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Wheat productivity as affected by replacement of mineral fertilizers (NPK) with PGPR as biofertilizer in combination with compost as organic fertilizer under new reclaimed sandy soil

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ABSTRACT

A field experiment was carried out on a sandy soil at own farm at Ismailia Governorate, Egypt during two winter seasons of 2020/2021–2021/2022. The study concerned with the effect of integrated use of plant growth promoting rhizobacteria (*B. ploymyxa*, *B. megaterium* and *B. circulans*), organic fertilizer (2 ton compost fed^{-1}) in combination with different levels of mineral NPK fertilizer on growth, chemical composition, yield and some yield component of wheat (*Triticum aestivum* cv. Misr 3). Mineral NPK fertilizers were applied at four levels (100, 75, 50 and 25%) from the recommended dose of mineral NPK fertilizers. Two methods were applied for PGPRs, the first one was seed coating method (($PGPR_1$) applied at sowing (4g inoculum 100g grains^{-1}), while the second method was a mixture of liquid cultures ($PGPR_2$) applied as a soil drench after 45 days from sowing (5 L fed^{-1}). Treatments inoculated with PGPRs and amended with compost were applied in combination with 75, 50 and 25% NPK mineral fertilizer levels. The experimental design was arranged in a randomized complete block design (RCBD) with three replicates. The obtained results revealed that the full recommended dose treatment was surpassed the other tested levels of application (75, 50 or 25% NPK) in all tested wheat characters. While, wheat plants inoculated with mixture of PGPRs and compost in combination with 75, 50 and 25% NPK fertilizers achieved a salient increase in all tested wheat characters in comparison to using the same mineral fertilizers level alone. Treatment comprising rhizobacterial inoculation ($PGPR_1$+$PGPR_2$) and amended with compost in the presence of 75% of mineral fertilization gave values comparable to full dose of mineral NPK (100% NPK) treatment and the difference could not reach the level of significance. Such fertilization treatment attained the highest values of all wheat growth parameters, nutrients accumulated in tissues, wheat yield and its components. In general, rhizobacterial ($PGPR_1$+ $PGPR_2$) inoculation combined with mineral NPK fertilizers achieved increases of 7.5, 19.1, 23.8, 17.1, 12.8 and 14.1% for a number of tillers/plant, number of spikes/m^2, number of grains/spike, biological yield, straw yield and grain yield, respectively, over than mineral NPK fertilizer treatments. Hence, application of bio- and organic fertilizers are a good agricultural practice to improve wheat productivity, increasing the efficiency of using mineral fertilizers under sandy soil conditions, and thus reducing the reliance on mineral fertilizers to preserve the environment from pollution.

Keywords: Plant growth promoting rhizobacteria (PGPR), Biofertilizers, Organic fertilizer, Wheat vegetative growth, Yield and its components.

1. Introduction

Globally cereals are considered the main staples food including wheat (*Triticum aestivum* L.) is the most important cereal crop and it is the major source of food in Egypt. Increasing wheat production is an essential national target to fill the gap between production and consumption, by using high yielding of wheat cultivars and appropriate agronomic practice. Extensive cultivation of wheat in the newly reclaimed soil in Egypt seemed to be imperative to circumvent the problem of insufficient wheat grain supply as well as, intensive chemical fertilizers have introduced undesirable and sometimes catastrophic consequences by polluting air, soil and aquatic systems (Ali and Abo-El-Wafa, 2006).

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Sandy soils are often dry, nutrient deficient, and have low water holding capacity as well as moisture stress had negatively impacts physiological and biochemical mechanisms, and ultimately reduced crop growth and productivity (Khan *et al.* 2019).

Both biofertilizers and organic fertilizers are eco-friendly and have been proved to be effective and economical alternate of chemical fertilizers and led to improves erosion, buffering, reduces mineral fertilizers requirement, improving the nutritive status, increasing soil fertility and crop production (Verma *et al.* 2010; El-Sirafy *et al.* 2012; Kakraliya *et al.* 2017; Saleemi *et al.* 2017 and Mohamed *et al.* 2019).

Furthermore, such positive effects and the many efforts to decrease N, P and K chemical fertilization by using bio and organic fertilizer might both reduce the high costs and environmental pollution at wheat cultivation field under Egyptian sandy soil (Abdel-Warith *et al.* 2010; Abdel-Lateef 2018 and Badawi *et al.* 2021).

The main purpose of this work to evaluate the possibility of replacement of some mineral N, P and K fertilizers by application plant growth promoting rhizobacteria (PGPR) in combination with organic fertilizer to alleviate the harmful effects of higher doses of mineral N, P and K fertilizers on the growth, yield and yield components of wheat crop and the rise of the agricultural costs as well as the environmental pollution under sustainable agricultural system for Egyptian sandy soils.

