Colegio de Postgraduados

Growth and yield models for black beans under magnetization and pH variation in a greenhouse

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ABSTRACT

Objective: To estimate growth and yield variations in common beans (*Phaseolus vulgaris* L.) treated with a magnetized nutrient solution considering two factors: magnet exposure time and pH level. The significance of this crop lies in its nutritional and economic value.

Design/Methodology/Approach: We used a hydroponic system with magnetized Steiner nutrient solution. The design was completely randomized, with a 4×6 factorial treatment arrangement and three replications. Factor A comprised exposure times (0.333 hours, 2 hours, chronic, and without magnetization), while Factor B covered solutions with different pH levels (3, 4, 5, 6, 7, and 8). We then applied a multiple regression analysis using the SAS software.

Results: Models for vegetative growth variables (plant height, root length, root dry weight, and foliar biomass) and seed yield components (number of pods, number of grains per pod) were statistically significant ($p<0.0001$). Coefficients of determination ranged from 59.7% to 82%, percentages considered appropriate to explain the observed variability.

Study limitations/Implications: While the models showed acceptable coefficients of determination, it is essential to consider other factors that were not assessed in this study: exposure to sunlight, insect influence, and diseases that could impact the responses of the bean crop.

Findings/Conclusions: Appropriate models to describe vegetative growth and seed yield of the common bean, concerning magnetization time and nutrient solution acidity, include variables such as plant height, root length, root dry weight, foliar biomass, total biomass, number of pods, and number of grains per pod.

Keywords: *Phaseolus vulgaris* L.; Greenhouse; Magnets.

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INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is crucial for human nutrition in tropical and subtropical regions. Latin America leads in common bean production and consumption, comprising 45% of global production (Smith and Rao, 2021). This crop has a significant economic and nutritional role —it contains iron, potassium, magnesium, phosphorus,

vitamins B1 and B6, folate, and niacin (Gonzalez-Gonzalez and Guertin, 2021; Ramirez-Cabral, Kumar, and Taylor, 2016). Historical crop data are essential for predicting yields (Gonzalez-Gonzalez and Guertin, 2021). These data are collected throughout the growth cycle, considering management and conditions (Poudel *et al.*, 2022). In Mexico, simulation models have been used to anticipate bean yields (Medina-García *et al.*, 2010; Spoorthi *et al.*, 2022). Applying magnetic fields improves bean growth, nutrient absorption, and productivity (Mroczek-Zdyrska *et al.*, 2016; Hozayn *et al.*, 2017; Vashisth and Joshi, 2017). Magnetic fields affect water's physicochemical and molecular properties (Krishnaraj *et al.*, 2017; El-Sabrout and Hanafy, 2017). On a biological level, they affect membrane permeability, ion flow, enzymatic processes, and metabolic pathways (Pang, 2014; Sheykina, 2016). This study aims to model the growth and yield of common beans in a greenhouse, considering the nutrient solution's pH level and magnetization time.

MATERIALS AND METHODS

We conducted our experiment in February 2019 at the greenhouse of the Universidad Autónoma Agraria Antonio Narro, Unidad Laguna, in Torreón, Coahuila, Mexico (25° 31" 11' N, 103° 25" 57' W, 1123 masl). The area has a hot desert climate (BWh) with maximum temperatures of 40 °C and minimums of 6 °C. The average precipitation is 250 mm (García, 2004). We used a hydroponic system with Steiner (1966) nutrient solution, making pH adjustments with sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) (Santos-Cavalcante *et al.*, 2016). The solution was magnetized with neodymium magnets 2.5 cm long and 2.0 cm in diameter with a field intensity of 0.380 Tesla. The experimental design was completely randomized with a 4×6 factorial treatment arrangement and three replications. Factor A considered different exposure times (0.333 hours, 2 hours, chronic, and without magnet), while factor B covered pH variations (3 to 8) in the nutrient solution. We employed growing degree days to assess vegetative development, using the formula $GD = \sum_{i=0}^{n}(Xi - Tb)$. For physiological time, we considered the accumulation of heating degree days since the transplant of the bean plants into the greenhouse (Romero Félix *et al.*, 2019). We conducted multiple regression analyses using the Statistical Analysis System program (SAS, 1999).

RESULTS AND DISCUSSION

Heat units in seed growth, development, and yield

The total heat units (HU) accumulated during growth, development (PH), and seed yield (NP and SY) equaled 1410 °C d. This accumulation was distributed between transplant, start of flowering (522 °C d), and harvest (HAR) in approximately 126 days. We observed that the accumulation of heat units during the phenological cycle of black bean cultivation follows a linear equation: (HU=31.67210+331dds) R^2=0.98 (Figure 1).

