

Effect of magnesium fertilization and boron spraying on the growth and yield of two variety of potatoes (*Solanum tuberosum* L.) cultivars in calcareous soil in northern Iraq

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Abstract

A field experiment was conducted to study the effect of magnesium fertilization and boron spraying on some growth and yield characteristics of two potato cultivars in one of the fields of the College of Agriculture and Forestry/University of Mosul in northern Iraq. The field was divided into 3 panels (each panel represents a replicate) and each field was divided into 24 experimental units. Then, the potato cultivars CARRERA (v_1) and PREMABELLE (v_2) were planted. Magnesium was added at four levels (0, 40, 80, 120) kg h⁻¹ and the symbols were given (Mg₀, Mg₁, Mg₂, Mg₃) respectively, while boron was added at three levels (0, 25, 50) mg L⁻¹ and the symbols were given (B₀, B₁, B₂) respectively. The results showed the superiority of the (Mg₃) treatment in all the studied traits and recorded the highest value for the trait of dry weight of the vegetative part (43.69) g plant⁻¹, the total yield of tubers (56.48) tons ha⁻¹, the percentage of dry matter in tubers (17.60)%, the percentage of starch in tubers (11.68)%, the percentage of protein in tubers (9.35)%, the magnesium content in the plant (23.26) mg kg⁻¹, and the boron content in the plant (1.13) mg B kg⁻¹ plant. As for the effect of spraying with boron, treatment (B₂) was superior and recorded the highest value for the trait of dry weight of the vegetative part (41.95) g plant⁻¹, total yield of tubers (52.48) tons h⁻¹, percentage of dry matter in tubers (18.05)%, percentage of starch in tubers (12.08)%, percentage of protein in tubers (10.66)%, magnesium content in the plant (21.97) mg kg⁻¹, and boron content in the plant (1.33) mg B kg⁻¹ plant.

Introduction

Potatoes are one of the most important crops after wheat, rice and corn, and they also rank first among tuber crops. Potatoes belong to the Solanaceae family, and their cultivation is widespread in large areas of the world, as the area planted with potatoes amounts to 19,463,040 hectares, while the global production of potatoes amounted to 368,096,362 tons. In Iraq, the area used for potato cultivation is estimated at about 42,000 hectares, while its production in Iraq amounts to about 580,000 tons (FAO,2019). Potato productivity is affected by several factors, the most important of which are climatic factors, soil characteristics, seed sizes, and service operations. Potato varieties differ in yield and tuber size, as a good variety produces a higher yield and larger tubers compared to poor varieties. Tuber maturity also varies from one variety to another. Iraqi potato production is insufficient to meet local consumption, which requires the introduction of new varieties with higher productivity and better quality to fill the gap in production (Al-Bahash and Najm Abdullah ,2006). Magnesium plays an important role in protein formation and carbohydrate metabolism, increases crop tolerance and resistance to stress, is a major component of chlorophyll pigment and an activator of plant metabolic reactions (Poberezhny and Wszelaczynska, 2011). Magnesium is also one of the essential nutrients that enhances plant nitrogen uptake and controls many important processes in photosynthesis and production (Senbayram et al.,2015) .Boron is a micronutrient that plays an important role in stabilizing some important materials for cell walls, activating cell plasma membranes, enhancing cell division, and differentiating plant tissues. This makes it one of the elements that directly affect cell growth (Goldberg and Glaubig 1985). Boron fertilization increases the net rate of photosynthesis due to the increased chlorophyll content in plant leaves (Rafeii and Pakkish, 2014). The research aims to study the effect of magnesium fertilization and boron spraying on some growth and yield characteristics of potato plants.

Material and Methods

Prepare samples:

This study was conducted in one of the agricultural fields affiliated to the College of Agriculture and Forestry, University of Mosul, Nineveh Governorate/Iraq, with the aim of studying the effect of magnesium fertilization and boron spraying on some growth and yield characteristics of the potato cultivars CARRERA(v_1) and PREMABELLE(v_2). Samples were taken from the field soil before planting to study the physical and chemical properties of the field soil. Then the field was divided into three panels (each panel represents a replicate) and each panel was divided into 24 experimental units, each with an area of (3×3) m², leaving a distance of 1/2 m between the units and a distance of 1.5 m between the replicates. Then, potato tubers were planted in rows, where each experimental unit included 4 rows of 3 m length and 12 tubers in each row (48 tubers in the experimental unit) and a depth of (10-12) cm. Potato seeds were planted manually by manually digging holes in the rows and

placing the seeds in them and covering them manually as well. Magnesium sulphate fertilizer MgSO_4 (16% MgO) was added at four levels (0, 40, 80, 120) kg ha^{-1} which were given the symbols (Mg0, Mg1, Mg2, Mg3) respectively. Boron was added by foliar spraying using boric acid H_3BO_3 (17% boron) at three levels (0, 25, 50) mg l^{-1} which were given the symbols (B0, B1, B2, B3) respectively and was added in two sprays, the first after 70 days from planting and the second after twenty days from the first spray.

