Improving wheat yield and quality through an integrated nutrient management system

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Abstract

In order to evaluate the effect of different chemical and biological fertilizers on wheat (Triticum aestivum L. cv. Pishtaz), this experiment was conducted in 2013 at the research field of Islamic Azad University, Karaj branch, Iran. The experiment was conducted in the form of a randomized complete block design (RCBD) with four replications and the eight following treatments: (1) control (without any fertilizer application), (2) urea + triple super phosphate, (3) urea + plant growth promoting rhizobacteria (PGPR), (4) urea + mycorrhiza, (5), urea + mycorrhiza + PGPR, (6) PGPR + triple super phosphate, (7) PGPR and (8) PGPR + mycorrhiza. At the end of the growth period, the following traits were measured: plant height, the number of tillers, 1000 kernels weight, grain yield, total biologic yield, protein content and the harvest index. Analysis of variance indicated that the treatments of the experiment had significant effect on all the measured traits at P≤0.01, except for the protein content which was not affected by the treatments. Mean comparison showed that nitrogen + PGPR + mycorrhiza treatment was the most effective treatment and resulted in the highest plant height (94 cm), the number of tillers (7.2), 1000 kernels weight (44.41 g), grain yield (8645.3 kg/ha) and biologic yield (19762.5). However, the harvest index was the highest in PGPR treatment (58.97). Results of this experiment reveled the effect of integrated nutrient management on wheat yield and quality.

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Introduction

Wheat is the most important strategic food crop around the world and in Iran. Sustained production of wheat is important to feed the increasing world population. On the other hand, world population explosion in recent decades has caused excessive application of chemical fertilizers in agricultural systems; resulting in severe environmental and health problems (Cho et al., 2008; Garnier et al., 2010).

However, it is not possible to stop the application of chemical fertilizers to agricultural systems. A logical way is to reduce the application rate by Integrated Nutrient management (INM) method. INM tries to reduce the need for chemical fertilizers by taking advantages of non-chemical sources of nutrients such as the manures, composts and biofertilizers (Gopalasundaram et al., 2012; Prasad et al., 2002). Biofertilizers application not only increases plants growth and yield, but increase soil microbial population and activity; resulting in improved soil fertility (Biyari et al., 2008).

Biofertilizers consist of various types of microorganisms. There are some microorganisms in soil which are in close relation with plant roots and are called Plant growth Promoting rhizobacteria (PGPR). They include free-living bacteria which promote plant growth even in polluted soils. *Azospirillum, Azotobacter, Pseudomonas, Bacillus* and *Thiobacillus* are examples of these bacteria (Vessey, 2003; Zahir et al., 2004). Burd et al. (2000) and Niess (2002) reported that plant growth promoting bacteria reduced the toxicity of heavy metals and increased plant growth and yield. Zahir et al. (2004) found that plant growth promoting rhizobacteria increased plant growth and yield through phytohormones production. Inoculating seeds with these bacteria increases germination rate and plant biomass accumulation (Glick, 1995).

*Azotobacter* is a heterotroph free-living nitrogen-fixing bacterium (Cleyt-Marel et al., 2001). Yang et al. (2004) found up to 15% improvement in yield of maize, wheat and millet when inoculated with *Azotobacter* bacteria. They reported that wheat grain yield, nitrogen uptake and straw yield increased by 8.2%, 5.3% and 2.6%, respectively, as the result of *Azotobacter* inoculation.

*Azospirillum* is an associative nitrogen-fixing bacterium which affects plants growth and yield (Tilak et al., 2005). Bashan and Levanony (1990) reported the effect of *Azospirillum* inoculation on wheat growth and yield. Mohammed et al. (2012) tested the effect of inoculating wheat seeds with *Bacillus* bacteria and reported the enhanced growth and yield. Kumar et al. (2009) inoculated *Artemisia pallens* L. with *Azospirillum* and found that the inoculation increased plant growth, biomass accumulation and essential oil yield.

*Pseudomonas* is a gram negative chemooorganotroph bacterium. Some species of this genus are considered as PGPR but some other species are considered as pathogen to plants causing diseases (Crowley et al., 1991). Patidar (2001) tested the effect of *Pseudomonas* inoculation on sorghum (*Sorghum bicolor*) and found an improvement in grain yield.

*Bacillus* bacteria are another group of PGPR. Defreitas (2000) tested the effect of *Bacillus* bacteria inoculation on wheat and reported the beneficial effect of the bacteria. Mohammed et al. (2012) reported that inoculating wheat seeds with *Bacillus* bacteria increased plant growth and yield.

