number, leaf area index and greenness duration and as well as, it led to more dry matter accumulation and grain yield (Alazmani 2015). Muurinen et al. (2007) documented that increasing of grain yield and nitrogen harvest index depend on NUtE, with a strong correlation among NUtE and Nitrogen harvest index and nitrogen utilization efficiency. Moreover, it reflects the plant ability in nitrogen transferring into grains. Montemuro et al. (2006) in their study on wheat reported that nitrogen accumulation and remobilization from vegetative parts to grain is the main source of grain yield quality. In all plants, leaves stem and pods are the most important sources of nitrogen remobilization to grains. Giambalwo et al. (2010) in a study on durum wheat genotypes at low nitrogen amount declared that nitrogen use efficiency had no considerable significant difference among genotypes. There are some evidence demonstrating correlation between available nitrogen and accumulation biomass, but it is so tough to quantify that. A comparing experiment was carried out on durum wheat, bread wheat and barley during years 2004/2005/2006/2007. The result showed that nitrogen uptake correlated with grain yield and final biomass at maturity advent (Cossani et al. 2012). Maddahyazdi (2006) reported that, nitrogen use efficiency in wheat ranged from 68.54 grgr⁻¹ for Zagros cultivar to 61.91 gr gr⁻¹for Tajan cultivar.

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Nitrogen deficiency is one of the main problems in Iran soils. In the present study, winter cereals were compared with respect of their ability in nitrogen use efficiency, nitrogen uptake and nitrogen harvest index.

**Materials and Methods**

**Site and location**

The experiment was carried out in factorial randomized complete block design with three replications at experimental research field of Gonbad Kavous University, Iran. Bread wheat (*Triticum aestivum* L), durum wheat (*Triticum Turgidom* L.), barley include two rowed barley, six-rowed barley and hull less barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.) and triticale (*Triticum wittmak* L.) were evaluated at two Nitrogen fertilizer application rates, zero and optimum rates, as Urea (46%) that applied 1/3 at sowing time, 1/3 at tillering stage and 1/3 at stem elongation. Fertilizer P and K were applied in autumn according to soil mineral analysis. Optimum nitrogen amount was determined based on nitrogen removal in total grain yield for each crop according to average of past 10 year's crop grain yield evidence. Nitrogen optimum rate calculated 150 kg ha⁻¹ for bread wheat and hull less barley, 120 kg ha⁻¹ for durum wheat and two rowed barley, 210 kg ha⁻¹ for six rowed barley, 90 kg ha⁻¹ for oat and 240 kg ha⁻¹ for triticale. Plots were sown on December 2014 at seedling rate of 270 per square meter for oat and barley and 350 per square meter for wheat and triticale.

**Taking samples and formulas**

Plant samples were gathered at anthesis stage and physiological maturity to record dry weight (oven dried at 80 °C after 48 hours) of the different aboveground plant organs (stems, green leaves, yellow leaves and spikes). Biomass and grain samples were analyzed for total nitrogen content using a micro-Kjeldahl. At maturity stage, around 2 square meters per plot were harvested in order to determine grain yield. The parameters have been calculated according to Murrinen et al. (2007) using the following formulas:

\[
\text{Nitrogen uptake efficiency (NUpE, kg kg)} = \frac{Nt}{N \text{ supply}}
\]

\[
\text{Nitrogen utilization efficiency (NUtE, kg kg}^{-1}) = \frac{Gy}{Nt}
\]

\[
\text{Nitrogen use efficiency (NUE, kg kg}^{-1}) = \frac{Gy}{N \text{ supply}}
\]

\[
\text{Nitrogen harvest index (NHI, %)} = \left(\frac{Ng}{Nt}\right) \times 100
\]

\[
\text{Protein ( %) = seed total nitrogen content } \times 5.7
\]

Data were subjected to an analysis of variance, with SAS version 9.1.3 software and means were compared with LSD in 5% level of probability.

**Results**

**Grain yield**

Results showed that interaction cereal × nitrogen was not significant on cereal grain yield (Table 1). Grain yield responded significantly to cultivar and nitrogen simple effect at 1% level. Cereal grain yield varied from 112.45 gr m⁻² in oat to 277.77 gr m⁻² in hull less barley (Table 2).