2. Martials and Methods

A field experiment was layout on a sandy soil at own farm, Ismailia Governorate, Egypt, during two successive growing winter seasons (2020/2021 and 2021/2022) to study the effect of replacement some amounts from mineral N, P and K fertilizers using biological and organic fertilizers on the productivity of wheat crop. The main physical and chemical properties of the used soil were estimated according to the methods described by Piper (1950) and Page *et al.* (1982) and the obtained data were recorded in Table (1).

Table 1: Some physical and chemical properties of soil used in both investigated seasons

Property	**Value**	
	2020/2021	**2021/2022**
Particle size distribution (%)		
Sand	85.9	85.3
Silt	6.8	7.2
Clay	7.3	7.5
Texture grade	Sandy	Sandy
Saturation percent (S.P %)	21.9	22.3
pH (soil paste)	7.63	7.65
E.C (dS m^{-1}, at 25°C)	0.28	0.30
Organic matter (%)	0.27	0.29
Total soluble-N (mg kg^{-1})	18.50	19.80
Available- P (mg kg^{-1})	4.48	5.35
Available-K (mg kg^{-1})	38.75	43.55
Soluble cations and anions (meq/L):		
Ca^{++}	0.63	0.68
Mg^{++}	0.44	0.51
Na^{+}	0.83	0.87
K^{+}	0.84	0.82
$CO_3^{=}$	0.00	0.00
HCO_3^{-}	0.81	0.83
Cl^{-}	1.58	1.67
$SO_4^{=}$	0.35	0.38
***DTPA-extractable (mg kg^{-1}):**		
Fe	2.10	2.25
Mn	0.45	0.47
Zu	0.51	0.57
Cu	0.17	0.15

*DTPA: Di-ethylene tri-amine penta acetic acid

2.1. Bacterial cultures and bio-inoculant preparation:

Three locally isolates of plant growth promoting rhizobacteria (PGPRs) were used as biofertilizers namely, *Bacillus polymyxa* (Bp) as a free N_2-fixing bacteria, *Bacillus megaterium* (Bm) as a phosphate-dissolving bacteria and *Bacillus circulans* (Bc) as a potassium-solubilizing bacteria (silicate bacteria). The rhizobacterial isolates were kindly obtained from Biofertilizers Production Unit, Agricultural Microbiology Research Department, Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), Giza, Egypt. The nutrient broth medium was used for activated and cultured of *B. polymyxa*, *B. megaterium* and *B. circulans* (Atlas, 2005). Cultures were incubated at 28ºC for three days on a rotary shaker until early log phase was developed to 10^9 viable cells ml^{-1}.

Two methods were applied for PGPR as a biofertilizer, the first one was grain coating ($PGPR_1$) method and, prepared by using neutral powdered of vermiculite mixed with 10% Irish peat was packed in polyethylene bags (300g bag^{-1}), each bacterial culture was injected into the carrier to satisfy 60% of the maximal water holding capacity with bacterial load > 5 x 10^7 $CFUg^{-1}$ and used at a rate of 4g inoculum 100g $grains^{-1}$ at the planting time. The second method ($PGPR_2$) was applied as mixed liquid cultures (1:1:1) from the three different isolates used (B.p + B.m+ B.c) at a rate of 5L fed^{-1} with bacterial load > 10^9 CFU ml^{-1} inoculant and added 45 days after planting.

2.2. Organic fertilizer:

Matured compost was applied at the rate of 2 ton fed^{-1} during soil preparation (15 days before sowing) and ploughed with the surface layer of the soil. The main traits of the used compost were determined according to the procedure outlined by (Page *et al.* 1982 and Pare *et al.* 1997). The main physical, chemical and biological traits of compost are shown in Tables (2).

Table 2: Some physical, chemical and biological characteristics of the compost used

Property	Value
Bulk density (kg m^{-3})	585.0
Water holding capacity (%)	202.8
pH (1:10 extract)	6.83
E.C (dS m^{-1}, at 25ºC)	4.63
Organic carbon (%)	24.52
Organic matter (%)	42.17
Total nitrogen (%)	1.45
C/N ratio	16.91
Total phosphorus (%)	0.96
Total potassium (%)	1.91
Total soluble-N (mg kg^{-1})	921.7
Available-P (mg kg^{-1})	283.4
Available- K (mg kg^{-1})	963.8
***DTPA-extractable (mg kg^{-1}):**	
Fe	231.2
Mn	56.7
Zn	42.52
Cu	7.3
Weed seeds	Nil
Nematode	Nil
**Germination test of cress seeds (%)	89.0

*Di-ethylene tri-amine penta acetic acid.
**Cress seeds incubated for 48 hr.

