Effect of Adding Mycorrhizal and Bacterial Fertilizers and Organic Acids on the Sustainability of Potato Quality Traits and Yield

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Abstract

A field experiment was conducted in one of the fields in Babil Governorate during the spring season 2024–2025 to cultivate potato (Borin variety) in silty loam soil, classified at the order of Typic Toriffulvent. The study aimed to investigate the effect of adding mycorrhizal and bacterial fertilizers and organic acids on sustainable soil development and the growth and yield of potato. The experiment included two factors: the first factor was the addition of mycorrhizal and bacterial fertilizers at three levels (0, 10 g per hole, and 10 ml per hole), designated as M0, M1, and M2, respectively. The second factor was the addition of humic acid at three levels (0, 20, and 40 kg ha^-1), designated as H0, H1, and H2, respectively. The experiment was carried out according to a Randomized Complete Block Design (RCBD) with 27 experimental units. At maturity, quality traits and yield were measured, and tuber samples were taken to determine N, P, K concentrations in the tubers and in the soil after planting. Results indicated that the H2M2 treatment gave the highest indicators for quality traits and yield (percentage of dry matter in tubers, protein percentage in tubers, starch percentage in tubers, tuber yield and number), which reached (18.77, 10.56, 13.25, 45.75, and 7.20) consecutively, compared to the control treatment H0M0, which recorded (15.33, 6.53, 9.55, 24.31, and 3.77) consecutively.

Keywords: Mycorrhizal fertilizer, bacterial fertilizer, organic acids, potato, sustainable development, quality traits, tuber yield.

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Introduction

Potato is one of the important Solanaceae crops due to its high nutritional value among tuber crops. It contains protein, water, carbohydrates, vitamins, and some minerals such as potassium, phosphorus, and iron. It ranks fourth after wheat, rice, and maize. Potato is used in various food industries and is cultivated in Iraq in several varieties that differ in their resistance to diseases and insect infestations, as well as in productivity, which is influenced by genetic and nutritional factors [20]. Biofertilizers are defined as substances composed of a variety of beneficial microorganisms capable of facilitating nutrient delivery to plant roots and increasing the availability of nutrients in the rhizosphere. They are considered more effective than chemical fertilizers, which pose environmental risks. Their advantages include low production costs and environmental friendliness [2 ,11.[

The use of mycorrhizal Azotobacter improves plant quality and increases yield by enhancing vegetative growth after supplying the plant with available nutrients. The importance of biofertilization lies in stabilizing and increasing the availability of essential nutrients for plant uptake (Almamori et al., 2020). It also has the ability to produce growth regulators and inhibit pathogen growth, thereby increasing plant tolerance to environmental stresses[9,14 .[

Bacterial fertilizers (Azotobacter) play a significant role in nitrogen fixation through the secretion of nitrogenase enzymes that convert atmospheric nitrogen into mineral forms available for plant absorption. They are widely used in biofertilizers due to their ability to indirectly enhance nutrient availability by secreting hormones, enzymes, vitamins, and growth regulators[20 [

The addition of organic acids, such as humic acid, greatly enhances nutrient availability by lowering soil pH and releasing carbon dioxide in the presence of water, forming carbonic acid. This increases nutrient availability, enhances plant protein content, stimulates soil microorganisms, and serves as a medium for nutrient transfer from soil to plant[8,24] As indicated above, few studies have addressed the combined role of mycorrhizal and bacterial fertilizers in the presence of organic acids, including humic acid, despite their significant effect on enhancing all growth indicators and potato yield. Therefore, this study aimed to investigate the effect of mycorrhizal and bacterial fertilizers on certain growth traits and potato yield, study the role of organic acids in nutrient availability, and identify the best combination of experimental factors for optimal soil nutrient sustainability.

Materials and Methods

A field experiment was conducted during the fall season 2024 to cultivate potato (Borin variety) in one of the fields in Babil Governorate in silty loam soil, classified at the order of Typic Toriffulvent. Several random composite soil samples were taken from the field before plowing at a depth of 0–30 cm. Soil samples were mixed to form a composite sample, air-dried, ground, and sieved through a 2 mm mesh. The sample was used to estimate some physical and chemical properties of the field soil. Table 1 shows some results of the physical and chemical analyses of the soil before planting.