Estimation of physical and chemical properties of soil

The physical and chemical properties of the study soil were estimated as follows:

Soil Texture

It was estimated by the hydrometer method, according to what was stated in (rayan,1990)

pH

The (pH) value was measured in the saturated paste extract of the soil using a pH-meter.

EC

The (EC) value was measured in the saturated paste extract of the soil using an Ec-meter.

Calcium Carbonate

It was measured by the gravimetric method using standard hydrochloric acid (3) according to the method mentioned in (USDA. 2004).

Organic matter (OM)

It was determined by oxidation of organic carbon with potassium dichromate solution $\text{K}_2\text{Cr}_2\text{O}_7$, then titration with ferrous ammonia sulphate solution after adding drops of diphenylamine indicator.

studied characteristics

Dry weight of the vegetative part (g/plant^{-1})

: It was calculated by selecting (5) plants randomly, cutting them from the area of contact with the soil, and drying them in the oven at 70°C until the weight was fixed, then calculating the (dry) weight.

Total yield of tubers (tons ha^{-1}):

It is calculated by removing the tubers of the two middle vines of each experimental unit and the total yield is calculated in hectares.

Dry weight of tubers

Calculated using the equation (Al-Jabouri, 1995):

$$\text{percentage of dry matter in tubers (\%)} = \frac{\text{Dry weight of tubers}}{\text{Wet weight of tubers}}$$

Starch in tubers (%)

It is calculated according to the following law (AOAC, 2000):

$$\% \text{starch} = 17.55 + 0.891 (\% \text{ of dry matter of tubers} - 24.182)$$

Protein in tubers (%):

It is calculated as follows (Rastovski and Vanesetal, 1987):

$$\% \text{ of protein in tubers} = \% \text{ of nitrogen} \times 6.25$$

Estimation of nutrients (Mg, B) in tubers:

0.5 g of the ground plant sample was taken and digested using concentrated sulfuric acid and drops of concentrated perchloric acid with heating until a clear solution was obtained. Then the solution was placed in plastic containers and the volume was completed to 100 ml with distilled water to estimate the elements as follows:

1. Magnesium: Estimated by titration with EDTA solution (Richards, 1954)

2. Boron: Estimated using azomethane-H (Bingham, 1982).

Statistical analysis

The data were analyzed statistically using the SAS program for the year 2001 and according to Duncan's test at a probability level of 0.05 (Al-Rawi, 2000).

Table 1. Physical and chemical properties of the study soil

No.	Parameters	Value A	Unit
1	Clay	37.525	%
3	Sand	8.525	%
2	Silt	53.95	%
4	Textures	Silty clay loam	-
5	pH	7.98	-
6	EC	0.23	dS.m ⁻¹
14	CaCO ₃	21.32	Meq/100g Soil
15	Organic Matter	1.78	%

Dry weight of the vegetative part (g plant⁻¹):

Table (2) shows the effect of fertilization with magnesium sulfate and spraying with boron and the interaction between them on the dry weight of the vegetative part of the potato varieties CARRERA and PREMABELLE, where the results showed a significant effect of magnesium fertilizer on the dry weight of the vegetative part, which ranged from 35.79 g plant⁻¹ in the Mg₀ treatment to 43.69 g plant⁻¹ in the Mg₃ treatment, and the percentage of increase was 22.07%, This is attributed to the role of magnesium in increasing the activity of many enzymes, which leads to increased division and elongation of plant cells, which is positively reflected on the indicators of vegetative growth of the plant, including the dry weight of the vegetative part (Barker and pilliam, 2015). These results are consistent with what was stated by (Al-Barzanji, 2006, Rehm, 2008, Mahmoud, 2011, and Al-Naimi, 2011), who showed that magnesium fertilization is positively reflected on the vegetative growth characteristics of the potato plant, such as the dry weight of the vegetative part.

