Colegio de Postgraduados

Hydroponic corn (*Zea mays* L.) fodder production through the implementation of mineral fertilization: a comparative study

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ABSTRACT

Objective: To produce hydroponic corn forage using a mineral fertilization planning with three different seed types and to determine the optimal concentration for production and livestock feeding.

Design/Methodology/Approach: A completely randomized experimental design was used. The following study variables were included in the design: plant height, root length, stalk thickness, and fresh biomass. Five hundred grams of three different variety seeds were selected, washed, disinfected, soaked, covered, aerated, and placed in plastic trays. Starting from the fifth day, the seeds were watered with formulated solutions until the end of production.

Results: Plant height reached 17.25 cm, at a 50% concentration; root were 12.55 cm long, at a 25% concentration with Sinaloa seeds; stalks were 2.40 mm thick, at a 25% concentration with Bajío seeds; and biomass recorded 1.184 kg at a 50% concentration with Sinaloa seeds.

Study Limitations/Implications: A greenhouse is not essential for fodder production, as long as the minimum necessary conditions (light, humidity, and temperature) are met.

Findings/Conclusions: The 50% nutrient solution had a positive influence on the study variables that used Sinaloa variety seeds. Therefore, hydroponics would be a reliable and practical technique for producers, useful during periods of prolonged drought; it would significantly counteract agroclimatological setbacks in the agricultural, livestock, and environmental sectors.

Key words: nutrient solution, hydroponics, agronomic variables, mineral treatments.

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INTRODUCTION

Hydroponic green fodder (HGF) is obtained from the germination of seeds or grains and can be used as a nutritional supplement for several animal species. It has an excellent protein percentage (Contreras *et al.*, 2015), an adequate balance between soluble and insoluble fiber, high dry matter digestibility, and a good energy contribution (Bedolla-Torres *et al.*, 2015). The intensive production of HGF in a protected environment is less prone to climate change, enables a scheduled and periodical production all year round, making an efficient use of water and reducing the use of agrochemicals and labor (Candia, 2015).

This technique does not require soil, its fodder mass can be fully (100%) consumed, it provides an ongoing supply of goods every day of the year, it prevents digestive alterations, and has lower disease incidents (Suarez, 2015). Several species, including pulses and leguminous plants, have been used for HGF production (Naik *et al.*, 2017).

Hydroponics is an alternative to agriculture: this technique provides the ideal conditions for the development and growth of plants, using only water and a full nutrient solution (Gilsanz, 2007). According to Núñez-Torres and Guerrero-López (2021), watering with a nutrient solution helps to increase biomass production, improves nutritional quality, and optimizes cutting time.

Consequently, the purpose of this project was to compare the effects of the application of mineral nutrient solutions on various morphological variables in three corn varieties.

MATERIALS AND METHODS

The study was carried out in Xalapa, a city located in northern Veracruz, at 1,460 m.a.s.l. In average, the climate is humid-temperate, with a mean temperature of 18 °C. A 4×4 m^2 space was used, with concrete walls, cement tiles, and a 2-m long × 2.19-m tall window. Mean temperatures ranged from 10 to 15 °C and a 20-75% relative humidity were recorded. Seeds from three different varieties of commercial hybrid corn were used (Sinaloa, Bajío, and Exportación), to obtain a total of 24 kg of seed.

Experiment design

HGF was produced according to the method proposed by Reyes *et al.* (2012), with some modifications: seed selection (whole, dry seeds, and 85% germination capacity); prewashing of 500 g of seeds per variety (Mejia-Castillo and Orellano-Núñez, 2019); disinfection with 2% sodium hypochlorite; washing and submersion in water for a full day; then allow aeration and rest for another 24 hours, ensuring the samples are enshrouded in black bags. The seeds were sown in 36 plastic trays watered with 250-ml sprinklers. Only water was used during the first four days, followed by a nutrient solution (NS) from days 5 to 14; treatments with a 0, 25, 50, 75% dilution of NS with minerals (hydroponic nutriments) (Linch) were applied in demijohns labelled A and B (FAO, 2001). A Steren® thermo-hygrometer was used to record the mean temperature (11 °C) and humidity (75%).