Table 1: Physical and chemical properties of field soil before planting

property	Unit	Values	Reference
Soil pH	-	7.70	Richaids, 1954
Electrical Conductivity (ECe)	$dS \cdot m^{-1}$	3.45	
Cation Exchange Capacity (CEC)	$cmolc \cdot kg^{-1}$ soil	22.25	Page et al., 1982
Soil Organic Matter (SOM)	%	7.33	Bashour & Al-Sayegh, 2007
Gypsum	$g\ kg^{-1}$ soil	31.30	Page et al., 1982
Lime		240.25	
Soluble Cations in Soil Solution			
Calcium (Ca^{2+})	$mmol\ L^{-1}$	7.50	Bashour & Al-Sayegh, 2007
Magnesium (Mg^{2+})		6.25	
Sodium (Na^{+})		5.31	
Potassium (K^{+})		0.95	
Soluble Anions in Soil Solution			
Sulfate (SO_4^{2-})	$mmol\ L^{-1}$	9.50	Bashour & Al-Sayegh, 2007
Chloride (Cl^{-})		11.05	
Bicarbonate (HCO_3^{-})		4.30	
Carbonate (CO_3^{2-})		-	
Soil Fractions			
Sand	$g \cdot kg^{-1}$	250	Page et al., 1982
Silt		475	
Clay		275	
Texture		Loam	-
Bulk Density	$mg\ m^{-3}$	1.33	Blake & Hartge, 1986
Field Capacity	%	22.00	Page et al., 1982
Permanent Wilting Point		13.00	
Available Water		9.00	

The experiment was conducted in the field over an area of 624 m² (dimensions: 39 m × 16 m). The experimental site was plowed using a moldboard plow to a depth of 25 cm, with two perpendicular plowings for proper soil leveling and preparation. The field was divided into three main sectors, each consisting of nine experimental units. The size

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of each experimental unit was 9 m² (3 × 3 m) with four ridges, each 3 m long, and a spacing of 75 cm between the ridges, according to Moharam and [4]. Gaps of 3 m were left between the sectors, with a 2 m buffer at the beginning and end of each sector. Additionally, 1 m spacing was maintained between treatments to prevent nutrient transfer during fertilization.

The experiment studied the effect of two factors. The first factor was the addition of microbial fertilizers: 0 g (control), 10 g of mycorrhizal inoculum per hill, and 10 ml of Azotobacter per hill, denoted as M0, M1, and M2, respectively. The second factor was the application of humic acid at three levels: 0, 20, and 40 kg ha^{-1}, denoted as H0, H1, and H2, respectively. Consequently, the experiment comprised 3 × 3 = 9 treatments, replicated across three sectors, resulting in 3 × 3 × 3 = 27 experimental units in total.

Indicators of Qualitative Yield Traits

.1 Dry Matter Percentage in Tubers

Tuber samples were collected, weighed, and dried in an electric oven at 70°C until a constant weight was achieved, following [7, Al-Sahaf (1989). The dry matter percentage was calculated using the following formula:

Dry Matter Percentage in Tubers (%)=Weight of dried tubersFresh weight of tubers×100

.2 Protein Percentage in Tubers

The protein percentage was determined on a dry weight basis according to A.O.A.C. (1970), using the following formula:

Protein (% DW)=Nitrogen content (%)×6.25

.3 Starch Percentage in Tubers

Starch content was calculated using the A.O.A.C. (1970) formula:

%Starch=17.55+0.89×(%Dry Matter−24.18(

.4 Yield (mg ha^{-1}(

Yield and its components were measured by harvesting tubers from five randomly selected plants in the middle ridge of each experimental unit and extrapolating to per hectare using the formula:

Total Yield=Yield per experimental unitUnit area (9 m²)×10000 m²

.5 Number of Tubers per Plant

The total number of tubers per plant was calculated as follows:

Number of Tubers per Plant=Total tubers in unitNumber of plants sampled

Results and Discussion

Dry Matter Percentage in Tubers

Statistical analysis (Table 2) indicated that the addition of microbial fertilizers (mycorrhiza and Azotobacter), humic acids, and their interactions significantly increased the dry matter percentage in tubers. The bacterial fertilizer significantly enhanced this trait, with the highest value observed in treatment M2 (17.72%) compared to M1 (17.04%), while the lowest value was recorded in the control M0 (15.72%.(

Application of humic acid also significantly increased tuber dry matter, with the highest value observed in H2 (17.85%) compared to H1 (16.72%) and H0 (16.17%). Moreover, the interaction between microbial fertilizers and humic acid significantly improved dry matter content, with the highest value observed in

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treatment H2M2 (18.77%), which was not significantly different from H2M1 (17.88%). The lowest value was recorded in the control interaction H0M0 (15.33%.(

Table 2: Effect of microbial fertilizers, humic acids, and their interaction on tuber dry matter percentage.