The interaction between the varieties and magnesium fertilization significantly affected the dry weight of the vegetative part, as the treatment V₁Mg₃ recorded the highest value for this trait, reaching 47.67 g plant⁻¹, with an increase rate of 65.18% compared to the treatment V₂Mg₀, which recorded the lowest value of 28.86 g plant⁻¹. As for the effect of foliar spraying with boron, treatment B₂ outperformed and recorded the highest value of 41.95 g plant⁻¹ compared to the comparison treatment B₀, which recorded 36.31 g plant⁻¹, This is attributed to boron in improving the physiological and biochemical processes of the plant by increasing the activity of meristematic tissues and increasing the division and elongation of plant cells. Boron also plays a role in the production, regulation and preparation of auxin in the plant, which enhances the vegetative growth characteristics of the plant, including the dry weight of the vegetative part (Ali, 2014 and Naqib and Jahan, 2017). The interaction between the varieties and boron spraying treatments also significantly affected the dry weight trait of the vegetative part, which ranged from 48.09 g plant⁻¹ in treatment V₁B₁ to 31.63 g plant⁻¹ in treatment V₂B₀.

Regarding the interaction between mineral fertilization with magnesium and foliar spraying with boron, the results showed that treatment B₂Mg₃ was superior by giving the highest value for the dry weight of the green part, which reached 46.45 g plant⁻¹,

while treatment B₀Mg₀ recorded the lowest value, which reached 33.20 g plant⁻¹. The triple interaction between the varieties, mineral fertilization with magnesium and foliar spraying with boron also had a significant effect on the dry weight of the green part, which recorded its highest value of 50.67 g plant⁻¹ in

treatment V1B2Mg3, with an increase rate of 85.60% compared to the lowest value of 27.30 g plant⁻¹ in treatment V₂B₀Mg₀. As for the effect of the varieties, the results showed that the CARRERA variety was significantly superior in the dry weight of the vegetative part, as it recorded the highest value of 45.01 g plant⁻¹ compared to the PREMABELLE variety, which recorded the lowest value of 34.08 g plant⁻¹.

spraying on Dry weight of the vegetative part (g plant⁻¹)

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

Total yield of tubers (ton ha⁻¹)

Table 2. Effect of magnesium fertilization and boron

varieties	boron fertilization	Magnesium fertilization				varieties × Boron	Effect of varieties	Effect of Boron
		Mg ₀	Mg ₁	Mg ₂	Mg ₃			
V ₁	B ₀	39.10 fgh	40.97 dg	41.17 dg	42.70 cde	40.98 c	45.01 a	36.31 c
	B ₁	45.27 bc	48.17 ab	49.30 a	49.63 a	48.09 a		40.38 b
	B ₂	43.80 cd	44.37 cd	44.93 bc	50.67 a	45.94 b		41.95 b
V ₂	B ₀	27.30 m	29.83 klm	33.50 ij	35.90 hi	31.63 e	34.08 b	
	B ₁	27.67 lm	30.97 klm	31.00 jkl	41.00 dg	32.66 e		
	B ₂	31.60 jk	38.63 gh	39.33 efg	42.23 cf	37.95 d		
varieties *	V ₁	42.72 c	44.50 bc	45.13 b	47.67 a			
Mg	V ₂	28.86	33.14 e	34.61 e	39.71 d			
Mg * B	B ₀	33.20 f	35.40 ef	37.33 de	39.30 cd			
	B ₁	36.47 e	39.57 cd	40.15 bc	45.32 a			
	B ₂	37.70 de	41.50 bc	42.13 b	46.45 a			
Effect of Magnesium		35.79 c	38.82 b	39.87 b	43.69 a			

Table (3) shows the effect of magnesium sulfate fertilization and boron spraying and their interaction on the total yield rate of the two potato varieties CARRERA and PREMABELLE. The results showed a significant effect of magnesium sulfate fertilizer on the total yield values of the potato crop. The Mg₃ treatment recorded the highest average of 56.48 ton ha⁻¹, with an increase rate of 28.16% compared to the unfertilized Mg₀ treatment, which recorded the lowest value

for the total yield of tubers of 44.07 ton ha⁻¹. The results also showed a significant effect of the interaction between the varieties and magnesium sulfate fertilizer on the total yield average, as the V₁Mg₃ treatment outperformed and recorded the highest value for the trait of 61.12 ton ha⁻¹, while the V₂Mg₀ treatment recorded the lowest value of 39.19 ton ha⁻¹.

As for the effect of foliar spraying with boron, the results showed that treatment B₂ was superior, giving the highest average total yield of 52.48 ton ha⁻¹ compared to the comparison treatment, which recorded 48.83 ton ha⁻¹. This is attributed to the contribution of boron in the manufacture of carbohydrates, which helps in the division of plant cells, and this is positively reflected in the dry weight of the vegetative part. These results are consistent with what was indicated by Tantawy et al. (2017), who showed that adding boron as a spray on the potato plant had a positive effect on the vegetative growth characteristics of the plant. The interaction between the varieties and boron spraying treatments also had a significant effect on the average total yield, as treatment V₁B₂ recorded the highest value for the trait, reaching 57.35 ton ha⁻¹, while treatment V₂B₀ recorded the lowest value, reaching 43.87 ton ha⁻¹.