Statistical Design

A completely randomized design was used, consisting of four NS treatments (0, 25, 50, and 75%), three repetitions per treatment, and a total of 36 trays. Each treatment was evaluated in two periods (6 and 14 days). Ten seedlings were randomly selected per each NS treatment, corn variety, and repetition. HGF production was determined at 6 and 14 days, considering plant height (cm), root length (cm), and stalk thickness (mm). Fresh weight (g) was determined weighing all the plants per tray per NS treatment and corn variety (N=36). The statistical analyses were carried out using the MiniTab statistical software ver. 21.3 (Minitab, 2023). A three-way ANOVA was used to consider the 0, 25, 50, and 75% NS treatments in the corn varieties as fixed factors, at 6 and 14 days of germination. The interactions between the factors were calculated with post hoc Tukey's HSD tests.

RESULTS AND DISCUSSION

Evaluation of seedling height

Table 1 shows the results of the height evaluation of corn HGF. The Bajío and Sinaloa varieties recorded the greatest increase from day 6 to day 14 of the experiment. The Bajío variety increased by 10.73 cm, while the Sinaloa variety plants grew 10.81 cm. The Exportación variety increased by 8.33 cm. At 14 days, the Sinaloa variety plants were in average 16.05 cm tall, followed by Bajío (15.01 cm) and Exportación (13.26 cm). The tallest plants had been supplemented with 50% NS, followed by plants that received 25% NS (15.07 cm). Plants supplemented with 75% NS recorded the lowest average height (14.36 cm). Statistical comparison suggests that the Sinaloa variety has the best development at 14 days of watering with 25 and 50% NS concentrations. On the contrary, corn plants from the Exportación variety were the smallest at 14 days, with 0 and 75% NS.

Table 1. Plant height in several periods, varieties, and NS concentrations.

Period *Variety (%)*NS	N	Average	Group										
14 Sinaloa 50	10	17.25	A										
14 Sinaloa 25	10	15.97	A	B									
14 Sinaloa 75	10	15.5		B	C								
14 Sinaloa 0	10	15.38		B	C								
14 Bajío 50	10	15.3		B	C								
14 Bajío 75	10	15.1		B	C								
14 Bajío 25	10	15		B	C	D							
14 Bajío 0	10	14.6			C	D							
14 Exportación 25	10	14.25			C	D							
14 Exportación 50	10	13.7				D	E						
14 Exportación 0	10	12.6					E						
14 Exportación 75	10	12.5					E						
6 Sinaloa 25	10	6.87						F					
6 Sinaloa 50	10	6.75						F					
6 Exportación 25	10	6.7						F					
6 Exportación 50	10	5.7						F	G				
6 Bajío 50	10	5.1							G	H			
6 Bajío 75	10	4.5							G	H	I		
6 Sinaloa 75	10	4.42							G	H	I	J	
6 Bajío 25	10	4.2								H	I	J	
6 Exportación 75	10	3.95								H	I	J	K
6 Exportación 0	10	3.35									I	J	K
6 Bajío 0	10	3.15										J	K
6 Sinaloa 0	10	2.82											K

Means without a common letter significantly differ.

Evaluation of root length

The Sinaloa variety recorded the greatest increase in root length: 6.61 cm from day 6 to day 14. During the same period, the Bajío and Exportación varieties increased by 2.23 and 2.36 cm, respectively. The greatest increase regarding root length, from day 6 to day 14, was recorded with 25% (3.38 cm) and 75% NS (3.37 cm). A significative increase was likewise recorded with 25% NS (8.63 cm), followed by 50% (8.35 cm). A significative increased was equally recorded with 25% NS (8.63 cm), followed by 50% (8.35 cm). The tallest plants at 14 days belonged to the Sinaloa variety supplemented with 25 and 50% NS. Finally, the lowest growth was recorded at 14 days by the Bajío variety, with 25 and 75% NS (Table 2).