Fungal & Bacterial Fertilizer	Humic Acid Levels			Mean
M0	**H0**	**H1**	**H2**	
M1	15.33	15.73	16.10	15.72
M2	16.25	17.00	17.88	17.04
	16.95	17.43	18.77	17.72
	16.17	16.72	17.58	Mean
Humic Acid Levels	**Interaction**		**Fungal & Bacterial Fertilizer**	**L.S.D (0.05)**
H	**H * M**		**M**	
0.42	0.96		0.42	

Percentage of Protein in Tubers(%)

The statistical analysis results in Table 3 indicated that the application of biofertilizers, whether fungal or bacterial, had a significant effect on increasing the percentage of protein in tubers. The highest value was recorded in treatment M2, reaching 9.12%. The fungal biofertilizer alone also significantly affected this trait, with a value of 8.26%, while the lowest protein percentage in tubers was observed in the control treatment M0, with a value of 6.80%.Application of organic acids (humic acid) also had a significant effect on increasing the protein percentage in tubers, with the highest value recorded in treatment H2 at 8.99%, compared to treatments H1 and H0, which had values of 8.03% and 7.16%, respectively. Humic acid caused a significant increase in protein percentage in tubers, with the highest value in H2 reaching 12.26%, compared to H1 and H0, which were 11.65% and 10.81%, respectively.

It is also evident from the same table that the two-way interaction between biofertilizer (fungal and bacterial) and humic acid had a significant effect on increasing the protein percentage in tubers. The highest value was observed in the H2M2combined treatment, reaching 10.56%, which was not significantly different from H2M1, which recorded 9.43%, whereas the lowest value was in the control interaction H0M0, at 6.53%, representing a 61.7% increase .

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Table 3. Effect of fungal and bacterial biofertilizers, organic acids, and their interactions on protein percentage in tubers

Fungal & Bacterial Fertilizer	**Humic Acid Levels**			**Mean**
M0	**H0**	**H1**	**H2**	
M1	6.53	6.89	7.00	6.80
M2	7.10	8.25	9.43	8.26
	7.85	8.95	10.56	9.12
	7.16	8.08	8.99	Mean
Humic Acid Levels	**Interaction**		**Fungal & Bacterial Fertilizer**	**L.S.D (0.05)**
H	**H * M**		**M**	
0.55	1.39		0.55	

Percentage of Starch in Tubers(%)

The statistical analysis results in Table 4 indicated that the study factors—application of fungal and bacterial biofertilizers, organic acids, and their interactions—had a significant effect on increasing the starch percentage in tubers. The bacterial biofertilizer in treatment M2 significantly increased starch content, reaching the highest value of 12.54%, compared to fungal biofertilizer treatment M1, which recorded 12.19%, while the lowest starch percentage was observed in the control treatment M0, at 9.98%.

Application of organic acids (humic acid) significantly increased starch percentage in tubers, with the highest value recorded in H2, reaching 12.26%, compared to H1 and H0, which were 11.65% and 10.81%, respectively.

As seen in the same table, the two-way interaction between biofertilizer (fungal and bacterial) and humic acid significantly increased starch percentage in tubers. The highest value was observed in treatment H2M2 (bacterial biofertilizer with the third level of humic acid) at 13.25%, which was not significantly different from H2M1 (fungal biofertilizer with humic acid), which recorded 13.00%, whereas the lowest value was observed in the control interaction H0M0, at 9.55%.

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Table 4. Effect of fungal and bacterial biofertilizers, organic acids, and their interactions on starch percentage in tubers

Fungal & Bacterial Biofertilizer	**Humic Acid Levels**			**Mean**
M0	**H0**	**H1**	**H2**	
M1	9.55	9.89	10.52	9.98
M2	11.15	12.43	13.00	12.19
	11.73	12.65	13.25	12.54
	10.81	11.65	12.26	Mean
Humic Acid Levels	**Interaction**		**Fungal & Bacterial Fertilizer**	**L.S.D (0.05)**
H	**H * M**		**M**	