The results also showed a significant effect of the interaction between magnesium sulphate fertilizer and boron foliar spray, as treatment B₂Mg₃ outperformed and recorded the highest average total yield of 61.72 ton ha⁻¹, with an increase rate of 48.40% compared to treatment B₀Mg₀, which recorded the lowest average for the trait of 41.59 ton ha⁻¹.

The triple interaction between the varieties, soil fertilization with magnesium sulphate, and foliar spraying with boron had a significant effect on the average total plant yield, as treatment V₁B₂Mg₃ outperformed and recorded the highest average of 65.62 ton ha⁻¹, with an increase rate of 85.79% compared to treatment V₂B₀Mg₀, which recorded the lowest average of ton ha⁻¹.

Regarding the effect of varieties, the CARRERA variety was significantly superior and recorded the highest value for the average total yield of 56.08 ton ha⁻¹ compared to the PREMABELLE variety, which recorded the lowest value for the average total yield of 45.27 ton ha⁻¹.

Table 3. Effect of magnesium fertilization and boron

spraying on Total yield of tubers (ton ha⁻¹)

varieties	boron fertilization	Magnesium ferlization				× varieties Boron	Effect of varieties	Effect of Boron
		Mg ₀	Mg ₁	Mg ₂	Mg ₃			
V ₁	B ₀	47.86 ef	50.64 de	59.88 bc	56.74 bc	53.78 b	56.08 a	48.83 c
	B ₁	51.08 de	55.26 cd	61.06 ab	60.99 ab	57.10 a		50.72 b
	B ₂	47.91 ef	55.98 bc	59.88 bc	65.62 a	57.35 a		52.48 a
V ₂	B ₀	35.32 i	44.14 fgh	45.02 fgh	51.00 de	43.87 d	45.27 b	
	B ₁	42.29 gh	43.65 fgh	44.66 fgh	46.74 efg	44.33 d		
	B ₂	39.96 h	46.49 efg	46.20 efg	57.81 bc	47.61 c		
varieties *	V ₁	48.95 c	53.96 b	60.27 a	61.12 a			
	V ₂	39.19 e	44.76 d	45.30 d	51.85 b			
Mg	B ₀	41.59 f	47.39 d	52.45 bc	53.87 b			
	B ₁	46.69 de	49.45 cd	52.86 bc	53.86 b			

B	B ₂	43.93 ef	51.23 bc	53.04 b	61.72 a			
Effect of Magnesium		44.07 d	49.36 ab	52.79 ab	56.48 a			

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

percentage of dry matter in tubers (%):

The results of Table (4) showed the effect of magnesium sulfate fertilizer and boron spraying on Percentage of dry matter in tubers, as the results showed a significant effect of magnesium sulfate fertilization on the average of Percentage of dry matter in tubers, as the Mg₃ treatment recorded the highest value of 17.60 %, with an increase rate of 2.50% compared to the unfertilized Mg₀ treatment, which recorded the lowest value of 17.17 %.

The interaction between varieties and magnesium sulfate fertilization significantly affected the average of Percentage of dry matter in tubers, which ranged from 17.09% in treatment V₁Mg₀ to 17.71% in treatment V₂Mg₃. The increase in the dry weight of tubers with the increase in the level of added magnesium is attributed to the increase in the concentration of magnesium in the plant as a result of fertilization with it, which led to an increase in the chlorophyll content of the leaves and then an increase in the products of carbon metabolism and their accumulation in the plant and their transfer to the rest of its other parts such as tubers, thus increasing the Percentage of dry matter in tubers. This is consistent with what Al-Dhabibi (2003) found, who found that adding magnesium by spraying led to a significant increase in the Percentage of dry matter in tubers.

The results also showed a significant effect of spraying with boron on the average dry weight of tubers, as treatment B₂ recorded the highest value for this trait, reaching 18.05%, while the comparison treatment B₀ recorded the lowest value, reaching 16.78%, and the percentage of increase between the two treatments reached 7.57%, which is consistent with what was reached by (Shaker and Rasool, 2023), who found that spraying with boron led to a significant increase in the Percentage of dry matter in tubers. As for the effect of the interaction between varieties and spraying with boron, treatment V₂B₂ outperformed and recorded the highest average of Percentage of dry matter in tubers, reaching 18.09%, while treatment V₂B₀ recorded the lowest average, reaching 16.67%. Regarding the interaction between magnesium sulphate fertilization and boron spraying, treatment B²Mg₃ outperformed by recording the highest value for the average of Percentage of dry matter in tubers, reaching 18.32%, compared to treatment B₀Mg₂, which recorded the lowest value for the trait, reaching 16.62%.

