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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 $P \leq 0.01$, 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 sever 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 chemoorganotroph 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, 1m^2 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 $P \leq 0.05$.

Results and discussion

Plant height

Analysis of variance showed that the treatments of the experiment had significant effect on plant height at $P \leq 0.01$ (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 pee 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.

OC (%)	TNV (%)	Total N (%)	P $_{ava.}$ (ppm)	K $_{ava.}$ (ppm)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
0.91	10	0.057	5	101	102	0.74	13

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.

SOV	df	Plant height	Number of tillers	1000 kernels weight	Grain yield	Total biologic yield	Protein content	Harvest index
Block	3	ns	ns	ns	*	ns	ns	ns
Treatment	7	**	**	**	**	**	ns	**
Error	21	4.58	0.47	2.62	4019.5	138920.6	1.96	1.80
CV (%)	-	2.65	3.84	3.30	1.92	2.43	10.47	3.06

ns, nonsignificant; *, significant at P≤0.05; **, significant at P≤0.01.

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. Bakhshaei *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.

Treatments	Plant height (cm)	Number of tillers	1000 kernels weight (g)	Grain yield (kg/ha)	Total biologic yield (kg/ha)	Protein content (%)	Harvest index
Control	70.5f	3.2g	27.23e	4418f	9536.3f	13.08a	46.33c
N + P	87.25b	6.8b	29.63d	6186e	19299.3a	13.09a	32.05e
B + B	76.5de	5.6e	36.54c	6845.25d	14599.3d	13.49a	46.89c
N + G	77.75d	5.8de	37.70c	6995.25d	14230.0d	14.18a	49.16b
N + B + G	94a	7.2a	44.41a	8645.3a	19762.5a	13.73a	43.75d
P + B	81.5c	6cd	44.98a	7518.25c	17034.8b	13.70a	44.13d
B	74e	4.5f	41.25b	6956d	11794.8e	12.84a	58.97a
B + G	84.5bc	6.3c	46.28a	8036.5b	16212.3c	13.02a	49.57b

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. Bakhshaei *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 pee 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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