2.3. Mineral fertilizers:

Ammonium sulphate (20.5% N), calcium supper phosphate (15.5 P_2O_5) and potassium sulphate (48% K_2O) were used at the 100, 75, 50, and 25% from the recommended fertilizer doses per feddan (120 kg N, 30 kg P_2O_5 and 24 kg K_2O). Phosphorus was added during soil preparation, while nitrogen and potassium fertilizers were applied in three equal doses at 0, 21 and 35 days after sowing.

2.4. Field experiment:

Wheat (*Triticum aestivum* cv. Misr 3) supplied by the Wheat Research Department, Filed Crops Research Institute, Agricultural Research Center (ARC), Giza, Egypt and applied at rate 60 kg fed^{-1}. The experiments were laid out in randomized complete block design (RCBD) with three replicates and each plot area was 5 m^2 (1/840 fed^{-1}).

The following fertilization treatments were conducted: -

T_1- 100% NPK mineral fertilizer
T_2- 75 % NPK mineral fertilizer
T_3- 50 % NPK mineral fertilizer
T_4- 25 % NPK mineral fertilizer
T_5- 75 % NPK + biofertilizer ($PGPR_1$) + 2 ton compost fed^{-1}
T_6- 50 % NPK + biofertilizer ($PGPR_1$) + 2 ton compost fed^{-1}
T_7- 25 % NPK + biofertilizer ($PGPR_1$) + 2 ton compost fed^{-1}
T_8- 75 % NPK + biofertilizer ($PGPR_1$) + ($PGPR_2$) + 2 ton compost fed^{-1}
T_9- 50 % NPK + biofertilizer ($PGPR_1$) + ($PGPR_2$) + 2 ton compost fed^{-1}
T_{10}- 25% NPK + biofertilizer ($PGPR_1$) + ($PGPR_2$) + 2 ton compost fed^{-1}

At vegetative growth stage (60 days from sowing) ten wheat plants were uprooted from each plot to assay the following vegetative parameters: plant height (cm), number of tillers $plant^{-1}$ and dry weight of shoots (g $plant^{-1}$) as well as their N, P and K uptake (mg $plant^{-1}$). At harvest stage, the following parameters were estimated: number of spikes m^{-2}, estimated by counting the number of spikes in randomly selected square meter area inside each plot; number of grains $spike^{-1}$, determined as the average number of grains obtained from 10 randomly selected spikes for each plot and grain yield (g $plant^{-1}$) as well as grain yield (kg $plot^{-1}$), the biological yield (kg fed^{-1}), grain yield (kg fed^{-1}), straw yield (kg fed^{-1}) and 1000-grain weight (g), as an average of four 100-grain random samples was recorded. The percentage of N, P, K and crude protein of grains was also determined according to methods of Page *et al.* (1982) and A.O.A.C. (2005). Statistical analysis (L.S.D at the level of 0.05) was carried out according to Snedecor and Cochran (1982).

3. Results and Discussion

3.1. Vegetative growth characters:

The results of vegetative growth characters of wheat plants, i.e., plant height (cm), number of tillers $plant^{-1}$ and dry weight of shoots (g $plant^{-1}$) after 60 days from sowing are shown in Table (3). The obtained data revealed that application of both bio and organic fertilizers in combination with different levels of N, P and K mineral fertilizers (75, 50 and 25%) achieved significant differences and gave significant increases in all tested wheat growth characters as compared to uninoculated treatments fertilized with the same mineral N, P and K fertilizers level. This could be due to the essential role of compost and co-inoculation with the mixture of PGPRs in enhancing wheat plant growth. The lower rate of N, P and K fertilizers (25%) with or without $PGPR_1$ and $PGPR_2$ gave the lowest values (45.5, 53.9 and 69.1cm) for plant height, (3.45, 3.83 and 4.45 $plant^{-1}$) for number of tillers and (3.33, 3.60 and 3.93g $plant^{-1}$) for shoot dry weight. The increasing application rate of mineral N, P and K caused an increase in these values with no significant differences were found as compared between 100% mineral N, P and K fertilizers and both 75 and 50% mineral N, P and K fertilizers in the presence of compost and $PGPR_1$+ $PGPR_2$. The highest values recorded were 91.4 cm, 6.50 $plant^{-1}$and 4.98 g $plant^{-1}$ for plant height, number of tillers and shoot dry weight, respectively as an average the two tested seasons. Moreover, no significant increases were found as compared between both treatments of $PGPR_1$ and $PGPR_1$+$PGPR_2$ in presences of 75 and 50 % NPK mineral fertilizers.

This result was previously achieved by Attia and Abd El Salam (2016); Kakraliya *et al.* (2017) and Phullan *et al.* (2017) who reported that the synergy between PGPR as biofertilizer and organic amendment at low mineral N, P and K fertilizers, creating a favorable habitat for plant growth and led to increase wheat growth parameters such as plant height, number of tillers and plant dry weight.