As for the effect of the triple interaction between varieties, magnesium sulphate fertilization and boron spraying, treatment V₁B₂Mg₃ was superior and recorded the highest value for the average of Percentage of dry matter in tubers, reaching 18.37%, compared to treatment V₂B₀Mg₂, which recorded the lowest value of 16.38%. The varieties also did not show a significant effect on the average of Percentage of dry matter in tubers, as the CARRERA variety recorded 17.33%, while the PREMABELLE variety recorded 17.35%.

Table 4. Effect of magnesium fertilization and boron

spraying on Dry weight of tubers (%)

varieties	boron fertilization	Magnesium ferlization				× varieties Boron	Effect of varieties	Effect of Boron
		Mg ₀	Mg ₁	Mg ₂	Mg ₃			
V ₁	B ₀	16.83 def	16.93 cf	16.85 def	16.97 cde	16.89 d	17.33 a	16.78 c
	B ₁	17.09 cde	17.05 cde	17.10 cd	17.13 cd	17.09 c		17.20 b
	B ₂	17.36 c	18.07 ab	18.20 ab	18.37 a	18.00 a		18.05 a
V ₂	B ₀	16.67 efg	16.54 fg	16.38 g	17.07 cde	16.67 e	17.35 a	

	B ₁	17.14 a	16.98 cde	17.30 c	17.80 b	17.30 b		
	B ₂	17.97 ab	18.03 ab	18.10 ab	18.27 a	18.09 a		
varieties *	V ₁	17.09 d	17.35 bc	17.38 bc	17.49 b			
Mg	V ₂	17.26 bcd	17.18 cd	17.26 bcd	17.71 a			
Mg	B ₀	16.75 de	16.74 e	16.62 e	17.02 cd			
*	B ₁	17.11 c	17.01 cd	17.20 c	17.46 b			
B	B ₂	17.66 b	18.05 a	18.15 a	18.32 a			
Effect of Magnesium		17.17 b	17.27 b	17.32 b	17.60 a			

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

Starch percentage in tubers (%):

Table (5) shows the effect of fertilization with magnesium sulfate and spraying with boron and their interaction on the percentage of starch in tubers for the potato varieties CARRERA and PREMABELLE, as the mineral fertilization treatment with magnesium Mg₃ outperformed and recorded the highest value of 11.68% and an increase of 3.36% compared to the comparison treatment Mg₀ which recorded the lowest value of 11.30%, the results also showed a significant effect of the interaction between the varieties and the added magnesium on the percentage of starch in tubers, as the treatment V₂Mg₃ achieved the highest value for this trait of 11.78% and an increase of 4.90% compared to the treatment V₁Mg₀ which recorded the lowest value of 11.23%. The increase in the percentage of starch in tubers with the increase in the level of magnesium fertilization may be due to the increase in the dry weight of tubers, and this is consistent with what was reached by (Al-Dhabibi, 2003), who found that adding magnesium led to a significant increase in the percentage of starch in tubers.

The results also showed that boron spraying treatments significantly increased the average percentage of starch in tubers, as treatment B₂ recorded the highest value of 12.08%, while the comparison treatment B₀ recorded the lowest value of 10.09%, and the percentage of increase was 19.72%. This is attributed to the role of boron in the starch formation process (Hadi et al., 2023). This is consistent with (El-Dissoky and Abdel-Kadar, 2013), who concluded that spraying with boron led to an increase in the percentage of starch in potato tubers.

The bilateral interaction between varieties and foliar spraying with boron significantly affected the average starch percentage in tubers, as treatment V₂B₂ recorded the highest value of 12.12%, while treatment V₂B₀ recorded the lowest value of 10.85%. As for the interaction between magnesium and boron, treatment B₂Mg₃ outperformed and recorded the highest value for the average starch percentage in tubers of 12.32%, while treatment B₀Mg₂ recorded the lowest value of 10.80%. The triple interaction between varieties, magnesium fertilization and boron spraying significantly affected the starch percentage in tubers, as treatment V₁B₂Mg₃ recorded the highest value of the trait of 12.37%, while treatment V₂B₀Mg₂ recorded the lowest value of 10.60%.

As for the effect of varieties, it had no significant effect on the average starch percentage in tubers, which amounted to 11.44% in the variety and 11.46% in the PREMABELLE variety.