It can be observed from the results presented in Tables 2, 3, and 4 that the application of fungal and bacterial biofertilizers as well as organic acids all significantly influenced the increase in the percentage of dry matter, starch, and protein in potato tubers. The effect of applying the fungal biofertilizer can be attributed to the complementary role played by these microorganisms in enhancing nutrient uptake and increasing the physiological efficiency of the plant. This increase is mainly due to the enhanced phosphorus absorption facilitated by mycorrhiza, along with the stimulation of plant hormone production by Azotobacter, which promotes photosynthetic activity and carbohydrate accumulation in tubers[5,16]. Furthermore, the effect can also be ascribed to the ability of Azotobacter bacteria to fix atmospheric nitrogen and convert it into forms readily available for plant uptake, thereby increasing the concentration of nitrogenous compounds such as amino acids and proteins, which reflects positively on improving the quality traits of potato tubers as shown in the above tables. These findings are consistent with [18] who reported that inoculation with Azotobacter increased the protein and starch content in potato tubers by 28% compared to the non-biofertilized control, highlighting the pivotal role of this bacterium in nitrogen nutrition.

Dual inoculation with mycorrhiza and Azotobacter achieved a significant improvement in the above quality traits, which can be attributed to the overall enhancement of macro- and micronutrient uptake and increased photosynthetic efficiency, leading to higher accumulation of solids in tubers. These results align with [23] who reported a 15% increase in dry matter with mycorrhizal application compared to the control. The effect of mycorrhiza is also associated with improved plant growth due to its content of organic acids and nutrients, which increase root exudates and the number of viable bacterial cells, thereby enhancing soil organic carbon. Both biofertilizers, mycorrhiza and Azotobacter, secrete enzymes such as cellulase that play a clear role in decomposition, leading to an increase in dry matter and, consequently, the percentage of starch and protein[3,4[

Moreover, the addition of organic acids (humic acid) significantly increased all the

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quality traits of potato. Humic acid stimulates root hair growth, enlarges the absorption surface area, enhances the activity of enzymes associated with nutrient uptake and translocation within the plant, activates photosynthesis, increases chlorophyll production, and improves membrane permeability for ion absorption, thereby positively affecting the quality traits of potato[17] . These results are in agreement with Al-Harbi et al. (2023), who reported that humic acid increased all quality traits in potato tubers, including dry matter, starch, and protein content. They indicated that the application of 5 L ha^{-1} of humic acid increased protein content by 13.4% compared to the control. Organic acids, particularly humic acid, play a significant role in improving soil fertility, enzyme activity, and cell membrane permeability. This increase can also be attributed to the effect of humic acid on plant growth and photosynthetic products that are translocated to tubers, enhancing their quality traits. Humic acid increases starch content by enhancing photosynthetic and nutritional efficiency, raises protein content by improving nitrogen uptake and activating metabolic reactions, and improves dry matter by regulating water absorption, thus reducing water loss. These results are consistent with [5,10, 13.[

Tuber Yield (mg ha^{-1}(

The results of the statistical analysis presented in Table 5 indicate that the application of fungal and bacterial biofertilizers along with organic acids significantly increased total tuber yield (mg ha^{-1}). The application of Azotobacter significantly affected this trait, giving the highest value in treatment M2 (37.70 mg ha^{-1}), compared to treatment M1 (fungal biofertilizer) which recorded 33.43 mg ha^{-1}. The lowest yield was observed in the control treatment M0, with 25.06 mg ha^{-1}. Similarly, the application of humic acid significantly increased total yield, with the highest value in treatment H2 (37.75 mg ha^{-1}) compared to H1 and H0 (31.40 and 27.03 mg ha^{-1}, respectively), representing significant increases of 20.2% and 39.6%.

It is also evident from the same table that the interaction between biofertilizers and organic acids had a significant effect on total tuber yield. The highest value was observed in the combined treatment H2M2 (45.75 mg ha^{-1}), which was not significantly different from H2M1 (41.65 mg ha^{-1}). The lowest yield was recorded in the control H0M0 (24.31 mg ha^{-1}.(

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Table 5. Effect of fungal and bacterial biofertilizers, organic acids, and their interaction on total tuber yield (mg ha⁻ ¹.(

Fungal & Bacterial Biofertilizer	Humic Acid Levels			Mean
M0	H0	H1	H2	
M1	24.31	25.00	25.87	25.06
M2	27.25	31.39	41.65	33.43
	29.55	37.80	45.75	37.70
	27.03	31.40	37.75	mean
Humic Acid Levels	**Interaction**		**Fungal & Bacterial Fertilizer**	**L.S.D (0.05)**
H	**H * M**		**M**	
3.15	5.25		3.15	

Number of Tubers (Tuber per Plant⁻ ¹(

The results of the statistical analysis (Table 6) indicated that the study factors—application of fungal and bacterial biofertilizers and organic acids, as well as their interactions—significantly affected the number of tubers per plant (Tuber per Plant⁻ ¹). The bacterial biofertilizer had a significant effect on this trait, giving the highest value for treatment M2, which reached 6.30, compared to treatment M1 (fungal biofertilizer application), which recorded 5.81 tubers per plant. The lowest number of tubers was observed in the control treatment M0, with a value of 4.29 tubers per plant.