In addition to the bacteria, the symbiosis of mycorrhizal fungi also boosts plants growth and yield. In this symbiotic system, the hyphae of the mycorrhiza cover plant roots and receive sugars, amino acids, vitamins and some other organic compounds from the plant and in return provide plant with mineral nutrients such as phosphorus and also protect root against biotic invaders. The hyphae of mycorrhiza increase plant ability to absorb water and nutrients (Al-Karaki, 2006; Cardoso and Kuyper, 2006). Ratti et al. (2001) reported that inoculating *Cymbopogon martini* with mycorrhizal fungi increased plant biomass accumulation and phosphorus absorption. Sorial (2001) also reported
that mycorrhizal inoculation increased wheat grain yield under drought stress condition. Miller (2000) found that Water Use Efficiency (WUE) is higher in mycorrhizal plants due to higher photosynthesis rate; enabling mycorrhizal plants to tolerate drought stress better than the non-mycorrhizal plants.

Nutrient management is a complicated topic with large unknown aspects. The effects of soil and climatic conditions on the nutritional treatments make it even more complicated; requiring the necessity of various experiments in different environmental conditions. Regarding the benefits of integrated nutrient management, this experiment was conducted to evaluate the effect of chemical nitrogen and phosphorus fertilizers along with plant growth promoting rhizobacteria and mycorrhizal fungi on growth, yield and quality of wheat.

Materials and methods
To evaluate the effect of different chemical and biological fertilizers on wheat (*Triticum aestivum* L. cv. Pishtaz), this experiment was conducted in 2013 at the research field of Islamic Azad University, Karaj branch, Iran (35°48' N, 50°48' E, 1292 m above the sea level). To determine soil physico-chemical properties, samples were taken from field at the depth of 0-30 cm for laboratory analysis. Results of soil analysis indicated that the soil at the test site was a sandy loam (clay, 34%; silt, 22%; sand, 44%) with the pH of 7.8 and EC of 3.62 ds/m. Other soil physico-chemical properties are listed in Table 1.

The experiment was conducted in the form of a randomized complete block design (RCBD) with four replications. Treatments included:

1. Control (without any fertilizer application)
2. Urea (N) + triple super phosphate (P)
3. Urea (N) + plant growth promoting rhizobacteria (B)
4. Urea (N) + mycorrhiza (G)
5. Urea (N) + mycorrhiza (G) + plant growth promoting rhizobacteria (B)
6. Plant growth promoting rhizobacteria (B) + triple super phosphate (P)
7. Plant growth promoting rhizobacteria (B)
8. Plant growth promoting rhizobacteria (B) + mycorrhiza (G)

The field was prepared on Nov. 12, by the means of a moldboard plow, disk, leveler and furrower. Each experimental plot included five furrows with 50 cm intervals and seeds were planted on both sides of the each furrow. Seeds were planted on Nov. 18.

Plant growth promoting rhizobacteria included the mixture of nitroxin (*Azotobacter + Azospirillum*) + bio-super phosphate (*Pseudomonas + Bacillus*) which was applied 4 L/ha. To inoculate seeds with this mixture, seeds were spread on aluminum sheet and the mixture of plant growth promoting rhizobacteria was sprayed on them. Then, seeds were planted after they were dried. Mycorrhiza (*Glomus intraradices*) was applied in soil at the planting time. Triple super phosphate was applied to field (150 kg/ha) at the field preparing stage. Urea (150 kg/ha) was split into three parts: on part was applied prior to seeding, the second part was applied at the stem elongation and the last part was applied at the grain filling stage.

The sampling was conducted in early July when the spikes were yellow. 10 plants were harvested and the following traits were measured: plant height, the number of tillers, 1000 kernels weight, grain yield, total biologic yield, protein content and the harvest index. To measure grain yield and biologic yield, 1m² of each plot was harvested and weighted.

Finally, data were tested to be normal prior to statistical analysis. Then, data were analyzed using SAS and means were compared according to the Duncan’s multiple range test at P≤0.05.

Results and discussion

*Plant height*
Analysis of variance showed that the treatments of the experiment had significant effect on plant height at P≤0.01 (Table 2). All treatments increased plant
height compared with the control (Table 3). Mean comparison showed that plant height was the highest in nitrogen + PGPR + mycorrhiza (94 cm) and the lowest in the control (70.5 cm). The effect of nutritional treatments on plants height is well documented. Dileep Kumar et al. (2001) found that inoculating pea plants with Pseudomonas fluorescence increased plant height compared with the non-inoculated plants. Zaied et al. (2007) tested the effect of plant growth promoting rhizobacteria on non-legume plants and found an improvement on plant height. Khorramdel et al. (2008) also tested the effect of Azospirillum, Azotobacter and mycorrhiza on Nigella sativa L. and observed that application of the biofertilizers increase plant height compared with the non-inoculated plants. They reported that the most effective treatment on the plant height was Azospirillum + mycorrhiza.