Table 5. Effect of magnesium fertilization and boron

spraying on Starch percentage in tubers (%)

varieties	boron	Magnesium fertilization	× varieties	Effect of	Effect of
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	fertilization	Mg ₀	Mg ₁	Mg ₂	Mg ₃	Boron	varieties	Boron
V ₁	B ₀	11.00 def	11.08 ce	11.01 def	11.12 cde	11.06 d	11.44 a	10.95 c
	B ₁	11.22 cde	11.19 cde	11.23 cd	11.26 cd	11.23 c		11.32 b
	B ₂	11.46 c	12.10 ab	12.22 a b	12.37 a	12.04 a		12.08 a
V ₂	B ₀	10.85 efg	10.74 fg	10.60 g	11.21 cde	10.85 e	11.46 a	
	B ₁	11.27 cd	11.12 cde	11.41 cd	11.86 b	11.42 b		
	B ₂	12.01 ab	12.07 ab	12.13 ab	12.27 a	12.12 a		
varieties * Mg	V ₁	11.23 d	11.46 bc	11.49 bc	11.58 b			
	V ₂	11.38 bcd	11.31 cd	d11.38 bcd	11.78 a			
Mg * B	B ₀	10.93 de	10.91 e	10.81 e	11.16 cd			
	B ₁	11.25 c	11.16 cd	11.32 c	11.56 b			
	B ₂	11.74 b	12.08 a	12.17 a	12.32 a			
Effect of Magnesium		11.30 b	11.38 b	11.43 b	11.68 a			

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

Protein percentage in tubers (%):

The results of Table (6) show the effect of magnesium sulfate fertilization, boron spraying, and their interaction on the protein percentage in tubers of the potato varieties CARRERA and PREMABELLE. Magnesium sulfate fertilization treatments significantly affected the average protein percentage in tubers, which ranged from 8.04% in the Mg₀ treatment to 9.35% in the Mg₃ treatment, with an increase of 16.29%. The interaction between the varieties and magnesium fertilizer also significantly affected the average protein percentage in tubers, as the V₁Mg₃ treatment outperformed and recorded the highest value of 9.42% compared to the V₂Mg₀ treatment, which recorded the lowest value of 7.69%. The increase in the protein percentage with the increase in the level of added magnesium is attributed to the fact that magnesium helps in the formation of many organic materials, in addition to its role in activating the RuBiSco enzyme, which is one of the most important enzymes in providing protein in plants by stimulating the fixation of atmospheric carbon dioxide in the Calvin cycle. (Al-Domi et al., 1995), and this is consistent with what was reached by (Ciećkoe et al., 2010), who noted that adding magnesium as a spray to the plant led to a significant increase in the percentage of protein in tubers.

As for the effect of foliar spraying with boron, the results showed that it had a significant effect on the protein percentage in tubers, which ranged from 6.83% in treatment B₀ to 10.66% in treatment B₂, with an increase of 56.08%. This is attributed to the role of boron in protein production, which is positively reflected in the percentage of protein in tubers (Mahler, 2004). This is consistent with what was reached by (Shaker, 2022), who found that spraying with boron led to a significant increase in the percentage of protein in tubers.

The interaction between varieties and foliar spraying with boron had a significant effect on the protein percentage in tubers, as treatment V₂B₂ recorded the highest average of the trait, reaching 10.98%, compared to treatment V₂B₀, which recorded the lowest average of 6.35%. As for the interaction between magnesium fertilization and foliar spraying with boron, treatment

B₂Mg₃ outperformed and recorded the highest value for the average protein percentage in tubers, reaching 11.67%, while the unfertilized treatment B₀Mg₀ recorded the lowest value, reaching 6.36%. The triple interaction between varieties, mineral fertilization with magnesium, and foliar spraying with boron also had a significant effect on the protein percentage trait in tubers, which ranged from 5.76% in treatment V₂B₀Mg₀ to 12.66% in treatment V₂B₂Mg₃. As for the effect of the varieties, the results showed that the CARRERA variety was superior in the percentage of protein in tubers, which reached 8.91%, while the PREMABELLE variety recorded 8.38%.

Table 6. Effect of magnesium fertilization and boron

spraying on Protein percentage in tubers (%)

