The Effect of *T. harzinum* Inoculum, Organic Manure, and Irrigation Intervals on the Availability of Phosphorus and Potassium in Mung Bean (*Vigna radiata* L.) Soil

Firas Hamza Omran[1] and Jawad Abdl-Kadhim Kamal[2]
[1,2]College of Agriculture, University of Al-Qadisiyah, Al-Qadisiyah, Iraq.
[1]E-mail: frashmzh73@gmail.com

Abstract.

This study was conducted to determine the effect of bio-inoculation, organic fertilizers, and irrigation timing on the availability of phosphorus and potassium in the soil of the fields of the mung bean (*Vigna radiata* L.). The experiment was carried out on clay silty loamy soil to produce a local variety of mung bean (Kadhrawi) during the fall agricultural season in 2022 in Najaf Governorate. The factorial experiment was designed according to a Randomized Complete Block Design (RCBD) with three replicates. The experimental treatments included two levels of *T. harzinum* fungal inoculum that are K0 (without fungal inoculation) and K1 (inoculation of fungi), three levels of poultry manure M0, M1, and M2, respectively represent, 0, 2, 4 tons ha^{-1}, and three irrigation periods with water from wells S0, S1, S2 which respectively are every 5, 10, 15 days. The results were compared based on the values of the least significant difference (L.S.D). The interaction treatment K1M1S1 resulted in the highest significant difference of available phosphorus in the soil, 13.931 mg kg $soil^{-1}$ compared to the control 5.641 mg kg $soil^{-1}$. Likewise, the available potassium in the soil is 130.90 mg kg $soil^{-1}$ compared to the comparison treatment 115.37 mg kg $soil^{-1}$.

Keywords. *T. harzinum*, Organic fertilizer, Phosphorus, Potassium, Mung bean.

1. Introduction

Most farmers use chemical fertilizers excessively to achieve the maximum productivity of crops to achieve the required yield. However, the increase in these fertilizers leads to the absorption of a large part of the elements of nitrogen, phosphorus, and potassium, and the residues of these fertilizers will be deposited, which will lead to the deterioration of the soil environment, in addition to the soil's poverty of organic matter. Therefore, using bio-inoculum and organic fertilizers was an appropriate substitute for chemical fertilizers [1]. These inoculants are used by mixing them with seeds or polluting the roots of seedlings before planting or applying them directly to the soil to increase nutritional availability by activating them in the roots [2].

Fungi are among the widely used biological inoculum globally, and one of these fungi is *T. harzinum*. It is a widespread fungus at the soil level, as it produces many beneficial enzymes and promotes root growth and plant development by increasing the availability of nutrients in the soil [3]. Trichoderma fungus promotes root growth and helps form an extensive root system, thus leading to the plant's water stress tolerance. This fungus contributes to the plant's tolerance of challenging environmental conditions and promotes plant growth by contributing to cycles of elements, including nitrogen, phosphorus, and sulfur. It is vital in alkaline conditions as it dissolves trace elements such as iron, manganese, zinc, and copper [4]. Poultry manure is an essential and effective organic fertilizer, as it reduces the damage of irrigation water salinity and increases plant tolerance to stress. It increases water holding capacity and

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aeration, improves soil pore distribution, improves root secretions such as organic acids that regulate soil pH, and reduces the harmful effect of salts in soil solution. In addition, it improves ventilation conditions and oxygen movement to the soil organisms, thus increasing the biological activity and the availability of nutrients [5].

In the last two decades, the cultivated areas in Iraq decreased. One of the most important reasons for the decrease in cultivated areas is water scarcity and its impact on all agricultural activities, soil fertility, and productivity. The water scarcity in Iraq is due to the lack of precipitation and the decrease in the imports of the Tigris and Euphrates rivers. Therefore, it has become necessaryto follow the correct methods in the scientific and correct exploitation of water resources, which would reduce water consumption and increase the efficiency of its use [6].