Table 1. Physico-chemical properties of the test site soil.

<table>
<thead>
<tr>
<th>OC (%)</th>
<th>TNV (%)</th>
<th>Total N (%)</th>
<th>P ava. (ppm)</th>
<th>K ava. (ppm)</th>
<th>Fe (mg/kg)</th>
<th>Zn (mg/kg)</th>
<th>Mn (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.91</td>
<td>10</td>
<td>0.057</td>
<td>5</td>
<td>101</td>
<td>102</td>
<td>0.74</td>
<td>13</td>
</tr>
</tbody>
</table>

The number of tillers.

Results of our experiment indicated that application of nutritional treatments significantly affected the number of tillers at P≤0.01 (Table 2). Mean comparison showed that the number of tillers was higher in all treatments than in the control (Table 3). The highest number of tillers was achieved in nitrogen + PGPR + mycorrhiza (7.2 tillers/plant) and the lowest number of tillers was achieved in the control (3.2 tillers/plant). The effect of biofertilizers and chemical fertilizers on the number of tillers was also observed in other experiments such as those of Emtiazi and Hojan (2002). Cassán et al. (2009) also reported that chemical nitrogen fertilizer, Azospirillum and Azotobacter bacteria application increased the number of tillers in rice plants. Sary et al. (2009) found that application of biofertilizers and chemical fertilizers to wheat increased the number of tillers.

Table 2. Analysis of variance of the effect of treatments on the measured traits.

<table>
<thead>
<tr>
<th>SOV</th>
<th>df</th>
<th>Plant height</th>
<th>Number of 1000 kernels</th>
<th>Grain yield</th>
<th>Total biologic yield</th>
<th>Protein content</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>3</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Treatment</td>
<td>7</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>ns</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>4.58</td>
<td>0.47</td>
<td>2.62</td>
<td>4019.5</td>
<td>138920.6</td>
<td>1.96</td>
</tr>
<tr>
<td>CV (%)</td>
<td>-</td>
<td>2.65</td>
<td>3.84</td>
<td>3.30</td>
<td>1.92</td>
<td>2.43</td>
<td>10.47</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1000 kernels weight

Analysis of variance showed the significant effect of treatments on 1000 kernels weight at P≤0.01 (Table 2). All nutritional treatments increased the value of this trait compared with the control (Table 3). Mean comparison showed that this trait was the highest in PGPR + mycorrhiza (46.28 g) and the lowest in the control (27.23 g). Our findings indicate that application of biofertilizers and chemical fertilizers increase wheat kernels weight; these findings are in agreement with the results of other experiments. Emtiazi and Hojan (2002) reported that inoculating wheat plants with Azospirillum bacteria increased wheat kernels weight. Sorial (2001) also tested the effect of mycorrhizal inoculation on wheat plants and reported the enhancement of 1000 kernels weight.

Grain yield.

Results indicated that application of biofertilizers and chemical fertilizers significantly affected grain yield at
P≤0.01 (Table 2). All treatments increased grain yield compared with the control but grain yield was the highest (8645.3 kg/ha) in nitrogen + PGPR + mycorrhiza (Table 3). Grain yield was the lowest in the control (4418 kg/ha). The treatments of our experiment mainly provide nitrogen and phosphorus to plants; N and P are the two very important macronutrients for growth and yield of plants. Nitrogen is a key element which is involved in the structure and synthesis of protein, nucleic acids, RNA, DNA and chlorophyll. It is also important for anion / cation balance, cell division and flowering (Askari and Moradi Dalini, 2001; Wiedenhoeft, 2006). Phosphorus is another important macronutrient playing roles in various biochemical processes in plants such as energy transfer. Phosphorus is also involved in the structure of some proteins, cell wall, RNA and DNA (Gheibi and Malakouti, 2004; Tiessen, 2008). Khan et al (2010) reported that the maximum grain yield and the number of tillers were achieved 80 kg P/ha was applied. In another experiment, Magani and Kuchinda (2009) concluded that increased P application rate resulted in the enhancement of grain yield and protein content of two cowpea cultivars. In addition to chemical fertilizers, biofertilizers also provide N and P to plants. Bakhshai et al. (2010) observed that applying chemical and biological fertilizers increased grain yield in wheat plants. Sorial (2001) found that mycorrhizal inoculation increased wheat grain yield. Patidar (2001) also found that Pseudomonas inoculation increased sorghum (Sorghum bicolor) grain yield. Yang et al. (2004) reported an average of 15% improvement in yield of maize, wheat and millet when inoculated with Azotobacter bacteria. They reported that wheat grain yield increased by 8.2% as the result of Azotobacter inoculation.

