IJANR
International Journal
of Agriculture
and Natural Resources

Int. J. Agric. Nat. Resour. 49(3):147-156. 2022
www.ijanr.cl

CROP PRODUCTION

DOI 10.7764/ijanr.v49i3.2338

RESEARCH PAPER

Inorganic fertilization improves *Agave potatorum* Zucc growth and nutrition

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Abstract

S. Sánchez-Mendoza, G. Bautista-Aparicio, and A. Bautista-Cruz. 2022. Inorganic fertilization improves *Agave potatorum* Zucc growth and nutrition. Int. J. Agric. Nat. Resour. 147-156. *Agave potatorum* Zucc is a wild agave used for mezcal (a traditional alcoholic beverage) production in Oaxaca, Mexico, but little information is available on its response to nitrogen (N) and phosphorus (P) fertilization. The effect of different N (0, 23.7, 47.5, and 71.2 mg N per kg soil) and P (0, 14.1, 28.3, and 42.5 mg P per kg soil) doses on *A. potatorum* growth, nutrition and total soluble solid in stem (TSS) was assessed using a two-factor completely randomized design under nursery conditions. Relative to the control, the highest increase in response variables was unfolded leaf number (UL) 37.3%, leaf relative chlorophyll (LRCC) 9.6% and leaf nitrate content (LNO) 42.7% with 71.2 mg N per kg soil; plant height (PH) 39.1%, stem diameter (SD) 17.2%, and leaf dry weight (LDW) 70.2% with 47.5 mg N per kg soil; leaf P content (LP) 78.2% with 23.7 mg N per kg soil; root density (RD) 28.5% and LRCC 5.5% with 28.3 mg P per kg soil; LP 34.7%, LNO 16.8% with 14.1 mg P per kg soil; and TSS 19.0% with 42.5 mg P per kg soil. The combined application of N and P also enhanced stem dry weight, root dry weight, root length, SD, LDW, PH, UL, LP, TSS, LNO and LCRR. The application of N and P favors growth, nutrition and TSS in *A. potatorum*; therefore, it could be an important alternative for agronomic management of this agave species under nursery conditions. Further research is recommended to assess the response of *A. potatorum* to N and P fertilization under field conditions.

Keywords: Agave, nitrogen fertilization, phosphorus fertilization, plant growth, plant nutrition.

Introduction

Mexico possesses 90% of the world's species of the *Agave* genus (García-Mendoza, 2010). Agaves are economically important for the state of Oaxaca (Mexico) because they are the raw material to produce mezcal (Ortíz-Hernández et al., 2018), a traditional alcoholic beverage. In addition to its uses as food, medicine, ornament, fertilizer, spirits, housing construction material and agricultural implements, agaves have potential for intensive fuel production and for carbon sequestration (García-Mendoza, 2010). One of the wild agaves used to produce mezcal is *Agave potatorum* Zucc, locally called "maguey tobalá" in the Central Valleys of Oaxaca and "maguey papalometl" in the Oaxacan Mixtec region. The

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Received May 15, 2021. Accepted Dec 06, 2022
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mezcal made with this agave is in high demand regionally because of its excellent organoleptic quality conferred by its aromatic and volatile compounds, mostly methanol, acetic acid, and ethyl acetate, and in smaller proportions, esters, ketones, acids, and furans have been identified (Vera-Guzmán et al., 2009). Mezcal producers collect agave stems or "piñas" in wild plantations before the plants can emit flowers and seeds. This limits natural sexual reproduction, and unfortunately, there is no record that *A. potatorum* reproduces asexually. This irrational extraction of wild agave populations has caused a considerable decrease in populations (Ortíz-Hernandez et al., 2018). Since *A. potatorum* grows mainly in the wild and is rarely cultivated, limited information is currently available regarding its agronomic management.

