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Research Article

Effect of *T. harzianum* and *G. mosseae* Biological Inoculation and Phosphate Rocks on the Availability of NPK in the Rhizosphere of Barley Crop (*Hordium Valgari* L.)

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Abstract

Biological fertilizers are of great importance in further improving agricultural production. Therefore, the effect of fungal fertilizers with isolates of *T. harzianum* and *G. mosseae* and levels of phosphate rock on NPK availability in the rhizosphere of the barley crop was studied. A field trial was conducted on clay loamy soil to produce a variety of barley crops named (Samir 1) during the autumn agricultural season in 2021 in the Al-Qadisiyah Governorate. The factorial experiment was designed according to a Randomized Complete Block Design (RCBD) with three replications. The factors of the experiment included two levels of *T. harzianum* inoculum (T0, control and T1, fungal inoculation), two levels of *G. mosseae* inoculum (G0, control and G1 fungal inoculation), and four levels of phosphate rock (P0, P1, P2, and P3) with an amount (0,1000,1500, and 2000) t/ha^{-1}. The results present that the interaction treatment (*G. mosseae* + *T. harzianum* and phosphate rock of 1000 t/ha^{-1}) resulted in a significant increase in the availability of nitrogen, phosphate, and potassium (NPK) in the soil 41.32, 16.54, and 225.43 mg/kg/soil^{-1}, respectively, compared to the control.

Keywords: T. harzianum; G. mosseae; Phosphate rocks; Barley plant; NPK

Introduction

Biological inoculums are the application of biological origin, consisting of bacterial or fungal cells or both, mainly bacteria that secrete plant hormones that stimulate plant growth. These biological inoculums are derived from the isolation, purification, and characterization of specific strains of beneficial microorganisms in soil grown in an appropriate place. These inoculums are applied by mixing them with seeds or contaminating the roots of seedlings before planting or applying them directly to the soil to increase nutritional availability by activating them in the roots [1]. Mycorrhiza is one of the most common soil fungi that directly affects the plant host through various mechanisms. For example, it directly affects the absorption of phosphorous and mineral elements, increases plant resistance to water stress, and protects against pathogens.

In the early seventies, the importance of mycorrhizal fungi began to appear with its increasing importance with time because it interferes with different vegetation types, which necessitates the identification and study of these fungi, including species genera and isolates that live in agricultural soils [2]. Trichoderma is a fungus spreading at the soil level that produces enzymes and promotes root growth and plant development by increasing the availability of nutrients in the soil [3, 4]. Trichoderma works to form large root groups by promoting root growth and increasing plant stress tolerance. The fungus serves to tolerate the plant's environmental conditions. It is a fungus that promotes plant growth by contributing to the cycles of elements, including nitrogen, phosphorous, and sulfur. It has an essential role in the primary conditions, working on the solubility of microelements such as iron, manganese, zinc, and copper [5, 6].

Phosphate rock is the primary material for the production of phosphate fertilizers. This ore can be treated with sulfuric acid to produce natural calcium phosphate and can also be treated with phosphoric acid to produce triple superphosphate [7]. Phosphate rocks contain 11-16% phosphorous and 25-37% P2O5, while Akashat rocks are rich in phosphorous content up to 30% P2O5 [8] and are mostly insoluble in water. 5-17% of the total phosphorous is dissolved in the citrate solution depending on the chemistry of the rock and the rock's softness [9, 10]. Phosphate rock contains 11-16% phosphorous and 25-37% P2O5. Akashat rocks are rich in phosphorous content of up to 30% P2O5 [8], most of which is insoluble in water, and 5-17% of total phosphorous is soluble in citrate solution, depending on the chemical nature of the rock and the degree of its softness the rock [9-11].

Barley, a crop belonging to the *Poaceae* family, is grown in large world areas in winter. The barley crop has essential uses as fodder and is ranked fourth in second importance after wheat, rice, and corn [12]. Through the preceding, the objectives of the study include the following:

- Studying the effect of *T. harzianum* on the availability of NPK in the soil.
- Studying the effect of *G. mosseae* on the availability of NPK in the soil.
- Studying the interaction between *T. harzianum* and *G. mosseae* on the ratio of NPK available in the soil.
- Studying the effect of phosphate rocks on the percentage of NPK available in the soil at different levels.