Evaluation of stalk diameter

The Bajío variety recorded the highest increase in stalk diameter (0.1 cm) from day 6 to day 14. The Exportación and Sinaloa varieties increased by 0.08 and 0.09, respectively. Diameter increased by 0.1 cm with 25% and 75% NS concentrations. For their part, the Bajío and Sinaloa varieties recorded a greater diameter at 14 days with 25% NS. Finally, the Exportación variety recorded the lowest values with 75 and 0% NS (Table 3).

Table 2. Tukey's multiple comparison of root length.

Period *Variety (%) *NS	N	Average	Group									
14 Sinaloa 25	10	12.55	A									
14 Sinaloa 50	10	12.4	A									
14 Sinaloa 0	10	11.55	A	B								
14 Sinaloa 75	10	10.5		B	C							
14 Exportación 25	10	9.5			C							
14 Bajío 0	10	7.3				D						
6 Sinaloa 50	10	7.1				D						
6 Sinaloa 25	10	7				D						
14 Exportación 50	10	6.75				D	E					
6 Exportación 25	10	6.5				D	E	F				
14 Bajío 50	10	5.9				D	E	F				
14 Exportación 75	10	5.8				D	E	F				
6 Exportación 50	10	5.75				D	E	F				
14 Exportación 0	10	5.7				D	E	F	G			
6 Bajío 50	10	4.9					E	F	G	H		
14 Bajío 75	10	4.75						F	G	H	I	
14 Bajío 25	10	3.85							G	H	I	J
6 Sinaloa 75	10	3.46								H	I	J
6 Exportación 75	10	3.35								H	I	J
6 Bajío 75	10	3.05								H	I	J
6 Sinaloa 0	10	2.97									I	J
6 Exportación 0	10	2.7										J

Means without a common letter significantly differ.

Table 3. Tukey's multiple comparison test of stalk diameter.

Period *Variety * (%) NS	N	Average	Group							
14 Bajío 25	10	2.4	A							
14 Sinaloa 25	10	2.39	A							
14 Exportación 50	10	2.37	A	B						
14 Sinaloa 50	10	2.37	A	B						
14 Exportación 25	10	2.33	A	B	C					
6 Sinaloa 50	10	2.31	A	B	C	D				
6 Sinaloa 25	10	2.29	A	B	C	D	E			
14 Bajío 50	10	2.27	A	B	C	D	E			
6 Bajío 50	10	2.27	A	B	C	D	E			
6 Exportación 50	10	2.25	A	B	C	D	E			
6 Exportación 25	10	2.24	A	B	C	D	E	F		
14 Sinaloa 75	10	2.19	A	B	C	D	E	F		
14 Sinaloa 0	10	2.17	A	B	C	D	E	F	G	
6 Bajío 25	10	2.16	A	B	C	D	E	F	G	H
14 Bajío 75	10	2.15	A	B	C	D	E	F	G	H
14 Bajío 0	10	2.13		B	C	D	E	F	G	H
14 Exportación 75	10	2.09			C	D	E	F	G	H
6 Sinaloa 0	10	2.08			C	D	E	F	G	H
6 Bajío 0	10	2.07				D	E	F	G	H
6 Sinaloa 75	10	2.06				D	E	F	G	H
6 Bajío 75	10	2.05					E	F	G	H
6 Exportación 75	10	1.99						F	G	H
14 Exportación 0	10	1.92							G	H
6 Exportación 0	10	1.91								H

Means without a common letter significantly differ.

Evaluation of total biomass

The Sinaloa variety recorded the largest biomass production values at 14 days (787.83 g), followed by Bajío (712.08 g) and Exportación (671.66 g). The greatest biomass was reported with 50% NS (920 g), followed by 25% NS (702.77 g) and 75% NS (630.66 g). The Sinaloa variety, fertilized with 50% NS, showed the highest biomass amount.