Mung bean is one of the essential leguminous crops grown worldwide and is most common in tropical and subtropical regions. It is usually grown to obtain its seeds, which have a high nutritional value for humans because it contains a high percentage of protein, which is rich in the amino acid lysine, which is lacking in many grains. It is also used as green fodder in animal feed. The mung crop has a short growing season (70-90) days and tolerates drought and heat conditions in all stages of its growth except for the flowering stages [7]. The study aimed to investigate the effect of *T. harzinum* inoculum, organic fertilizer, and irrigation intervals on the availability of phosphorus and potassium in the soil of mung beans.

2. Materials and Methods

2.1. Experiment Site

A field experiment was carried out in silty clay loamy soil to grow the mung bean crop, *Vigna radiate* L., a local variety (Kadhrawi), during the fall planting season 2022, in a farm located in Al-Abbasiya district, Najaf Governorate-Iraq. Soil samples were taken randomly from different areas in the field and mixed well to make a composite sample representing the field's soil before planting. Part of it has been preserved for biological estimates. Then the remaining part was dried by placing it in an oven at a temperature of 70 ° C° and finely ground and sifted through a sieve with a diameter of 2 mm to conduct the physical and chemical tests of the soil of the field before planting.

2.2. Experiment Design

The factorial-designed experiment was carried out according to the Randomized Complete Block Design (RCBD). The field was divided into three main sectors, with 54 experimental units distributed randomly, each sector with 18 experimental units.

2.3. Experimental Treatments

- Fungal inoculation with two levels: K0 = no application of fungal inoculum (*T. harzianum*) and K1 = application of *T. harzianum*.
- Organic manure included three levels of organic manure (poultry waste) based on weight: M0 = 0 ton ha^{-1}, M1 = 2 ton ha^{-1}, and M2 = 4 ton ha^{-1}.
- Irrigation periodicity included three irrigation periods: S0 = irrigation every 5 days, S1 = irrigation every 10 days, and S2 = irrigation every 15 days.

2.4. Chemical and Physical Analyses

- Degree of soil reactivity (pH): It was estimated in the soil-saturated paste extract using a pH meter using the method described by [8].
- Electrical Conductivity (ECe): The electrical conductivity of the saturated paste extract was estimated using an Ec meter according to the method mentioned in [8].
- Cation exchange capacitance (CEC) of positive ions (CEC): It was estimated using sodium acetate (1 Mn) and

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ammonium acetate (1 Mn) according to what was stated by [9].

- Organic matter (O.M): The percentage of organic carbon was estimated by the wet digestion method using potassium dichromate according to what was stated by [2], as in the following equation: % of Organic Matter = % of Organic Carbon x 1.724
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- Bulk density (gm cm^3): It was estimated according to what was stated in [10], using the Core Sampler method.
- Available nitrogen in the soil: The amount of available nitrogen was determined using the potassium chloride (KCL) extraction method. Nitrogen was estimated using the Keldall apparatus, according to [11].
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- Available phosphorus in the soil: the available phosphorus in the soil was extracted by sodium bicarbonate $NaHCO_3$, color developed with ammonium molybdate and ascorbic acid, and determined by spectrophotometer, according to the method of Olsen and Sommers reported in [10].
- Available potassium in the soil: The available potassium was extracted using ammonium acetate (NH_4OAC) and estimated using a flame photometer, according to [8].

2.5. Determination of Negative and Positive Dissolved Ions

- Calcium Ca^{+2} and Magnesium Mg^{+2}: Dissolved calcium and magnesium were obtained by extracting the soil with distilled water and measuring their concentration in the extract by titration with EDTA solution according to what was stated by [8].
- Sodium Na^+: It was estimated using a flame photometer according to what was stated by [9].
- Carbonate $CO3^{-2}$ and bicarbonate $HCO^-{}^3$: were estimated in the saturated soil extract by titration with Richards' solution [8].
- Sulfate $SO4^{-2}$: It was determined by precipitation with barium chloride ($BaCl^2$) according to what was stated by [9].
- Soil texture was estimated by the hydrometer method described by [12].