For plants to grow adequately and to obtain good yields, it is necessary to provide macronutrients, such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg), and micronutrients, including iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), molybdenum (Mo), chlorine (Cl), boron (B) and nickel (Ni). When a soil does not provide one of these nutrients in the amount required by the plant, it is necessary to apply fertilizer that contains it (Enríquez del Valle et al., 2016). Nitrogen is the main limiting plant nutrient in most terrestrial ecosystems since plants need it in large amounts (Martínez-Ramírez *et al.*, 2013). It is the principal component of proteins, nucleotides, amides, and amines; it is a structural constituent of cell walls and chlorophyll. It also participates in many metabolic reactions (Alcantar & Trejo, 2012). Phosphorus is the second-most limiting plant nutrient in natural ecosystems or under cultivation. It is a constituent of ATP, nucleic acids, phospholipids, and certain enzymes. It intervenes in the system of energy transfer in the plant. It is also essential for root growth, flowering and fruit and seed formation (Balta-Crisólogo et al., 2015). When the supply of N and P is limited, even when the rest of the nutrients are present in adequate concentrations, the plant exhibits deficient growth, development, and nutrition (Martínez-Ramírez et al., 2013). Because of their unique physiological and anatomic adaptations, *Agave* species can proliferate in regions with little precipitation and low soil fertility (Bautista-Cruz et al., 2007). Previous studies have demonstrated that agave plants respond positively to inorganic fertilization. Variables such as plant height, number of unfolded leaves, plant stem diameter, biomass accumulation, leaf area, number of primary roots, root volume, root dry weight and leaf chlorophyll content have shown the best response (Díaz et al., 2011; Martínez-Ramírez et al., 2012; Martínez-Ramírez et al., 2013; Orea-Lara et al., 2014; Enríquez del Valle et al., 2016). However, scarce information is currently available on the response of *A. potatorum* to N and P fertilization. The objective of this study was to evaluate the effect of applying different doses of N and P on growth, nutrition, and total soluble solid content in *A. potatorum* under nursery conditions. The analysis of sugars in agave stems or "piñas" is important because the alcohol obtained from fermentation depends on the quantity of reducing sugars (Bautista-Cruz & Martínez-Gallegos, 2020).

Material and Methods

The study was conducted in Ocotlán de Morelos (16°48' N, 96°40' W), Oaxaca, Mexico, at an altitude of 1523 m.a.s.l. under nursery conditions. *Agave potatorum* seeds were donated by agave producers in Santa Catarina Minas, Ocotlán, Oaxaca (16°77´ N, 96° 61´W), who obtained seeds from the tallest plants with the largest stem diameter. Seeds were selected manually, eliminating those with signs of mechanical damage or insect attack. The selected seeds were planted in polystyrene germination trays with 200 cavities using Cosmopeat as substrate. The Cosmopeat had the following technical characteristics: fiber classification: fine, vermiculite: fine, pH: 5.5-6.5, electrical conductivity: 0.6-0.8 mmhos cm^{-1}, organic matter content: 68-82%, and ash content: 18-32%. One seed was deposited per cavity and watered every other day. These seeded trays were maintained in a nursery under uncontrolled environmental conditions.

Upon emergence of the first true leaf (45 days after planting), the seedlings were transplanted to 15×15 cm polyethylene bags with 3.7 kg native soil from the area where *A. potatorum* grows wild. Each polyethylene bag had 8 perforations measuring 1 cm in diameter on the periphery of the base to drain excess water. Pots were fertilized with one of four doses of N (0, 23.7, 47.5, and 71.2 mg N per kg soil) (Martínez-Ramírez et al., 2012) and one of four doses of P (0, 14.1, 28.3, and 42.5 mg P per kg soil) (García-Martínez et al., 2020). The N source used was ammonium sulfate (20.5-00-00), and the P source was triple calcium superphosphate (00-46-00). Fertilizers were applied twice: the first application was two weeks after transplant, and the second was six months after transplant. The fertilizer was manually applied around each plant at a depth of 5 cm. During the experiment, the plants were watered weekly; this interval was determined from visual observation of soil moisture loss. The total time of evaluation was 12 months after the transplant. The soil used in the experiment had clay texture, 1.4 g cm^{-3} bulk density, pH 5.5, 1.46 dS m^{-1} electric conductivity, and 3.7% organic matter.