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

varieties	boron fertilization	Magnesium fertilization				× varieties Boron	Effect of varieties	Effect of Boron
		Mg ₀	Mg ₁	Mg ₂	Mg ₃			
V ₁	B ₀	6.97 ljk	7.00 ijk	7.46 hij	7.80 ghi	7.31 e	8.91 a	6.83 c
	B ₁	8.48 fgh	8.78 efg	9.24 def	9.76 cde	9.06 c		8.44 b
	B ₂	9.72 cde	10.42 bc	10.55 bc	10.69 bc	10.34 b		10.66 a
V ₂	B ₀	5.76 l	6.29 k	6.48 hij	6.88 ijk	6.35 f	8.38 b	
	B ₁	7.39 hk	7.80 ghi	7.81 ghi	8.28 fgh	7.82 d		
	B ₂	9.92 cd	10.25 bcd	11.08 b	12.66 a	10.98 a		
varieties * Mg	V ₁	8.39 cd	8.73 bc	9.08 ab	9.42 a			
	V ₂	7.69 e	8.12 de	8.46 cd	9.27 ab			
Mg * B	B ₀	6.36 h	6.64 gh	6.97 gh	7.34 fg			
	B ₁	7.93 ef	8.29 e	8.52 de	9.02 d			
	B ₂	9.82 c	10.34 bc	10.82 b	11.67 a			
Effect of Magnesium		8.04 c	8.42 bc	8.77 b	9.35 a			

Magnesium content in plants (mg kg⁻¹):

Table (7) shows the effect of magnesium sulfate fertilization and boron spraying and their interaction on magnesium content in plants for the potato varieties CARRERA and PREMABELLE. The results showed a significant effect of adding magnesium on magnesium content in plants, which ranged from 18.32 mg kg⁻¹ in the Mg₀ treatment to 23.26 mg kg⁻¹ in the Mg₃ treatment, with an increase rate of 26.27%. The interaction between varieties and magnesium sulfate fertilization also had a significant effect on magnesium content in plants, which ranged from 14.87 mg kg⁻¹ in the V₂Mg₀ treatment to 24.95 mg kg⁻¹ in the V₁Mg₃ treatment. The increase in magnesium concentration in plants with the increase in the level of added magnesium sulfate

fertilizer is attributed to the increase in magnesium availability in the soil resulting from the addition of chemical fertilizer and thus its easy absorption by the plant (Al-Naimi, 2011).

As for the effect of foliar spraying with boron on the magnesium content in the plant, treatment B₂ was superior and recorded the highest value of 21.97 mg kg⁻¹, with an increase rate of 16.68% compared to the comparison treatment B₀, which recorded 18.83 mg kg⁻¹. As for the interaction between the varieties and boron spraying treatments, the results showed the superiority of treatment V₁B₁, which recorded the highest average magnesium content in the plant of 24.73 mg kg⁻¹ compared to treatment V₂B₀, which recorded 16.54 mg kg⁻¹.

Regarding the interaction between magnesium sulphate fertilizer and boron added by spraying, the B₂Mg₃ treatment was superior and recorded the highest average magnesium content in the plant, reaching 25.47 mg kg⁻¹, compared to the unfertilized B₀Mg₀ treatment, which recorded the lowest average, reaching 17.00 mg kg⁻¹. The superiority of boron spraying treatments in increasing magnesium concentration in the plant may be attributed to the role of boron in the effectiveness of the cell membrane in absorbing nutrients and transferring them to the plant parts and creating a state of balance for the elements. The increase in elements is also attributed to the role of boron in improving the plant's ionic transport system, which helps in the efficiency of ion absorption (Salih, 2013).

The triple interaction between the varieties, magnesium sulphate fertilizer and boron foliar fertilization had a significant effect on the magnesium content in the plant, which recorded its highest value of 26.90 mg kg⁻¹ in the V₁B₂Mg₃ treatment and its lowest value of 14.07 mg kg⁻¹ in the V₂B₀Mg₀ treatment. As for the effect of the varieties, the results showed that the CARRERA variety was significantly superior in the magnesium content in the plant and recorded the highest value of 23.19 mg kg⁻¹ compared to the PREMABELLE variety, which recorded 17.92 mg kg⁻¹.

Table 7. Effect of magnesium fertilization and boron

spraying on Magnesium content in plants (mg kg⁻¹)

varieties	boron fertilization	Magnesium fertilization				× varieties Boron	Effect of varieties	Effect of Boron
		Mg ₀	Mg ₁	Mg ₂	Mg ₃			
V ₁	B ₀	19.92 hi	20.97 fgh	21.39 fgh	22.22 dg	21.12 c	23.19 a	18.83 c
	B ₁	23.12 cde	24.60 bc	25.44 ab	25.74 ab	24.73 a		20.86 b
	B ₂	22.30 dg	22.63 def	23.03 cde	26.90 a	23.72 b		21.97 a
V ₂	B ₀	14.07 m	15.49 lm	17.50 jk	19.10 ij	16.54 e	17.92 b	
	B ₁	14.21 m	16.03 kl	16.13 kl	21.57 gh	16.99 e		
	B ₂	16.32 k	20.06 hi	20.47 ghi	24.04 bcd	20.22 d		
varieties * Mg	V ₁	21.78 cd	22.73 bc	23.29 b	24.95 a			
	V ₂	14.87 f	17.19 e	18.03 e	21.57 d			
Mg *	B ₀	17.00 h	18.23 g	19.44 efg	20.66 cde			
	B ₁	18.67 g	20.32 def	20.79 cd	23.66 b			