Table 1. The field soil's physical, chemical, and biological characteristics before planting
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Unit	Value	Trait	
------------------------	7.7	Reaction Degree (pH)	
DesiSmens M^{-1}	2.4	Electrical Conductivity (ECe)	
g kg $Soil^{-1}$	7.1	Organic matter O.M.	
	8.45	N	
Mg kg $Soil^{-1}$	6.6	P	Available

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	115.25	K	elements
Cml charge L^{-1}	13.8	Ca^{2+}	Soluble positive ions
	12.13	Mg^{2+}	
	13.9	Na^{1+}	
	115.25	K^{1+}	
Cml charge L^{-1}	18.96	SO_4^{2-}	Soluble negative ions
	12.4	HCO_3^{1-}	
	Nill	CO_3^{-2}	
g kg $Soil^{-1}$	57.6	Sand	Soil separators
	549.5	Silt	
	388.7	clay	
	silt clay Loamy		Soil texture
CFU	1.86×10^3		Total fungi

3. Results and Discussion

3.1. Available Phosphorus in Soil (mg P kg^{-1} soil)

The results of tables (2 and 3) showed a significant effect of applying *T. harzinum* fungus for the two growth stages of the plant (at the flowering period and the end-of-season period). The comparison treatment (K0) resulted in 7.609 and 5.496 mg P kg^{-1} soil, respectively, at the flowering period and the end of the end-of-season. This increase is due to the role of fungi in dissolving compounds that contain phosphorus in their composition, which leads to an increase in the availability of the element phosphorus in the soil [13,14].

The results of tables 2 and 3 present the effect of organic fertilization significantly on increasing the concentration of available phosphorus in the soil during the flowering and the end-of-season periods. The highest mean of available phosphorus content in the soil was at the level of 2 tons hectare (M1) 10.010 and 7.254 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively, compared to the control treatment (M0) (8.501 and 6.135) mg P kg^{-1} soil, respectively. This increase is attributed to the ability of organic fertilizers to increase the availability of phosphorus in the soil, whether it is direct in the processing of phosphorus in the soil when it decomposes as a source of phosphorus or indirectly by decreasing the pH of the soil and increasing the availability of phosphorus [15].

The irrigation periods (every 5, 10, and 15) significantly affected the soil content of available phosphorous and the two growth stages of the plant. For example, the irrigation treatment every 10 days resulted in the highest values, 10.220 and 7.610 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively, while the comparison treatment recorded the lowest value, 7.961 and 5.402 mg P kg^{-1} soil, respectively.

It is because phosphorous is a slow-moving element, and the decrease in soil moisture leads to a decrease in the level of available phosphorus in the soil. Therefore, there is a significant effect of the binary interaction, as the treatment K1 + M1 resulted in the highest averages for the concentration of available phosphorus in the soil, 12.300 and 8.951 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively. On the other hand, the comparison treatment K0 + M0 produced the lowest mean, 6.605 and 4.730 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively. This is attributed to the typical role between organic fertilizers and biological inoculum. The bio-pollen breaks down organic fertilizers that contain nutrients and thus increases the availability of elements in the soil [16].

The bilateral interaction between the irrigation periods and the *T. harzinum* inoculum, the treatment K1 + S1 made the highest value

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during the two growth stages of the plant, 12.244 and 9.07 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively. The comparison treatment K0 + S2 resulted in the lowest value, 6.507 and 4.324 mg P kg^{-1} soil, respectively, at the flowering period and the end-of-season. The reason for the increased availability of phosphorus concentration in the soil is due to the role of the Trichoderma fungus inoculum and its increase in activity in the appropriate humidity, i.e., during the irrigation period every 10 days [16].