Vegetative development

The best model for vegetative development based on the exposure time and pH of the magnetized nutrient solution was quadratic. A cubic model offered the highest coefficient

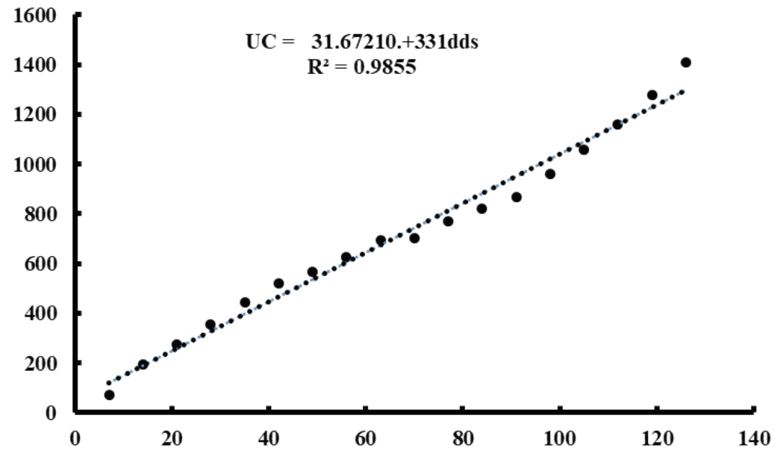

Figure 1. Heat unit accumulation in black beans in an experiment conducted under greenhouse conditions at the Universidad Autónoma Agraria Antonio Narro Unidad Laguna, Torreón, Coahuila, Mexico, 2018-2019.

of determination (R2) in plant height, root length, root dry weight, aboveground biomass, and total biomass.

$$PH = 122.07\ \text{pH} - 21.54\text{pH}^2 + 1.19\ \text{pH}^3 - 192.01$$

$$RL = 3.37MET - 0.13MET^2 + 62.07\ \text{pH} - 10.05\text{pH}^2 + 0.48\text{pH}^3 - 86$$

$$RDW = 7.43\ \text{pH} - 1.29\text{pH}^2 + 0.07\text{pH}^3 - 12.14$$

$$AGB = -7.36MET + 4.41MET^2 - 0.17MET^3 + 43.18\text{pH} - 7.62\text{pH}^2 + 0.42\text{pH}^3 - 69.47$$

$$TB = -8.06MET + 4.81MET^2 - 0.19MET^3 + 50.61\text{pH} - 8.91\text{pH}^2 + 0.49\text{pH}^3 - 81.61$$

Where PH=plant height; RL=root length; RDW=root dry weight; AGB=aboveground biomass; TB=total biomass; pH=pH of the magnetized solution; and MET=magnet exposure time.

Models for plant height, root length, root dry weight, aboveground biomass, and total biomass were statistically significant ($p<0.0001$) for all variables. Their coefficients of determination (R^2=0.597, 0.700, 0.576, 0.655, and 0.693) are acceptable and explain the variability from 59.7% to 70% (Table 1). These results are similar to those reported by Medina-García *et al.* (2010); Liu *et al.* (2019), and Vashisth and Joshi (2017), who indicate that magnetized water promotes the growth of seedlings, contributing to the development of roots and mineral nutrient contents. In this regard, Çelik *et al.* (2008) show the effects of irrigation with magnetized water compared to untreated water, and show that the former increases plant growth rate, noticeable in the increase in biomass.

Table 1. Multiple regression analysis for the model of vegetative development components in the Veracruz black bean variety, determined in an experiment under greenhouse conditions at the Universidad Autónoma Agraria Antonio Narro Unidad Laguna, Torreón, Coahuila, Mexico, 2018-2019.

Variables	Parameter	Estimator	Standard error	T-value	p>t	p>F	R^2
Plant height	Intercept	−192.01	28.48	−6.74	0.0001	0.0001	0.597
	pH	122.07	17.24	7.08	0.0001		
	pH^2	−21.54	3.28	−6.56	0.0001		
	pH^3	1.19	0.2	5.98	0.0001		
Root length	Intercept	−86.58	29.01	−2.98	0.004	<0.0001	0.7
	Time	3.37	0.96	3.52	0.0008		
	$Time^2$	−0.13	0.04	−3.22	0.002		
	pH	62.07	17.55	3.54	0.0007		
	pH^2	−10.05	3.34	−3.01	0.0037		
	pH^3	0.48	0.2	2.37	0.021		
Root dry weight	Intercept	−12.14	1.79	−6.8	0.0001	0.0001	0.576
	pH	7.43	1.08	6.87	0.0001		
	pH^2	−1.29	0.21	−6.27	0.0001		
	pH^3	0.07	0.01	5.67	0.0001		
Biomass area	Intercept	−69.47	9.71	−7.15	0.0001	0.0001	0.655
	Time	−7.36	2.26	−3.26	0.0018		
	$Time^2$	4.41	1.15	3.82	0.0003		
	$Time^3$	−0.17	0.04	−3.87	0.0003		
	pH	43.18	5.87	7.35	0.0001		
	pH^2	−7.62	1.12	−6.82	0.0001		
	pH^3	0.42	0.07	6.27	0.0001		
Total biomass	Intercept	−81.61	10.32	−7.91	0.0001	0.0001	0.693
	Time	−8.06	2.4	−3.36	0.0013		
	$Time^2$	4.81	1.22	3.93	0.0002		
	$Time^3$	−0.19	0.05	−3.97	0.0002		
	pH	50.61	6.24	8.11	0.0001		
	pH^2	−8.91	1.19	−7.5	0.0001		
	pH^3	0.49	0.07	6.88	0.0001		