Table 3: Effect of rhizobacterial inoculation (PGPR), compost and different levels of mineral N, P and K fertilizers on some wheat growth parameters after 60 days from sowing

Parameters	Plant height (cm)			Number of tillers ($plant^{-1}$)			Shoot dry weight (g $plant^{-1}$)		
Treatments	**S_1**	**S_2**	**X**	**S_1**	**S_2**	**X**	**S_1**	**S_2**	**X**
1 -100% NPK	87.9	88.3	88,1	6.33	6.66	6.45	4.63	4.81	4.72
2- 75% NPK	83.2	85.1	84.2	5.88	5.33	6.33	4.32	4.85	4.59
3- 50 % NPK	69.2	71.2	70.2	4.66	5.33	4.99	3.75	4.01	3.88
4-25% NPK	43.7	47.3	45.5	3.33	3.66	3.45	3.11	3.51	3.33
5-75%NPK + $PGPR_1$	86.3	87.8	87.1	6.01	6.33	6.17	3.85	3.96	3.91
6-50% NPK + $PGPR_1$	81.1	83.2	82.2	5.33	5.66	5.45	3.66	3.72	3.69
7-25% NPK + $PGPR_1$	53.1	54.7	53.9	36.6	4.00	3.83	3.54	3.66	3.60
8-75% NPK+ $PGPR_1$ + $PGPR_2$	89.7	93.1	91.4	6.33	6.66	6.50	4.92	5.03	4.98
9-50%NPK + $PGPR_1$ + $PGPR_2$	83.4	85.2	84.3	6.00	6.33	6.17	4.61	4.67	4.64
10-25% NPK+$PGPR_1$+ $PGPR_2$	66.7	71.4	69.1	4.33	4.66	4.45	3.87	3.98	3.93
L.S.D 0.05	5.99	6.31	8.4	0.39	0.41	0.53	0.53	0.52	0.70

- ($PGPR_1$): grain coating method - ($PGPR_2$): soil application method (a mixture of liquid cultures)
- Inoculated treatments amended with 2 ton compost fed^{-1}

3.2. Nutrients accumulation in shoot tissues:

Results in Table (4) show the effect of rhizobacterial inoculation (PGPR) as biofertilizer in presence of organic fertilizer (compost) at variance levels of inorganic N, P and K fertilizers (75, 50 and 25%) on the accumulation of N, P and K nutrients in shoot tissues of 60 days old wheat plants. The obtained data revealed that N, P and K uptake were significantly responded to all investigated treatments. With respect to N- uptake, there is no significant differences were found between the plants, which received 100% NPK fertilizer dose and plants inoculated with ($PGPR_1$) or ($PGPR_1$+ $PGPR_2$) in the presence of compost at the two levels of mineral fertilizers (75 and 50 % of NPK). The higher values attained were 71.33, 70.31 and 70.89 mg N $plant^{-1}$ for 100% NPK mineral fertilizers, (PGPR1) and ($PGPR_1$+ $PGPR_2$) combined with 75% of mineral NPK fertilizers, respectively, as an average for the two tested seasons.

Table 4: Effect of rhizobacterial inoculation (PGPR), compost and different levels of mineral N, P and K fertilizers on nutrients accumulated in wheat shoot tissues after 60 days from sowing

Parameters	Shoot N-uptake (mg N plant $^{-1}$)			Shoot P-uptake (mg P plant $^{-1}$)			Shoot K-uptake (mg K plant $^{-1}$)		
Treatments	**S_1**	**S_2**	**X**	**S_1**	**S_2**	**X**	**S_1**	**S_2**	**X**
1 -100% NPK	71.13	71.52	71.33	33.14	35.70	34.42	93.15	95.73	94.44
2- 75% NPK	66.73	69.37	68.05	32.68	33.01	32.85	89.66	91.51	90.59
3- 50 % NPK	48.21	51.35	47.78	31.15	32.27	31.71	77.31	82.11	79.71
4-25% NPK	39.11	43.24	41.18	25.14	36.11	25.63	53.42	55.7/8	54.59
5-75%NPK + $PGPR_1$	69.51	71.11	70.31	32.11	33.17	32.64	89.17	91.37	90.27
6-50% NPK + $PGPR_1$	67.81	64.53	66.17	31.75	32.19	31.97	88.11	89.93	89.02
7-25% NPK + $PGPR_1$	55.11	57.18	56.15	29.11	29.81	29.46	63.17	6.37	64.77
8-75% NPK+ $PGPR_1$ + $PGPR_2$	70.33	71.44	70.89	32.98	34.76	33.88	91.83	92.81	92.32
9-50%NPK + $PGPR_1$ + $PGPR_2$	66.81	70.17	68.49	31.54	32.27	31.91	88.31	90.71	89.51
10-25% NPK+$PGPR_1$+ $PGPR_2$	58.34	61.41	59.88	30.33	31.81	31.17	69.81	70.14	69.98
L.S.D 0.05	1.39	1.89	2.09	0.72	0.93	1.1	2.16	2.97	3.42