B	B ₂	19.31 fg	21.35 cd	21.75 c	25.47 a			
Effect of Magnesium		18.32 d	19.96 c	20.66 b	23.26 a			

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

Boron content in plants (mg B kg⁻¹ plant):

Table (8) shows the effect of fertilization with magnesium sulfate and spraying with boron and their interaction on the concentration of boron in the plant for the potato varieties CARRERA and PREMABELLE. The results showed a significant effect of adding magnesium on the boron content in the plant, which ranged from 0.92 mg B kg⁻¹ plant in the Mg₀ treatment to 1.13 mg B kg⁻¹ plant in the Mg₃ treatment, with an increase rate of 22.83%. The interaction between the varieties and fertilization with magnesium sulfate also had a significant effect on the concentration of boron in the plant, which ranged from 0.66 mg B kg⁻¹ plant in the V₂Mg₀ treatment to 1.34 mg B kg⁻¹ plant in the V₁Mg₃ treatment.

As for the effect of foliar spraying with boron on the concentration of boron in the plant, treatment B₂ was superior and recorded the highest value of 1.33 mg B kg⁻¹ plant, with an increase rate of 92.75% compared to the comparison treatment B₀, which recorded 0.69 mg B kg⁻¹ plant. As for the interaction between the varieties and boron spraying treatments, the results showed the superiority of treatment V₁B₂, which recorded the highest average concentration of boron in the plant of 1.52 mg B kg⁻¹ plant compared to treatment V₂B₀, which recorded 0.54 mg B kg⁻¹ plant.

Regarding the interaction between magnesium sulphate fertilizer and boron added by spraying, treatment B₂Mg₃ was superior and recorded the highest average boron concentration in the plant, reaching 1.51 mg B kg⁻¹ plant, compared to the unfertilized treatment B₀Mg₀, which recorded the lowest average, reaching 0.63 mg B kg⁻¹ plant. The superiority of treatment B₂ in boron concentration in the plant is attributed to the role of spraying in boron, which was positively reflected on its concentration in the plant. This is consistent with what was indicated by Al-Mohammadi and Al-Issawi (2015), who showed that foliar feeding is characterized by high efficiency in supplying the plant with the nutrients it needs.

The triple interaction between the varieties, magnesium sulphate fertilizer and boron foliar fertilization had a significant effect on the boron concentration in the plant, which recorded the highest value of 1.72 mg B kg⁻¹ plant in the V₁B₂Mg₃ treatment and the lowest value of 0.48 mg B kg⁻¹ plant in the V₂B₀Mg₀ treatment. As for the effect of the varieties, the results showed that the CARRERA variety was significantly superior in the boron concentration trait in the plant and recorded the highest value of 1.26 mg B kg⁻¹ plant compared to the PREMABELLE variety, which recorded 0.78 mg B kg⁻¹ plant.

Table 8. Effect of magnesium fertilization and boron

spraying on Boron content in plants (mg B kg⁻¹ plant):

varieties	boron fertilization	Magnesium fertilization				× varieties Boron	Effect of varieties	Effect of Boron
		Mg ₀	Mg ₁	Mg ₂	Mg ₃			
V ₁	B ₀	0.78 h	0.87 gh	0.84 gh	0.86 gh	0.84 d	1.26 a	0.69 c
	B ₁	1.34 cd	1.47 b	1.46 bc	1.44 bc	1.43 b		1.05 b
	B ₂	1.44 bc	1.40 bcd	1.52 b	1.72 a	1.52 a		1.33 a
V ₂	B ₀	0.48 k	0.50 jk	0.58 ijk	0.61 ij	0.54 f	0.78 b	
	B ₁	0.58 ijk	h0.63 h	h0.66 h	g h0.84 gh	0.68 e		

	B ₂	0.92 gh	1.10 f	1.21 ef	1.30 de	1.13 c		
varieties *	V ₁	1.19 c	1.25 bc	1.27 b	1.34 a			
Mg	V ₂	0.66 g	0.74 f	0.81 e	0.92 d			
Mg	B ₀	0.63 h	0.68 gh	0.71 gh	0.73 g			
*	B ₁	0.96 f	1.05 e	1.06 e	1.14 d			
B	B ₂	1.18 cd	1.25 c	1.36 b	1.51 a			
Effect of Magnesium		0.92 d	0.99 c	1.04 b	1.13 a			

Means within a column, row and their interactions followed with the same letters are not significantly different from each other according to Duncan multiple ranges test at significant level of 5%.

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