As for the triple interference, the treatment K1 + M1 + S1 had the highest average values for the concentration of available phosphorus in the soil, 13.931 and 10.327 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively. On the other hand, the comparison treatment K0 + M0 + S0 had the lowest mean, 5.641 and 3.682 mg P kg^{-1} soil, at the flowering period and the end-of-season, respectively.

Table 2. Effect of *T. harzinum* inoculum, organic fertilizer, and irrigation periods on the available phosphorus concentration in the soil (mg P kg^{-1} soil) at the flowering stage

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M × K Interaction	S mg P kg^{-1} soil			M	K
	15	**10**	**5**		
6.605	5.641	6.704	7.471	0	
7.720	6.559	8.544	8.057	2	0
8.501	7.322	9.342	8.840	4	
10.397	9.003	11.784	10.403	0	
12.300	10.713	13.931	12.255	2	1
9.720	8.529	11.017	9.614	4	
0.274		0.474		LSD .05	
	S × K Binary Interaction				
K Average	S			K	
	15	10	5		
7.609	6.507	8.197	8.123	0	
10.805	9.415	12.244	10.757	1	
0.158		0.274		LSD .05	
	S × M Binary Interaction				
M Average	S			M	
	15	10	5		
8.501	7.322	9.244	8.937	0	
10.010	8.636	11.237	10.156	2	
9.111	7.926	10.180	9.227	4	
0.194		0.335		LSD .05	
	7.961	10.220	9.440	S Average	
		0.194		LSD .05	

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Table 3. Effect of *T. harzinum* inoculum, organic fertilizer, and irrigation periods on the available phosphorus concentration in the soil (mg P kg^{-1} soil) at the end of the season stage.

M × K Interaction	S mg P kg^{-1} soil			M	K
	15	**10**	**5**		
4.730	3.682	4.970	5.538	0	0
5.556	4.362	6.334	5.973	2	
6.202	4.928	7.125	6.553	4	
7.540	6.174	8.735	7.712	0	1
8.951	7.442	10.327	9.084	2	
7.039	5.823	8.167	7.127	4	
0.243		0.421		LSD .05	
		S × K Interaction			
K Average	S			K	
	15	10	5		
5.496	4.324	6.143	6.021	0	
7.843	6.479	9.076	7.974	1	
0.140		0.243		LSD .05	
		S × M Interaction			
M Average	S			M	
	15	10	5		
6.135	4.928	6.853	6.625	0	
7.254	5.902	8.330	7.528	2	
6.620	5.375	7.646	6.840	4	
0.172		0.298		LSD .05	
	5.402	7.610	6.998	S Average	
		0.172		LSD .05	

3.2. Potassium Availability in the Soil (mg K kg^{-1} soil)

The results of tables 4 and 5 present a significant effect of applying *T. harzinum* (K1) to the two growth stages of the plant. This treatment had the highest significant increase in the average soil potassium content, 125.45 and 120.66 mg K kg^{-1} soil, respectively, while the comparison treatment (K0) had 121.93 and 116.75 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively. This increase is due to the role of fungi in increasing the availability of nutrients, including potassium, which helped increase its soil content. In addition, organic fertilization significantly increases the concentration of available potassium in the soil during the flowering period and the end-of-season period. As a result, the highest mean of available potassium content in the soil at the level of 2 ton ha (M1) was 124.98 and 119.84 mg K kg^{-1} soil at the flowering period and the end-of-season, respectively, compared to the control treatment (M0) 122.17 and 117.47 mg K kg^{-1} soil, respectively. This increase is attributed to the ability of organic fertilizers to increase the availability of potassium in the soil when it decomposes as a source of potassium or by decreasing the pH of the soil and increasing the availability of potassium [15].