For P and K uptake, data presented in Table (4) indicated that the plant inoculated with ($PGPR_1$+ $PGPR_2$) in combination with compost and 75% of mineral NPK fertilizers had no significant differences were found as compared to the treatment, which received the recommended dose of mineral fertilizers (100% NPK) and recorded the highest values of P-uptake (33.88 and 34.42 mg P $plant^{-1}$) and K-uptake (92.32 and 94.44 mg K $plant^{-1}$), as an average for the two tested seasons. It is clear that wheat crop planted in sandy soil showed high response to apply both PGPR and compost, which achieved many of the beneficial effects that are more attributed to one or more of PGP-related properties indicating an increase in root biomass and provides it with more branching and larger surface area, and then indirectly enhanced nutrient uptake capacity. These results are in conformity with those of Abo El-Ella and Abotaleb (2015); Rady *et al.* (2016) and El-Sayed and Hagab (2020) who reported that, application of PGPR and organic fertilizers are considered as practices of improving the nutritive and increasing NPK uptake under both lower levels of mineral fertilizers and sandy soil conditions.

3.3. Wheat yield and some yield components:

Data presented in Table (5) revealed that the number of spikes m^{-2}, number of grains $spike^{-1}$ and grain yield (g $plant^{-1}$) were significantly affected by application both $PGPR_1$ and $PGPR_2$ in combination with compost (2 ton fed^{-1}) and different levels of mineral NPK fertilizers. The inoculated treatments with PGPRs in the presence of 75, 50 and 25% mineral NPK fertilizers gave higher values for number of spikes/m^2, number of grains/spike and grain yield/ plant as compared to apply mineral NPK fertilizer alone. The recommended treatment (100% mineral NPK fertilizers) and the treatment that received 75% mineral NPK fertilizers + rhizobacterial inoculation ($PGPR_1$+$PGPR_2$) and compost recorded the higher values of the number of spikes/m^2, number of grains/spike and grain yield/plant with no significant differences between them. The highest values attained for number of spikes were (345.9 and 338.8 spike $plant^{-1}$) and number of grains (50.2 and 49.2 grain $spike^{-1}$), while grain yield was (89.6 and 90.3 g $plant^{-1}$) in the same order mentioned above as an average of the two tested seasons.

Many investigators confirmed the stimulating effect of PGPRs and compost in creating a favorable habitat for improving wheat yield parameters. In this respect, (Mohamed *et al.* 2019;Badawi *et al.* 2021 and Abdullah *et al.* 2022) reported that wheat plants treated with PGPRs and/or amended with compost in combination with lower levels of mineral fertilizers caused significant increases and gave values higher than using the same mineral NPK fertilizer levels alone.

Table 5: Effect of rhizobacterial inoculation (PGPR), compost and different levels of mineral N, P and K fertilizers on number of spikes/m^2, number of grains/spike and grain yield/plant under sandy soil conditions

Parameters	Number of spikes m^{-2}			Number of grains $spike^{-1}$			Grain yield (g $plant^{-1}$)		
Treatments	S_1	S_2	X	S_1	S_2	X	S_1	S_2	X
1 -100% NPK	343.1	348.6	345.9	49.7	50.7	50.2	88.5	90.6	89.6
2- 75% NPK	284.5	294.7	289.6	39.5	41.8	40.7	73.1	76.4	74.8
3- 50 % NPK	213.5	228.9	221.2	31.8	34.7	33.3	69.4	70.2	69.8
4-25% NPK	187.6	193.7	190.7	22.3	23.8	23.1	40.3	41.2	40.8
5-75%NPK + $PGPR_1$	338.9	340.7	339.8	47.8	49.1	48.5	85.7	87.3	86.5
6-50% NPK + $PGPR_1$	301.3	311.5	306.4	45.3	47.3	46.3	81.4	83.2	82.3
7-25% NPK + $PGPR_1$	215.7	227.8	221.8	36.2	39.8	38.0	55.7	56.3	56.0
8-75% NPK+ $PGPR_1$ + $PGPR_2$	331.7	345.8	338.8	48.5	49.9	49.2	89.2	91.3	90.3
9-50%NPK + $PGPR_1$ + $PGPR_2$	315.5	322.7	319.1	46.7	47.3	47.0	85.4	86.7	86.1
10-25% NPK+$PGPR_1$+ $PGPR_2$	273.8	281.5	277.7	39.3	41.8	40.6	58.4	59.2	58.8
L.S.D 0.05	13.11	15.13	18.83	4.39	5.23	6.41	2.13	2.87	3.33