**Nitrogen use efficiency and nitrogen harvest index**

Result showed that cereal × nitrogen interaction, cereal and nitrogen effects were not significant on nitrogen utilization efficiency, nitrogen uptake efficiency and nitrogen use efficiency. While cereals differed significantly in nitrogen uptake (P < 0.001). Also, nitrogen uptake efficiency responded to nitrogen fertilizer application at 5% level. However, the average of cereal nitrogen utilization efficiency was 31.03 kg kg⁻¹. The highest and the least nitrogen uptake was observed in hull less barley (57%) and oat (27%) respectively. Nitrogen uptake in triticale as the most adaptable and high yield cereal at Gonbad Kavous region was 49% and Nitrogen uptake was obtained for two rowed barley, bread wheat, six rowed barley and durum wheat 52%, 51%, 48% and 40% respectively.
Table 1: Mean square of nitrogen utilization, nitrogen uptake, nitrogen use efficiency, nitrogen remobilization, nitrogen harvest index, grain nitrogen content and grain protein.

<table>
<thead>
<tr>
<th>Changing Sources</th>
<th>Freedom degree</th>
<th>Grain yield</th>
<th>Nitrogen utilization</th>
<th>Nitrogen uptake</th>
<th>Nitrogen use efficiency</th>
<th>Nitrogen remobilization</th>
<th>Nitrogen harvest</th>
<th>Grain nitrogen</th>
<th>Grain protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>2</td>
<td>771.21</td>
<td>73.23</td>
<td>0.014</td>
<td>6.05</td>
<td>138.41</td>
<td>0.03</td>
<td>0.19</td>
<td>4.95</td>
</tr>
<tr>
<td>Cereal</td>
<td>6</td>
<td>16666.41**</td>
<td>73.86</td>
<td>0.099**</td>
<td>129.83**</td>
<td>1743.15**</td>
<td>0.027*</td>
<td>0.13</td>
<td>8.50**</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1</td>
<td>5816.26**</td>
<td>14.66</td>
<td>0.082*</td>
<td>45.30**</td>
<td>2409.26**</td>
<td>0.02</td>
<td>0.16</td>
<td>10.77*</td>
</tr>
<tr>
<td>Cereal × Nitrogen</td>
<td>6</td>
<td>504.29</td>
<td>22.32</td>
<td>0.015</td>
<td>3.92</td>
<td>326.81**</td>
<td>0.01</td>
<td>0.06</td>
<td>2.69</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>387.07</td>
<td>55.54</td>
<td>0.017</td>
<td>3.01</td>
<td>58.08</td>
<td>0.09</td>
<td>0.17</td>
<td>1.90</td>
</tr>
<tr>
<td>C.V</td>
<td></td>
<td>9.33</td>
<td>14.01</td>
<td>18.71</td>
<td>9.33</td>
<td>14.22</td>
<td>17.68</td>
<td>17.74</td>
<td>11.75</td>
</tr>
</tbody>
</table>

Table 2: Mean comparison of nitrogen utilization, nitrogen uptake, nitrogen use efficiency, nitrogen remobilization, nitrogen harvest index, grain nitrogen content and grain protein.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield (gr.m(^{-2}))</th>
<th>Nitrogen uptake efficiency</th>
<th>Nitrogen use efficiency</th>
<th>Nitrogen remobilization</th>
<th>Grain protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triticale</td>
<td>198.23c</td>
<td>0.65ab</td>
<td>17.50c</td>
<td>85.03a</td>
<td>12.76a</td>
</tr>
<tr>
<td>Bread wheat</td>
<td>223.08b</td>
<td>0.68ab</td>
<td>19.69b</td>
<td>48.80cd</td>
<td>11.84ab</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>186.87c</td>
<td>0.53b</td>
<td>16.49c</td>
<td>40.51c</td>
<td>11.06b</td>
</tr>
<tr>
<td>Two rowed barley</td>
<td>232.92b</td>
<td>0.69a</td>
<td>20.55b</td>
<td>31.62e</td>
<td>12.37ab</td>
</tr>
<tr>
<td>Six rowed barley</td>
<td>244.58c</td>
<td>0.64ab</td>
<td>21.58b</td>
<td>55.01bc</td>
<td>12.65ab</td>
</tr>
<tr>
<td>Hull less barley</td>
<td>277.77a</td>
<td>0.74a</td>
<td>24.51a</td>
<td>62.40b</td>
<td>12.19ab</td>
</tr>
<tr>
<td>Oat</td>
<td>112.46d</td>
<td>0.36c</td>
<td>9.92d</td>
<td>40.77d</td>
<td>9.38c</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>23.34</td>
<td>0.16</td>
<td>2.06</td>
<td>9.04</td>
<td>1.63</td>
</tr>
<tr>
<td>Zero</td>
<td>199.08b</td>
<td>0.66a</td>
<td>17.57b</td>
<td>46b</td>
<td>11.24ab</td>
</tr>
<tr>
<td>Optimum</td>
<td>222.61a</td>
<td>0.57b</td>
<td>19.64a</td>
<td>61.15a</td>
<td>12.26a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>12.48</td>
<td>0.08</td>
<td>1.10</td>
<td>4.83</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Table 3: Correlation among grain yield, nitrogen utilization, nitrogen uptake, and nitrogen use efficiency, nitrogen remobilization, nitrogen harvest index, seed nitrogen content and grain protein.