Materials and Methods

Experimental Site

The experiment was conducted on clay loamy soil to produce barley plant variety (Samir 1) during the fall agricultural season of 2021 in the Al-Qadisiyah Governorate / Al-Nouriah region / in one agricultural land belonging to the Al-Nouriah Forest Department. First, soil samples were taken from the field from all areas of the field and mixed to make a composite sample representing the field soil. Then the sample was dried pneumatically and crushed well, and then it was sieved through a sieve with an a-holes diameter of 2 mm to perform physical, chemical, and biological tests, as shown in Table (1).

Experience Design

The experiment was designed according to the Complete Randomized Block Design (RCBD). The field was divided into three replicates, 48 experimental units, and each sector included 16 treatments distributed randomly. The area of each experimental unit is 9 m2, and its dimensions are 3x3 m.

Experience Factors

The first factor of this study was the application of fungus (*T. harzianum*) on two levels:

- T0 = without *T. harzianum* application (control).
- T1 = with the application of *T. harzianum*.

The second factor of this study was the application of fungus (*G. mosseae*) on two levels

- G0 = without *G. mosseae* application (control).
- G1 = with the application of *G. mosseae*.

The third factor of this study was the application of phosphate rocks at four levels

- P0 = 0 t/h-1 without phosphate rocks applications (control)
- P1 = phosphate rocks applications at 1000 0 t/h^{-1}.
- P2 = phosphate rocks applications at 1500 0 t/h^{-1}.
- P3 = phosphate rocks applications at 2000 0 t/h^{-1}.

Trait		***Value***	***Unit***
PH		7.7	
EC		2.7	DesiSmens.M^{-1}
Soil texture		Clay Loam	
Soil Separators	Sand	215	g.kg^{-1}Soil
	Clay	375	
	Silt	410	
Organic matter		8.4	Mg.kg^{-1} Soil
Available ions	N	32.12	
	P	8.3	
	K	196.14	
Dissolved positive ions	Ca^{+2}	9.6	$mmol_c$. L^{-1}
	Mg^{+2}	10.2	
	Na^{+}	13.9	
	K^{+}	0.2	
	SO_4^{-2}	11.3	
Dissolved negative ions	HCO_3	12.4	
	CO^{3-2}	Nill	
Total fungi	$1.83 X 10^3$		Soil/g^{-1}/CFU

Table 1: Physical, chemical, and biological characteristics of the soil of the field soil.

Results and Discussion

Nitrogen Availability in Soil (mg/kg^{-1}/soil)

Table (2) presented the significant effect of *G. mosseae* application on the increasing soil nitrogen content of 39.20 mg/kg^{-1}/soil compared to the control 37.28 mg/kg^{-1}/soil. This increase is attributed to the role of *G.mosseae* in increasing the absorptive capacity of the plant through the development of the root system, the extension of the hyphae, and the extraction of nutrients, including nitrogen [13, 14]. The application of *T. harzianum* resulted in a significant increase in soil's nitrogen content of 39.74 mg/kg^{-1}/soil compared to the control 36.75 mg/kg^{-1}/soil. This increase is attributed to the fungus *T. harzianum* in forming chelating compounds with the complex compounds of the elements, so it works on releasing them and converting them to the available form [15, 16].

The addition of phosphate rock resulted in a significant increase in the average available nitrogen content in the soil, 38.93 mg/kg^{-1}/soil with treatment (P2) compared to the control treatment, 36.97 mg/kg^{-1}/soil. The reason is due to the nutritional needs provided by the phosphorous released from the phosphate rock to the organism endemic to the soil from the fungus *G. mosseae* or *T. harzianum* fungus to build many of the compounds inside their bodies that enter into building energy and internal organs, which led to an increase in their numbers. In addition, it is reflected in the weathering of rocks and their releasing of phosphorous and the role of phosphorus in the formation of an extensive root group targeted by endemic bacteria [17].