Table 3. The effect of the treatments on the measured traits.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant height (cm)</th>
<th>Number of 1000 kernels weight (g)</th>
<th>Grain yield (kg/ha)</th>
<th>Total biologic yield (kg/ha)</th>
<th>Protein content (%)</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>70.5f</td>
<td>3.2g</td>
<td>27.23e</td>
<td>4418f</td>
<td>9536.3f</td>
<td>13.08a</td>
</tr>
<tr>
<td>N + P</td>
<td>87.25b</td>
<td>6.8b</td>
<td>29.63d</td>
<td>6186e</td>
<td>19299.3a</td>
<td>13.09a</td>
</tr>
<tr>
<td>B + B</td>
<td>76.5de</td>
<td>5.6e</td>
<td>36.54c</td>
<td>6845.25d</td>
<td>14599.3d</td>
<td>13.49a</td>
</tr>
<tr>
<td>N + G</td>
<td>77.75d</td>
<td>5.8de</td>
<td>37.70e</td>
<td>6995.25d</td>
<td>14230.0d</td>
<td>14.18a</td>
</tr>
<tr>
<td>N + B + G</td>
<td>94a</td>
<td>7.2a</td>
<td>44.41a</td>
<td>8645.3a</td>
<td>19762.5a</td>
<td>13.73a</td>
</tr>
<tr>
<td>P + B</td>
<td>81.5c</td>
<td>6cd</td>
<td>44.98a</td>
<td>7518.25c</td>
<td>17034.8b</td>
<td>13.70a</td>
</tr>
<tr>
<td>B</td>
<td>74e</td>
<td>4.5f</td>
<td>41.25b</td>
<td>6956d</td>
<td>11794.8e</td>
<td>12.84a</td>
</tr>
<tr>
<td>B + G</td>
<td>84.5bc</td>
<td>6.3c</td>
<td>46.28a</td>
<td>8036.5b</td>
<td>16212.3c</td>
<td>15.02a</td>
</tr>
</tbody>
</table>

Means in a column followed by the same letter are not significantly different (P≤0.05).
N, urea; P, triple super phosphate; B, plant growth promoting rhizobacteria; G, mycorrhiza.

Total biologic yield
Analysis of variance indicated the significant effect of nutritional treatments on total dry yield at P≤0.01 (Table 2). Mean comparison showed that all treatments increase this trait compared with the control (Table 3). Biologic yield was the highest in nitrogen + PGPR + mycorrhiza (19762.5 kg/ha) although it was significantly the same as nitrogen + phosphorus treatment (19299.3 kg/ha). The lowest biologic yield was achieved in the control (9536.3 kg/ha). These findings are in agreement with those of other researchers who reported the effect of biofertilizers and chemical fertilizers on plants biologic yield and dry weight. Bakhshai et al. (2010) reported that application of various chemical and biological fertilizers increased grain yield, biologic yield and harvest index in wheat plants. Dileep Kumar et al. (2001) reported that inoculating pea seeds with Pseudomonas fluorescence increased plant
biologic yield. In another experiment, Biyari et al. (2008) tested the effect of *Azotobacter* inoculation on maize yield and yield components and reported that the inoculation increased plant biomass accumulation and biologic yield compared with the non-inoculated control. Ajimoddin et al. (2005) also found that the highest biologic yield of basil was achieved when 75% of the recommended dose of N and P was applied along with *Azospirillum* and mycorrhiza.

**Protein content**
Analysis of variance showed that the treatments of this experiment had no significant effect on wheat protein content (Table 2). Mean comparison also indicated that all treatments and the control were in the same group according to the Duncan's multiple range test (Table 3). These results are in contrast with those of Ozturk et al. (2003) who reported that inoculating wheat plants with *Azospirillum* increased grain protein content.

**Harvest index**
Results of our experiment indicated the significant effect of treatments on harvest index at $P \leq 0.01$ (Table 2). Mean comparison (Table 3) showed that the highest harvest index was achieved in PGPR treatment (58.97) and the lowest harvest index was achieved in nitrogen + phosphorus (32.05). An important point was that the harvest index was 46.33 in the control; it is higher than nitrogen + phosphorus treatment. It is probably because of the imbalanced effect of nitrogen + phosphorus treatment on plant vegetative growth and yield. So this treatment has affected the vegetative growth more than the grain yield, resulting in the reduction of harvest index.

The variation of harvest index in our experiment did not follow a clear model in different treatments. Generally it can be concluded that PGPR treatments and PGPR + mycorrhiza treatments had higher effect on grain yield and increased the harvest index. Sary et al. (2009) found that application of biological fertilizers had significant effect on different features of wheat. They reported that the combination 25% of biofertilizer + 75% of chemical fertilizer resulted in the achievement of the highest harvest index.

Bakhshaei et al. (2010) also reported that applying different chemical and biological fertilizers increased the harvest index in wheat plants.

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