Data in Table (6) revealed that grain yield (kg $plot^{-1}$), biological yield (kg fed^{-1}), grain yield (kg fed^{-1}), and straw yield (kg fed^{-1}) were significantly affected by rhizobacterial inoculation (PGPRs) and compost application in combination with lower rates (75 and 50%) of mineral NPK fertilizers as compared to untreated treatments. For instance, the treatment which received 75% mineral NPK fertilizers, compost and inoculated with rhizobacteria ($PGPR_1$ and $PGPR_2$) gave higher values for the above all tested parameters (2.27, 5124.8,1903 and 3221.8 kg) for grin yield $plot^{-1}$, biological yield fed^{-1}, grain yield fed^{-1} and straw yield fed^{-1}, as an average for the two tested seasons, respectively. On the other hand, the uninoculated treatment supplied with the recommended dose of mineral fertilizers (100% NPK) came in the second order and attained values (2.25, 5092.5, 1891 and 3202.0 kg) in the same order mentioned above. In general, the combined application of PGPRs, organic fertilizer and NPK mineral fertilizers (75, 50 and 25%) gave significant difference and recorded higher values of all tested yield parameters as compared to apply all tested levels of mineral NPK fertilizers only.

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It is evident that such combined treatments may act to improve sandy soil quality through affecting its chemical and biological features, production of specific activator compounds that have the ability to enhance nutrient and water availability leading to boost growth and productivity of the wheat crop. The result confirmed the findings of many researchers (Akhtar *et al.* 2009; Abd El-Lattief, 2013; Kakraliya *et al.* 2017 and Badawi *et al.* 2021). They concluded that the application of PGPRs and organic fertilizers caused a positive effects and significant increases in the productivity of wheat and in all its yield components as compared to untreated wheat plants.

Table 6: Effect of rhizobacterial inoculation (PGPR), compost and different levels of mineral N, P and K fertilizers on grain yield/plot, biological yield/fed, grain yield/fed and straw yield/fed under sandy soil conditions

Parameters	Grain yield (kg plot^{-1})			Biological yield (kg fed^{-1})		
Treatments	**S$_1$**	**S$_2$**	**X**	**S$_1$**	**S$_2$**	**X**
1 -100% NPK	2.19	2.30	2.25	4977.4	5207.6	5092.5
2- 75% NPK	1.82	1.88	1.85	4164.7	4275.9	4220.3
3- 50 % NPK	1.52	1.53	1.53	2348.4	3525.5	2936.9
4-25% NPK	1.88	0.92	0.90	2102.1	2205.6	2153.9
5-75%NPK + PGPR$_1$	2.13	2.19	2.16	4840.1	5006.9	4923.5
6-50% NPK + PGPR$_1$	1.99	2.03	2.02	4526.2	4607.2	4566.7
7-25% NPK + PGPR$_1$	1.17	1.18	1.18	2744.5	2794.7	2769.6
8-75% NPK+ PGPR$_1$ + PGPR$_2$	2.21	2.33	2.27	4995.4	5254.1	5124.8
9-50%NPK + PGPR$_1$ +PGPR$_2$	2.04	2.07	2.06	4646.2	4695.9	4671.1
10-25% NPK+PGPR$_1$+PGPR$_2$	1.22	1.29	1.26	2845.4	3002.7	2924.1
L.S.D 0.05	0.34	0.41	0.50	417.5	533.2	3833.07

Table (6): Cont.

Parameters	Grain yield (kg fed^{-1})			Straw yield (kg fed^{-1})		
Treatments	**S$_1$**	**S$_2$**	**X**	**S$_1$**	**S$_2$**	**X**
1 -100% NPK	1846	1935	1891	3131.4	3272.6	3202.0
2- 75% NPK	1532	1575	1554	2632.7	2700.9	2666.8
3- 50 % NPK	1273	1285	1274	2221.1	2240.5	2230.8
4-25% NPK	735	775	755	1367.1	1430.6	1398.9
5-75%NPK + PGPR$_1$	1793	1837	1815	3047.1	3169.9	3108.5
6-50% NPK + PGPR$_1$	1674	1703	1689	2858.2	2904.2	2881.2
7-25% NPK + PGPR$_1$	983	995	989	176.1	1799.7	1780.6
8-75% NPK+ PGPR$_1$ + PGPR$_2$	1853	1953	1903	3142.4	3301.1	3221.8
9-50%NPK + PGPR$_1$ +PGPR$_2$	1718	1736	1728	2992.8	2959.9	2944.1
10-25% NPK+PGPR$_1$+PGPR$_2$	1021	1083	1053	1824.4	1919.7	1872.1
L.S.D 0.05	213	254	311.33	375.2	417.8	528.07