The Table results also indicated the binary interaction between the fungi *G.mosseae* and *T. harzianum*, which produced the highest significant increase in the average available nitrogen content in the soil, 40.53 mg/kg^{-1}/soil compared to the control 35.62 mg/kg^{-1}/soil. The reason is attributed to the role of the mycorrhizae in increasing the availability of phosphorous, nitrogen, and potassium, as well as the secretions of the two organisms that increase the biomass of the two organisms in the roots of the host plant [18, 19]. The results of the Table confirmed that the triple interaction between (*G. mosseae* and *T. harzianum*) and phosphate rock produced the highest significant increase in the available nitrogen content in the soil, 41.32 mg/kg-1/soil with treatment (G1 + T1 + P1) compared to the control treatment (G0 + T0 + P0) 33.21 mg/kg^{-1}/soil.

Fungal (G)	***Fungal (T)***	***Phosphorus (P)***				***Mean of Binary overlap G x T***
		0	***1***	***2***	***3***	
0	0	33.21	35.82	36.54	36.92	35.62
	1	38.27	38.58	39.48	39.45	38.95
1	0	36.55	37.45	39.03	38.44	37.87
	1	39.83	41.32	40.68	40.27	40.53
LSD 0.05		0.76				0.39
Bi-interaction G x P						
Fungal (G)		P				Mean
0		35.74	37.20	38.01	38.19	37.28
1		38.19	39.39	39.86	39.36	39.20
LSD 0.05		0.55				0.28
Bi-interaction T x P						
Fungal (T)		P				Mean
0		34.88	36.63	37.79	37.68	36.75
1		39.05	39.95	40.08	39.86	39.74
LSD 0.05		0.55				0.28
P mean		36.97	38.29	38.93	38.77	
L.S.D. 0.05		0.39				

Table 2: Effect of fungal inoculums (*T. harzianum* and *G. mosseae*) and phosphate rock on nitrogen availability in soil.

Phosphorous Availability in the Soil (mg/kg^{-1}/soil)

There is a significant effect of applying *G. mosseae* fungus on the increase in the average soil content of phosphorous 14.91 mg/kg^{-1}/soil compared to the control 12.50) mg/kg^{-1}/soil, Table (3). The reason is attributed to the fungus *G. mosseae* in dissolving phosphorous and increasing the rates of water and nutrients absorption due to the roots' high absorption efficiency [20, 21]. On the other hand, *T. harzianum* resulted in a significant increase in the mean soil phosphorous content of 14.49 mg/kg^{-1}/soil compared to the control, 12.92 mg/kg^{-1}/soil. The reason is attributed to *T. harzianum* in dissolving compounds containing phosphorous in their composition, which increases the availability of phosphorous elements in the soil [22].

The application of phosphate rock resulted in a significant increase in the average content of available phosphorous in the soil, 14.29 mg/kg^{-1}/soil at the level (P3) compared to the control 12.63 mg/kg^{-1}/soil. The reason is attributed to the development and growth of the root system due to the released phosphorous from phosphate rock and the accompanying increase in radical secretions leading to an increase in phosphorous release [23, 24].

The bilateral interaction between fungi (*G. mosseae* and *T. harzianum*) resulted in the highest significant increase in the average content of ready phosphorous in soil (15.88) mg kg^{-1} soil compared to the control treatment (11.91) mg kg^{-1} soil. The reason is attributed to the fact that the biological inoculations caused a significant increase in the availability of phosphorus in the soil by reducing the acidity of the soil by releasing organic acids or protons [25]. The results of the Table confirmed that the triple interaction between (*G. mosseae* and *T. harzianum*) and phosphate rock resulted in the highest significant increase in the content of available phosphorous in soil 16.54 when treatment (G1 + T1 + P1) mg/kg^{-1}/soil compared to the control treatment (G0 + T0 + P0) 10.34 mg/kg^{-1}/soil. T.3