Plant response variables

At the end of the evaluation period, unfolded leaves (UL) were counted. Only ULs were considered since in agave plants, fully developed leaves are completely unfolded. Plant height (PH) was measured with a tape measure on all plants in each treatment. Additionally, half of the plants, i.e., four plants per treatment, were selected at random to determine the following variables. Stem diameter (SD) was measured with a digital Mitutoyo Vernier caliper. For root volume (RV), roots were placed in a 250 mL test tube containing a known volume of water, and the displaced volume was measured. Root density (RD) was obtained from the relationship between root mass and volume. Root length (RL) was determined by selecting the longest root, which was measured with a tape measure. To determine leaf dry weight (LDW), stem dry weight (SDW) and root dry weight (RDW), samples were dried in a Thermolyne Oven, Series 9000, at 65 °C until constant weight and then weighed on a CIVEQ analytical balance. Total soluble solids in the stem (TSS) were measured with a Servovendi^{TM} Model RHB32 ATC portable refractometer. The leaf relative chlorophyll content (LRCC) (i.e., greenness degree) was measured in terms of SPAD (Soil Plant Analysis Development) values using an atLEAF chlorophyll meter. The leaf nitrate content (LNO) was determined with a portable Laquatwin Horiba^{TM} nitrate meter. Leaf P (LP) was quantified by the vanadomolybdate method (Alcantar & Sandoval, 1999).

Statistical Analysis

The experiment was set using a two-factor completely randomized design. Factors N and P were evaluated at four levels each for a total of 16 treatments (Table 1). Each treatment was replicated eight times, with one plant considered a replicate. The data obtained were subjected to a two-way analysis of variance and Tukey's multiple comparison test with a significance level of $P \leq 0.05$. All statistical analyses were performed using statistical SAS v. 9.1 software.

Results

Effect of different doses of nitrogen on Agave potatorum growth

Relative to the control, the highest increase in plant response variables was obtained with the treatments UL 37.3%, LRCC 9.6% and LNO 42.7% with 71.2 mg N per kg soil (Tables 2 and 3); PH 39.1%, SD 17.2%, and LDW 70.2% with 47.5 mg N per kg soil; and LP 78.2% with 23.7 mg N per kg soil (Tables 2 and 3).

Table 1. Fertilization doses used in the experiment.

Treatment (T)	Fertilization doses
T1 (Control, no fertilization)	0 mg N per kg soil + 0 mg P per kg soil
T2	0 mg N per kg soil + 14.1 mg P per kg soil
T3	0 mg N per kg soil + 28.3 mg P per kg soil
T4	0 mg N per kg soil + 42.5 mg P per kg soil
T5	23.7 mg N per kg soil + 0 mg P per kg soil
T6	23.7 mg N per kg soil + 14.1 mg P per kg soil
T7	23.7 mg N per kg soil + 28.3 mg P per kg soil
T8	23.7 mg N per kg soil + 42.5 mg P per kg soil
T9	47.5 mg N per kg soil + 0 mg P per kg soil
T10	47.5 mg N per kg soil + 14.1 mg P per kg soil
T11	47.5 mg N per kg soil + 28.3 mg P per kg soil
T12	47.5 mg N per kg soil + 42.5 mg P per kg soil
T13	71.2 mg N per kg soil + 0 mg P per kg soil
T14	71.2 mg N per kg soil + 14.1 mg P per kg soil
T15	71.2 mg N per kg soil + 28.3 mg P per kg soil
T16	71.2 mg N per kg soil + 42.5 mg P per kg soil

Table 2. Mean ± standard error of the number of unfolded leaves (UL), plant height (PH), root length (RL), stem diameter (SD), leaf dry weight (LDW), stem dry weight (SDW), root dry weight (RDW), root density (RD), and root volume (RV), indicating the response of *Agave potatorum* Zucc to the application of different doses of N and P.

N and P doses (mg nutrient per kg soil)	UL	PH	RL	SD	LDW	SDW	RDW	RD	RV
		----------------- cm ------------------			------------------------ g ------------------			g cm^{-3}	cm^{-3}
N									
0	9.9±0.39b	7.4±0.34c	63.4±7.82a	2.9±0.20b	11.1±1.37b	5.0±0.81a	4.0±0.54a	0.9±0.07a	14.3±1.84a
23.7	12.5±0.38a	9.2±0.37ab	55.9±3.72ab	3.1±0.13ab	16.2±1.68a	5.2±0.52a	4.5±0.43a	0.8±0.02ab	17.5±1.91a
47.5	13.5±0.44a	10.3±0.32a	60.3±4.37ab	3.4±0.14a	18.9±1.59a	5.2±0.40a	4.7±0.43a	0.7±0.01b	18.8±1.95a
71.2	13.6±0.34a	8.9±0.27b	46.0±2.90b	2.9±0.12b	16.0±1.26ab	4.6±0.54b	3.2±0.33a	0.9±0.04ab	12.6±1.62a
P									
0	12.1±0.61a	8.5±0.45a	49.0±3.80a	2.9±0.22a	16.5±1.94a	4.3±0.54a	3.9±0.53a	0.7±0.02b	16.9±2.28a
14.1	12.4±0.50a	9.1±0.42a	54.8±4.17a	3.2±0.13a	15.4±1.60a	5.1±0.41a	4.2±0.38a	0.8±0.03ab	16.2±1.71a
28.3	12.2±0.29a	9.4±0.25a	62.7±6.30a	3.0±0.14a	13.0±1.56a	4.5±0.50a	3.8±0.44a	0.9±0.05a	13.9±1.79a
42.5	12.8±0.42a	8.8±0.32a	59.0±5.96a	3.2±0.13a	17.3±1.20a	6.1±0.73a	4.5±0.46a	0.9±0.06ab	16.2±1.83a