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen utilization efficiency</th>
<th>Nitrogen uptake efficiency</th>
<th>Nitrogen use efficiency</th>
<th>Nitrogen remobilization</th>
<th>Nitrogen harvest index</th>
<th>Seed nitrogen content</th>
<th>Seed protein</th>
<th>Grain yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen utilization efficiency</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen uptake efficiency</td>
<td>-0.43**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen use efficiency</td>
<td>0.26</td>
<td>0.71**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen remobilization</td>
<td>0.01</td>
<td>0.18</td>
<td>0.21</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen harvest index</td>
<td>0.32*</td>
<td>0.15</td>
<td>0.52**</td>
<td>0.20</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed nitrogen content</td>
<td>-0.14</td>
<td>0.79**</td>
<td>0.79**</td>
<td>0.22</td>
<td>0.72**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed protein</td>
<td>-0.14</td>
<td>0.64**</td>
<td>0.51**</td>
<td>0.38**</td>
<td>0.47**</td>
<td>0.75**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Grain yield</td>
<td>0.26</td>
<td>0.72**</td>
<td>0.98**</td>
<td>0.21</td>
<td>0.51**</td>
<td>0.79**</td>
<td>0.52**</td>
<td>1</td>
</tr>
</tbody>
</table>
Result showed that cereal × nitrogen interaction had no effect on nitrogen harvest index. Cereals differed significantly in nitrogen harvest index at 5% level of significance; but nitrogen application had no significant effect on it. The maximum and minimum nitrogen harvest index was obtained in hull less barley (0.66) and oat (0.44), respectively. Nitrogen harvest index obtained in triticale 0.51, bread wheat 0.54, durum wheat 0.56, two rowed barley 0.55 and six rowed barley 0.58. Nitrogen Harvest index correlated to grain yield significant positively that according to Montemur et al. (2006) and correlated to nitrogen use efficiency and nitrogen utilization efficiency showed 0.52 and 0.34 and correlated weekly to nitrogen uptake efficiency (0.15).

Nitrogen remobilization

Cereal × Nitrogen interaction showed significant effect on nitrogen remobilization at 1%. Increasing nitrogen rates resulted in increased nitrogen remobilization in all cereals. Nitrogen remobilization varied from 85.03 in triticale to 31.62 in two rowed barley. Nitrogen remobilization was obtained for bread wheat and durum wheat 48.80 kg.ha⁻¹ and 40.51 kg.ha⁻¹ that were lower than six rowed barley and hull less barley nitrogen remobilization (55.01 kg.ha⁻¹ and 62.40 kg.ha⁻¹). Nitrogen remobilization gained 40.77 kg.ha⁻¹ for oats.

Grain protein content

Cereal × nitrogen had no effect on grain nitrogen content and protein content. Result showed that, no significant difference was detected in seed nitrogen concentration by different nitrogen application rates. But cereals significantly differed in protein percent at 1% level. Nitrogen affects seed nitrogen percent at 5% level. Mean Protein percent in cereal varied from 9.38 to 12.37. Maximum seed protein content was recorded in triticale while minimum was observed in oat. Grain protein correlated significantly positive to grain nitrogen content (0.75). Nitrogen uptake and nitrogen use efficiency had significant positive relationship with seed protein percent (0.64 and 0.51 respectively).

Discussion

Grain yield

Cereal showed variable results in grain yield with superiority to Hull less barley as an adaptable crop to drought condition. Results demonstrated that the barley genotypes (two rowed barley, six rowed barley and hull less barley) had more grain yield in comparison with wheat group (bread wheat and durum wheat). It seems the condition accorded to barley genotypes, transferred more nutrients to grains. Table 2 shows that with increasing nitrogen rates from zero to optimum, significantly increased grain yield. Giambalwo et al. (2010) documented that morphological differences in wheat genotypes, lead to grain yield difference under zero and 80 kg ha⁻¹ nitrogen fertilizer rates. Biberdžić et al. (2010) on barley and triticale proved that, grain yield in the similar ecological condition at three nitrogen levels (80, 100 and 120 kg ha⁻¹) announced higher grain yield and 1000 grain weight under 80 kg.ha⁻¹ and 120 kg.ha⁻¹ for barley and triticale, respectively.