Fungal (G)	***Fungal (T)***	**Phosphorus (P)**				**Mean of Binary overlap G x T**
		0	***1***	***2***	***3***	
0	0	10.34	11.18	12.14	13.96	11.91
	1	12.26	13.08	13.77	13.25	13.09
1	0	12.51	13.98	14.75	14.49	13.93
	1	15.41	16.54	16.12	15.46	15.88
LSD 0.05		0.61				0.31
Bi-interaction G x P						
Fungal (G)		P				Mean
0		11.30	12.13	12.96	13.61	12.50
1		13.96	15.26	15.43	14.98	14.91
LSD 0.05		0.43				0.22
Bi-interaction T x P						
Fungal (T)		P				Mean
0		11.43	36.63	13.45	14.22	12.92
1		13.83	39.95	14.95	14.36	14.49
LSD 0.05		0.43				0.22
P mean		12.63	13.70	14.20	14.29	
L.S.D. 0.05		0.31				

Table 3: Effect of fungal inoculums, *T. harzianum* and *G. mosseae*, and phosphate rock on phosphorous availability in soil.

Potassium Availability in the Soil (mg/kg^{-1}/soil)

Table (4) presents the significant effect of *G. mosseae* application on increasing the average soil potassium content of 223.96 mg/kg^{-1}/soil compared to the control 220.06 mg/kg^{-1}/soil. The reason is attributed to *Glomus mossea* in the secretion of oxalates and proteins that lead to biological weathering events for clay minerals, so these acids replace the potassium installed in clay minerals [26]. The Table results also showed that the application of *T. harzianum* resulted in a significant increase in the average soil potassium content of 222.70 mg/kg^{-1}/soil compared to the control treatment of 221.31 mg/kg^{-1}/soil. The reason is attributed to the role of biofertilizers in increasing the availability of nutrients, including potassium, which helped increase its content in the soil. The results of the same Table also showed that the addition of phosphate rock resulted in a significant increase in the average available potassium content in the soil under treatment (P2) 222.80 mg/kg^{-1}/soil compared to the control 221.05 mg/kg^{-1}/soil. The reason is due to the role of phosphorous released from phosphate rock over time, which leads to the growth of an extensive root group, and with the increase in the rate of respiration in it, the secretion of CO_2 increases, which combines with water, the component of carbonic acid, which begins to spread towards the potassium-bearing minerals, and the release of potassium increases in the rhizosphere area [27].

The Table results indicated that the binary interaction between *G.mosseae* and phosphate rock (G1 + P2) gave the highest significant increase in the available potassium content in the soil, 224.89 mg/kg^{-1}/soil compared to the control (G0 + P0) 219.06 mg/kg^{-1}/soil. The reason is attributed to the role of mycorrhiza in increasing the decomposing of rocks and the absorption of nutrients, including potassium [28, 29]. The triple interaction between (*G.mosseae and T. harzianum*) and phosphate rock (G1 + T1 + P1) resulted in the highest significant increase in the available potassium content in the soil 225.43 mg/kg^{-1}/soil compared to the control (G0 + T0 + P0) 218.42 mg/kg^{-1}/soil.

Fungal (G)	*Fungal (T)*	*Phosphorus (P)*				*Mean of Binary overlap G x T*
		0	*1*	*2*	*3*	
0	0	218.42	219.11	219.98	220.42	219.48
	1	219.69	220.45	221.44	220.92	220.63
1	0	222.31	222.29	224.82	223.15	223.14
	1	223.77	225.43	224.96	224.94	224.78
LSD 0.05		0.52				0.26
Bi-interaction G x P						
Fungal (G)		P				Mean
0		219.06	219.78	220.71	220.67	220.06
1		223.04	223.86	224.89	224.05	223.96
LSD 0.05		0.37				0.18
Bi-interaction T x P						
Fungal (T)		P				Mean
0		220.37	220.70	222.40	221.79	221.31
1		221.73	222.94	223.20	222.93	222.70
LSD 0.05		0.37				0.18
P mean		221.05	221.82	222.80	222.36	
L.S.D. 0.05		0.26				

Table 4: Effect of fungal inoculum of *T. harzianum* and *G. mosseae* and phosphate rock on potassium availability in soil.

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