It is noted from tables (4 and 5) that the irrigation periods (5, 10, and 15) had a

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significant effect on the soil content of available potassium for the two periods of flowering and the end of the season. The irrigation treatment every 10 days resulted in the highest value, 126.58 and 120.45 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively, while the comparison treatment, which is the irrigation period every 15 days, recorded the lowest value 7.961 and 5.402 mg K kg^{-1} soil, respectively. This is because potassium is a slow-moving element, and the decrease in soil moisture leads to a decrease in the level of available potassium in the soil. Therefore, as shown in Tables 4 and 5, the binary overlap has a significant effect.

The treatment K1 + M1 had the highest mean in the concentration of available potassium in the soil, 127.48 and 122.57 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively, while the control treatment K0 + M0 recorded the lowest mean 119.20 and 114.48 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively. This is attributed to the typical role between organic fertilizers and bio-inoculum, as bio-inoculation breaks down organic fertilizers that contain nutrients and thus increases the readiness of elements in the soil, including potassium [15]. As for the bilateral interaction between the irrigation periods and the *T. harzinum* inoculum, the treatment K1 + S1 resulted in the highest value during the two growth stages of the plant, 128.27 and 122.54 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively. On the other hand, the comparison treatment K0 + S2 resulted in the lowest value, 117.76 and 114.37 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively. The increased availability of potassium concentration in the soil is due to the role of the Trichoderma fungus inoculation and its activity in the appropriate humidity, i.e., during the irrigation period every 10 days [16]. The triple interaction, the treatment K1 + M1 + S1, resulted in the highest average concentration of available potassium in the soil, 130.90 and 124.87 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively. On the other hand, the comparison treatment K0 + M0 + S0 made the lowest mean, 115.37 and 113.03 mg K kg^{-1} soil, at the flowering period and the end-of-season, respectively.

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Table 4. Effect of T. harzinum inoculum, organic fertilizer, and irrigation periods on the available potassium concentration in the soil (mg K kg^{-1} soil) at the flowering stage.

M × K Interaction	S mg P kg^{-1} soil			M	K
	15	**10**	**5**		
119.20	115.37	120.07	122.17	0	
122.48	118.37	125.53	123.53	2	0
124.10	119.53	127.73	125.03	4	
125.14	121.77	128.43	125.23	0	
127.48	123.67	130.90	127.87	2	1
123.73	120.07	126.83	124.30	4	
0.86		1.48		LSD .05	
S × K Binary Interaction					
K Average	S			K	
	15	10	5		
M × K Interaction	**S**			M	
	15	**10**	**5**		
121.93	117.76	124.44	123.58	0	
125.45	121.83	128.72	125.80	1	
0.49		0.86		LSD .05	
S × M Binary Interaction					
M Average	S			M	
	15	10	5		
122.17	118.57	124.25	123.70	0	
124.98	121.02	128.22	125.70	2	
123.92	119.80	127.28	124.67	4	
0.60		1.05		LSD .05	
	119.79	126.58	124.69	S Average	
		0.60		LSD .05	

Table 5. Effect of *T. harzinum* inoculum, organic fertilizer, and irrigation periods on the available potassium concentration in the soil (mg K kg^{-1} soil) at the end of the season stage.

M × K Interaction	S			M	K
	15	**10**	**5**		
114.48	113.03	114.20	116.20	0	
117.11	114.47	119.40	117.47	2	0
118.66	115.60	121.47	118.90	4	
120.46	119.17	122.13	120.07	0	
122.57	120.27	124.87	122.57	2	1
118.94	116.57	120.63	119.63	4	
0.66		1.14		LSD .05	
S × K Binary Interaction					

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K Average	S			K
	15	10	5	
116.75	114.37	118.36	117.52	0
120.66	118.67	122.54	120.76	1
0.38		0.66		LSD .05

S × M Binary Interaction

M Average	S			M
	15	10	5	
117.47	116.10	118.17	118.13	0
119.84	117.37	122.13	120.02	2
118.80	116.08	121.05	119.27	4
0.46		0.80		LSD .05
	116.52	120.45	119.14	S Average
		0.46		LSD .05

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