The data related to the percentage of nitrogen, phosphorous and potassium for wheat grains (Table 7) affected by rhizobacterial inoculation, organic and inorganic fertilization followed a similar pattern to that of vegetative growth stage. The obtained data indicate that the inoculation with rhizobacteria (PGPR) and application of compost under different levels of mineral NPK fertilizers (75, 50 and 25%) led to increase N, P and K contents of wheat grains compared to the treatments that received the same levels of mineral NPK fertilizers alone. However, the recommended treatment (100% NPK) recorded the highest values of N% (2.12), P% (0.30) and K% (0.80) as an average of the two tested seasons. The treatments, which fertilized with 75, 50 and 25% mineral NPK fertilizers in combination with ($PGPR_1$ and $PGPR_2$) and compost came in the second order and gave values (2.10, 1.99 and 1.94%) for N%, (0.30, 0.29 and 0.26) for P% and (0.79, 0.78 and 0.67%) for K%, respectively.

In fact, this improvement in the N, P and K percentages in wheat grains could be attributed to the biological role of such rhizobacteria and compost in promoting plant growth, N_2-fixation performance as well as P and K mobilization and phytohormone production. Such promotion is

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confirmed by many investigators (Devi *et al.* 2011; Kakraliya *et al.* 2017 and Kadhum *et al.* 2021) who reported that the integrated effect of PGPRs with organic and mineral fertilizers led to give a positive effect on grains yield and its nutrient contents as well as wheat grains quality.

Table 7: Effect of rhizobacterial inoculation (PGPR), compost and different levels of mineral N, P and K fertilizers on the percentage of nutrients in wheat grains under sandy soil conditions

Parameters	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
Treatments	S_1	S_2	X	S_1	S_2	X	S_1	S_2	X
1 -100% NPK	2.11	2.12	2.12	0.29	0.31	0.30	0.78	0.81	0.80
2- 75% NPK	1.93	1.95	1.94	0.23	0.26	0.26	0.72	0.76	0.74
3- 50 % NPK	1.92	1.94	1.93	0.23	0.24	0.24	0.63	0.64	0.64
4-25% NPK	1.90	1.91	1.91	0.22	0.22	0.22	0.56	0.58	0.57
5-75%NPK + PGPR$_1$	1.96	1.98	1.97	0.27	0.28	0.27	0.76	0.78	0.77
6-50% NPK + PGPR$_1$	1.94	1.95	1.95	0.26	0.27	0.27	0.74	0.75	0.77
7-25% NPK + PGPR$_1$	1.91	1.92	1.92	0.24	0.23	0.25	0.61	0.68	0.62
8-75% NPK+ PGPR$_1$ + PGPR$_2$	2.09	2.10	2.10	0.29	0.30	0.30	0.77	0.82	0.79
9-50%NPK + PGPR$_1$ + PGPR$_2$	1.98	1.99	1.99	0.23	0.29	0.29	0.76	0.79	0.78
10-25% NPK+PGPR$_1$+ PGPR$_2$	1.93	1.94	1.94	0.25	0.26	0.26	0.66	0.67	0.67
X	1.97	1.98	1.98	0.26	0.27	0.27	0.70	0.72	0.71
L S D	-	-	-	-	-	-	-	-	-

Data in Table (8) indicated that the application of PGPRs as biofertilizer in combination with compost (2 ton fed^{-1}) did support both 1000-grain weight (g) and crude protein (%) and caused significant differences as comported to untreated treatments and fertilized with different levels of mineral NPK fertilizers. As mentioned before, the results confirmed again the superiority of the treatment inoculated with rhizobacteria (PGPR$_1$ and PGPR$_2$) and amended with compost in combination with 75% NPK mineral fertilizers and the recommended NPK treatment (100%) and scored the highest values of 1000-grain weight (49.9 and 49.7g), respectively as an average to the two tested seasons. Also, data of grains crude protein showed no significant differences between the 100% NPK mineral fertilizer treatment (13.22%) and the treatment, which inoculated with rhizobacteria (PGPR$_1$ and PGPR$_2$) and amended with compost in combination with 75% NPK mineral fertilizers (13.10%). Hence, the combined treatments of PGPR$_1$ or (PGPR$_1$ and PGPR$_2$) with compost enhanced wheat productivity and yield quality and recorded percentage increases in 1000-grain weight and crude protein as compared with the treatment received mineral NPK fertilizers alone.