Yield components

The best model for yield components based on the exposure time and pH of the magnetized nutrient solution was quadratic. A cubic model offered the highest coefficient of determination regarding number of pods (NP), number of grains per pod (NGP), and seed yield (SY).

$$NP = 16.80\text{pH} - 1.55\text{pH}^2 - 33.00$$

$$NGP = 2.34MET - 1.04MET^2 + 0.04MET^3 + 18.77\text{pH} - 3.12\text{pH}^2 + 0.17\text{pH}^3 - 31.25$$

$$SY = -2.50MET + 1.45MET^2 - 0.06MET^3 + 14.83\ \text{pH} - 2.61\text{pH}^2 + 0.14\text{pH}^3 - 24.27$$

Models for number of pods (NP), number of grains per pod (NGP), and seed yield (SY), were statistically significant ($p<0.0001$) for yield components. The coefficients of determination ($R^2=0.65$, 0.821, and 0.708) were acceptable since they explain the variability from 65.0% to 82.1% (Table 2). While studying bean cultivation, Moussa (2011) Australia, USA, China and Japan indicated the type of irrigation water and its interaction with the plants. According to this study, irrigation water treated with magnetization achieved an increase in photosynthetic activity and better photoassimilates translocation efficiency. Fouad Abobatta (2019) reports that applying magnetic fields to Valencia orange increases yield, number, and quality of fruits, as well as number of flowers. Magnetic fields also increase the yield of strawberry fruits.

El-Ssawy *et al.* (2020) reported that using the NFT (nutrient film technique) hydroponic technique with magnetized water at a high intensity (level 3) led to a significant increase

Table 2. Multiple regression analysis for the model of seed yield components for the Veracruz black bean variety, determined in an experiment under greenhouse conditions at the Universidad Autónoma Agraria Antonio Narro Unidad Laguna, Torreón, Coahuila, Mexico, 2018-2019.

Variables	Parameter	Estimator	Standard error	T-value	P>t	P>F	R^2
Number of pods	Intercept	−33	3.92	−8.41	0.0001	0.0001	0.65
	pH	16.8	1.52	11.04	0.0001		
	pH^2	−1.55	0.14	−11.27	0.0001		
Number of grain per pod	Intercept	−31.25	3.25	−9.62	0.0001	0.0001	0.821
	Time	2.34	0.76	3.1	0.0029		
	$Time^2$	−1.04	0.39	−2.7	0.0087		
	$Time^3$	0.04	0.01	2.67	0.0095		
	pH	18.77	1.96	9.55	0.0001		
	pH^2	−3.12	0.37	−8.35	0.0001		
	pH^3	0.17	0.02	7.31	0.0001		
Performance seed	Intercept	−24.27	2.93	−8.27	0.0001	0.0001	0.708
	Time	−2.5	0.68	−3.66	0.0005		
	$Time^2$	1.45	0.35	4.18	0.0001		
	$Time^3$	−0.06	0.01	−4.21	0.0001		
	pH	14.83	1.77	8.35	0.0001		
	pH^2	−2.61	0.34	−7.73	0.0001		
	pH^3	0.14	0.02	7.09	0.0001		

in nutrient concentrations (N, P, and K) and total soluble solids, although the pH of the nutrient solution had to be reduced for lettuce. They also found an increase in water productivity, fresh yield, and number of lettuce leaves, along with high chlorophyll content.

CONCLUSIONS

Models for vegetative development and seed yield components comprised plant height, root length, root dry weight, aboveground biomass, total biomass, number of pods, and number of grains per pod. These components are the most appropriate to study the Veracruz black bean variety based on the time of exposure to magnetization and the acidity degree of the nutrient solution under greenhouse conditions.

Further studies should be conducted to determine the model's applicability in nutrient solutions based on magnet exposure time and pH variation.

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