Nitrogen use efficiency and nitrogen harvest index

Nitrogen use efficiency varied in cereals from 9.92 in oat to 24.51 in hull less barley. It seems that, oat root system and physiology is more developed than other cereal crops regarding nitrogen uptake. Different plants have various ability to nitrogen uptake and dry matter production from available soil nitrogen. Because of C:N ratio, variety, plant root system development, nitrogen available and plant tolerance to heat. Nitrogen use efficiency was obtained from 27 to 77 kg kg⁻¹ in wheat genotypes by Barraclough et al. (2010), 39% by Arregui and Guimda (2008) and 55.55 to 81.25 kg kg⁻¹ by Bakhshandeh et al. (2014). Ortiz et al. (2002) and Murrinen et al. (2007) declared genetic enhancement was effective for increasing nitrogen use efficiency in wheat and oat while, no changing have been observed in two rowed barley. Nitrogen harvest index defines as grain nitrogen
amount to plant total nitrogen at physiological maturity advent and shows nitrogen division from sources to grains (Komudini et al., 2002). Correlation table (table 3) demonstrated a positive significant relationship between nitrogen use efficiency and nitrogen uptake efficiency (0.71). In an investigation by Muurinen and Peltonen-Sainio, (2006) on wheat, barley and oat that recommended during 1901-2002, a linear positive significant relationship observed between nitrogen use efficiency and nitrogen uptake efficiency that was stronger in oat ($r^2=0.79$). There was not significant correlation between Nitrogen use efficiency and nitrogen utilization efficiency in wheat and barley but observed a weak relationship in oat.

Nitrogen remobilization

Difference in nitrogen remobilization in different cereals crops correlated positively to dry matter accumulation and nitrogen amount in pre anthesis event and environmental condition. These results are in agreement with Pampana et al. (2007). Bakhshande et al. (2014) reported that 57 percent of seed nitrogen amount is related to nitrogen remobilization of vegetative organs in pre anthesis and 11 percent is provided from direct soil nitrogen uptake and nitrogen remobilization after anthesis. Average of nitrogen remobilization in different plant parts was 72.2 percent. Nitrogen concentration in leaf and stem from anthesis event to maturity decreased 57 and 54 percent. Correlation table showed a weak positive relationship between nitrogen remobilization and grain yield (0.21). Variety, plant dating, condition, density and water stress affect nitrogen remobilization into seed in grain filling period that are the main factors on grain yield determination. Neonus and Batribud (2002) reported that grain yield correlate positive significantly to nitrogen and dry matter remobilization because of more nitrogen and dry matter storage at pre anthesis stage.

Grain protein content

Differences in grain protein content in winter cereals showed that genotypes as well as environmental condition affect seed protein and its production related to soil nitrogen supply at pre anthesis advent and seed filling duration. Nitrogen is the most important element affect grain protein content, and with nitrogen accumulation pre anthesis by nitrogen fertilizer application, grain nitrogen and protein accumulate. The main nitrogen source of cereal grain depended on above ground nitrogen amount that provide 60 to 92 percent of seed nitrogen accumulation. Brown (2010) reported that, triticale grain protein content increased up to 54 percent by using 120 kg ha$^{-1}$ nitrogen fertilizer in compare to no nitrogen application treatment. Grain yield correlated positive significantly with grain protein percent (0.51). Grain protein showed positive significant relationship with nitrogen remobilization and nitrogen harvest index (0.38 and 0.47). In an investigation on durum wheat in Mediterranean region, nitrogen application had no significant effect on grain nitrogen content and nitrogen harvest index (López-Bellido et al., 2006). The results of Alazmani (2015) on three barley genotypes (Sahra, Mahoor and Line 17) showed increasing in grain yield, grain protein and plant height with increasing nitrogen fertilizer amount. The results showed that consumption of 225 kg N ha$^{-1}$, is sufficient for the plant to reaching maximum yield.

Conclusion

Various responses in different winter cereals crops refers to the abilities in nitrogen uptake, root system development and genetic adaptation to final season heat stress, that describe a complex details of genetic and environmental interactions. The present results make fertilizer recommendation more difficult in order to reach the optimum yield according to optimum fertilizer application.

Acknowledgment

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References