HGF production involves a methodology for the development of plant biomass from the early seedling stages (embryogenesis and early progress phases), using seeds with a high germination index to generate a nutritious live fodder with outstanding digestibility, which is adequate for animal consumption (Bedolla-Torres *et al.*, 2015; Contreras *et al.*, 2015).

Consequently, the results of this research suggest that the Sinaloa variety recorded the greatest height (17.25 cm), with only 50% of fertilizer concentration. Tomalá (2021) reported an average height of 25 cm in corn germinules treated with bokashi fertilizers.

For his part, Suarez (2015) reports 28.79 cm at 12 days, using the FAO's nutrient solution. Meanwhile, Víquez and Soto (2017) recorded between 26.38 and 28.13 cm at 14 days with mineral nutrition. In turn, Machaca (2018) recorded 26.9 cm with liquid cattle manure. Likewise, Silva (2017) reported a 5.67-12.80 cm range with 6-12-day fertilizations, using various solutions supplemented with Raizal®, Cytokin®, and Newgibb® phytohormones. Finally, Valverde *et al.* (2017) reported an average of 14 cm at 12 days after germination, watering corn with conventional chemical and organic fertilizers.

Vélez (2020) reported a similar root length (10.99 cm) using a mineral fertilization process. Morales *et al.* (2012) observed 12.3-23.03 cm root growth in 10-14-day cultivars. Likewise, Valverde *et al.* (2017) recorded 12.49 cm in white corn at 12 days after fertilization. The stalk thickness results match the findings of Duran (2007), who reported 2.27 and 2.40 mm at 6 and 9 days after the fertilized germination, respectively. Espinosa (2019) suggests that supplying a nutrient diluted solution through a drip irrigation system would result in an up to 2.66 mm diameter at 12 days. In that sense, Cuadra-Quispe (2019) observed a 2.96 mm growth when certified corn seeds (type: V-53) were irrigated with 3.5% NS minerals. Finally, Varela Rojas (2016) proved that the diameter of HGF produced from certified corn seeds (NB-6, NB-S), using a chemical fertilizer, would reach approximately 3.3 mm at 15 days.

HGF has been established as an innovative technique for the generation of livestock sustenance that remediates inherent setbacks of traditional production, including deprived plots, scarce rainfall, high evaporation, and very low-quality water and soil resources. Consequently, it is taking shape as an alternative to conventional production procedures, contributing to the sustainability of farming activities in arid and semi-arid areas (Varela Rojas, 2016).

The biomass production results of this research were compared with those of previous studies. In the first place, Vélez (2020) recorded 2.11 kg/m^2 of sprouts using a 2 g/L dose of zeatin. Muñoz *et al.* (2008) reported 1.8-2.3 kg/m^2 corn production with several NS types and doses. Likewise, Preciado *et al.* (2014) applied vermicompost to corn, recording 1:7 germination ratios at 14 days; they recorded 1:5-1:6 ratios between native corn and organic NS, reporting 18.1-19.7 kg/m^2 of sprouts at 16 days. Finally, Tomalá (2021) observed a 2.38 kg yield with the use of mineral NS.

The germination process is unleashed when the seed is moisturized (watering). When roots and the first leaves appear, the plant is able to obtain nutrients from its surroundings and other essential elements for the synthesis of its own sustenance through photosynthesis. Therefore, the specimen must be subjected to ideal nutritional conditions, including watering processes that use mineral solutions (Gilsanz, 2007; Núñez-Torres and Guerrero-López, 2021).

CONCLUSIONS

HGF production complements commercial products used to feed cattle; it is particularly useful during drought periods, when fresh forage is scarce. Hydroponic crops are viewed as an outstanding nutrient source for animal diets; therefore, additional research must be carried out on this subject, using a greater variety of fodder plant species, to offer more options for producers. Consequently, HGF production is an efficient alternative that guarantees a constant supply of food for the animals, significantly counteracting agroclimatic setbacks.

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