Table 8: Effect of rhizobacterial inoculation (PGPR), compost and different levels of mineral N, P and K fertilizers on the 1000-grain weight and grains crude protein under sandy soil conditions

Parameters	1000-grain weight (g)			Crude protein of grains (%)		
Treatments	S_1	S_2	X	S_1	S_2	X
1 -100% NPK	49.3	50.1	49.7	13.19	13.25	13.22
2- 75% NPK	46.8	47.5	47.2	12.06	12.19	12.13
3- 50 % NPK	44.3	45.1	44.7	12.00	12.13	12.07
4-25% NPK	42.5	42.8	42.7	11.88	11.94	11.91
5-75%NPK + PGPR$_1$	48.9	49.7	49.3	12.25	12.38	12.32
6-50% NPK + PGPR$_1$	46.98	47.8	47.4	12.13	12.19	12.16
7-25% NPK + PGPR$_1$	42.3	42.9	42.6	11.94	12.00	11.97
8-75% NPK+ PGPR$_1$ + PGPR$_2$	49.1	50.7	49.9	13.06	13.13	13.10
9-50%NPK + PGPR$_1$ + PGPR$_2$	47.3	49.1	48.2	12.38	12.44	12.41
10-25% NPK+PGPR$_1$+ PGPR$_2$	42.2	43.8	43.2	12.06	12.12	12.90
L.S.D 0.05	1.54	1.63	2.11	0.23	0.35	0.39

In fact, PGPRs and compost have been shown to improve wheat grain quality significantly, when combined with 75% NKP mineral fertilizer. Our results are consistent with several researchers who have confirmed the beneficial role of combined application of bio-organic materials in increasing yield and improving wheat grain quality (Zaki *et al.* 2012; Rady *et al.* 2016 and Badawi *et al.* 2021).

Data in Table (9) indicates that the percentage increase of some vegetative growth and yield parameters of wheat plants inoculated with rhizobacteria ($PGPR_1$) or ($PGPR_1$+ $PGPR_2$) in combination with mineral NPK fertilizers attained an increases up to 7.5, 19.1, 23.8, 17.1, 12.8 and 14.1% for number of tiller/ plant, number of spikes/ m^2, number of grains/spike, biological yield (kg/fed), straw yield (kg/fed) and grain yield (kg/fed), respectively, over than mineral NPK fertilizer treatments. Generally, PGPR and compost have been shown to improve and increased the productivity and quality of wheat crop under sandy soil conditions. The obtained results are in agreement with (Khan *et al.* 2019; El-Kharbotly and Ghanem 2020; El-Sayed and Hagab 2020; Badawi *et al.* 2021; Abdullah *et al.* 2022 and Kumar *et al.* 2022) who reported that wheat crop inoculated and treated with PGPRs as biofertilizer in combination with compost as organic fertilizer and reduced the application of mineral NPK fertilizers under sandy soil conditions led to give higher values of vegetative growth parameters, wheat yield parameters (i.e., biological yield, straw yield and grain yield) and yield quality (i.e., N, P and K contents as well as crude protein percentage).

Table 9: Percentage increase of some growth and yield parameters of wheat plants inoculated with PGPR treatments as compared to fertilized plants with NPK mineral fertilizers (an average of the tested seasons)

Parameters	**Number of tillers**		**Number of spikes**		**Number of grains**		**Biological yield**		**Straw yield**		**Grain yield**	
Treatments	**(no. plant^{-1})**	**%**	**(no. m^{-2})**	**%**	**(no. spike^{-1})**	**%**	**(kg fed^{-1})**	**%**	**(kg fed^{-1})**	**%**	**(kg fed^{-1})**	**%**
NPK	5.31	-	261.9	-	36.83	-	3600.9	-	2374.6	-	1368.5	-
NPK+$PGPR_1$	5.15	-3	289.3	10.5	44.27	20.2	4086.6	13.5	2590.1	9.1	1497.7	9.4
NPK+$PGPR_1$+$PGPR_2$	5.71	7.5	311.9	19.1	45.60	23.8	4240.0	17.1	2679.3	12.8	1561.3	14.1

4. Conclusion

There is considerable evidence that the application of plant growth promoting rhizobacteria (PGPRs) is a promising strategy to improve crop yield for many crops as well as reduce the use of chemical fertilizers, thereby creating environment–friendly sustainable agriculture. PGPRs and organic fertilizers led to greatly enhance the productivity and quality of wheat plants when they integrated with lower rates of mineral NPK fertilizers. Hence, data confirmed the superiority of treatment comprising PGPRs inoculation (applied as grain coating and liquid cultures "soil drench") conjugated with compost (2 ton fed^{-1}) and 75% of the recommended dose of NPK mineral fertilizers, which surpassed other tested treatments and caused a significant augmentation in all studied wheat parameters. Such fertilization treatment may be acting as a good practice not only for increasing wheat productivity in sandy soil but also to reduce the reliance on chemical fertilizers and minimize the environmental pollution. Further studies need to be conducted using different wheat cultivars and different methods and concentrations of PGPRs along with organic fertilizers, particularly under sandy soil conditions to reduce and provide more amount of applied NPK mineral fertilizers.

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