Additionally, the application of organic acids (humic acid) significantly affected this trait, with the highest value recorded for treatment H2, reaching 6.13 tubers per plant, compared to treatments H1 and H0, which recorded 5.36 and 4.91 tubers per plant, respectively, corresponding to increases of 14.3% and 24.8%, respectively.

It is also noted from the same table that the binary interaction of biofertilizers (mycorrhiza and Azotobacter) with organic acids (humic acid) significantly increased the number of tubers per plant. The highest value was obtained in the H2M2 interaction treatment, reaching 7.20 tubers per plant, which was not significantly different from the H2M1 interaction treatment, which recorded 6.34 tubers per plant. The lowest value was observed in the control interaction H0M0, with a value of 3.77 tubers per plant, corresponding to an increase of 90.9%.

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Table 6. Effect of fungal and bacterial biofertilizers, organic acids, and their interactions on total number of tubers (Tuber per Plant^{-1}(

Fungal & Bacterial Biofertilizer	Humic Acid Levels			Mean
M0	H0	H1	H2	
M1	3.77	4.25	4.86	4.29
M2	5.25	5.85	6.34	5.81
	5.72	6.00	7.20	6.30
	4.91	5.36	6.13	mean
Humic Acid Levels	**Interaction**		**Fungal & Bacterial Fertilizer**	**L.S.D (0.05)**
H	**H * M**		**M**	
0.15	1.33		0.15	

It is observed from Tables 5 and 6 that the addition of fungal and bacterial biofertilizers, organic acids, and their interactions significantly influenced the increase in total yield (µg ha^{-1}) and the number of tubers (tuber plant^{-1}). The effect of Mycorrhiza inoculation on tuber number and yield can be attributed to its role in enhancing photosynthesis by increasing chlorophyll content in the plant, which in turn reflects positively on yield and tuber number. Moreover, these biofertilizers, Azotobacter and Mycorrhiza, contribute to increasing yield and tuber number by improving nutrient uptake, stimulating root growth, and enhancing the physiological balance of the plant[1] The addition of biofertilizers to the potato crop resulted in a significant increase, as these fertilizers promote growth regulators such as auxins and gibberellins, which improve root hair development, thereby increasing the surface area for nutrient absorption. These biofertilizers also stimulate root growth and increase root density, which enhances the vegetative biomass, consequently reflecting on tuber number and yield. Numerous studies have shown that the application of biofertilizers, such as Mycorrhiza and Azotobacter, plays an important role in improving the availability of nutrients through the physical and chemical enhancement of the soil by forming hyphal networks that bind soil particles, improve soil structure, increase aggregate stability, and retain soil organic matter. This positively affects yield characteristics and tuber number[6,12,22. [

It is also noted that the addition of organic acids (humic acid) significantly increased potato tuber yield and number. This effect may be due to the important role of humic acids in soil fertility, enhancing enzyme activity, and increasing the permeability of cell membranes to nutrients. Additionally, the increase in yield can be attributed to the effect of organic acids on plant growth and the enhancement of photosynthetic products, which are transported to the tubers, resulting in higher total tuber yield .

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The application of humic acid led to a clear increase in tuber starch content, total tuber number, and dry weight of the vegetative biomass, which helps improve vegetative growth. This, in turn, reflects on plant growth by transferring metabolic products to the vegetative parts and then to the tubers, leading to increased tuber weight and number, thus increasing total tuber yield. Moreover, humic acid, as a bio-organic fertilizer containing most macro- and micronutrients, significantly influences vegetative and reproductive traits of the plant. The addition of organic acids also enhances the availability of nutrients, particularly phosphorus, which contributes to the increase in tuber yield and number. These results align with the findings of[15, 21. [

Conclusions

The study concludes that the application of mycorrhizal and bacterial fertilizers, supplemented with organic acids, effectively improved the qualitative traits of potato plants and increased both tuber yield and number. This approach promotes the principles of sustainable agricultural production. Moreover, this biological integration reduced dependence on chemical fertilizers, enhanced soil fertility, and improved crop quality, thereby contributing to environmentally friendly and more sustainable agricultural production.

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