Means with the same letters in each column are not significantly different (Tukey≤0.05).

RV, RL, RD, RDW, SDW and TSS showed no significant responses to nitrogen fertilization (Tables 2 and 3).

Effect of different doses of phosphorus on Agave potatorum growth

Relative to the control, the highest increase in plant response variables was obtained with the treatments RD 28.5% and LRCC 5.5% with 28.3 mg P per kg soil; LP 34.7% and LNO 16.8% with 14.1 mg P per kg soil; and TSS 19.0% with 42.5 mg P per kg soil (Tables 2 and 3).

Effect of the interaction of different doses of nitrogen and phosphorus on Agave potatorum growth

Relative to the control, with the interaction of 0 mg N per kg soil+42.5 mg P per kg soil, SDW,

Table 3. Mean ± standard error of total soluble solids content in the stem (TSS), leaf relative chlorophyll content (LRCC), leaf nitrate (LNO), and leaf P (LP), indicating the response of *Agave potatorum* Zucc to the application of different doses of N and P.

N and P doses (mg nutrient per kg soil)	TSS °Bx	LRCC SPAD values	LNO	LP
			----------------------- mg kg^{-1}	---------------------
N				
0	14.5±1.00ab	56.0±1.22c	205.9±12.68b	10.1±1.27b
23.7	13.1±0.49b	57.6±0.57bc	279.3±15.76a	18.0±1.15a
47.5	15.5±0.92ab	59.9±0.64ab	265.9±10.42a	17.4±2.41a
71.2	16.9±0.80a	61.4±0.53a	293.9±25.59a	11.0±1.07b
P				
0	14.2±0.69b	57.4±0.91b	258.2±16.76b	14.1±1.77b
14.1	14.2±0.67b	57.4±0.79b	301.7±21.73a	19.0±1.49a
28.3	14.8±0.79ab	60.6±0.96a	254.4±18.93b	13.0±1.23bc
42.5	16.9±1.16a	59.5±0.73ab	230.7±13.57b	10.5±1.98c

Means with the same letters in each column are not significantly different (Tukey≤0.05).

Table 4. Mean ± standard error of the number of unfolded leaves (UL), plant height (PH), root length (RL), stem diameter (SD), leaf dry weight (LDW), stem dry weight (SDW), root dry weight (RDW), root density (RD), and root volume (RV), indicating the response of *Agave potatorum* Zucc to a combination of different doses of N and P.

N + P (mg nutrient per kg soil)	UL	PH	RL	SD	LDW	SDW	RDW	RD g cm^{-3}	RV cm^{-3}
		---------------------- cm		--------------------	------------------------- g		-----------------------		
0 + 0	7.7±0.64d	5.2±0.45b	37.1±8.31b	2.2±0.16c	6.5±0.99c	1.4±0.23b	1.6±0.48b	0.7±0.03a	7.7±2.46a
0+14.1	9.8±0.66cd	8.1±0.68ab	50.9±7.02ab	3.7±0.12ab	10.3±1.32abc	5.4±0.63ab	3.7±0.14ab	0.8±0.04a	14.5±0.64a
0+28.3	11.1±0.51abcd	8.6±0.21a	73.1±20.13ab	3.7±0.18ab	8.6±0.39bc	4.6±0.22ab	4.1±0.89ab	1.1±0.19a	14.5±3.22a
0+42.5	10.8±0.76bcd	7.8±0.63ab	92.3±10.44a	4.1±0.32a	19.0±2.13abc	8.7±0.94a	6.5±0.99a	1.0±0.21a	20.5±4.92a
23.7+0	12.8±0.81abc	9.0±0.77a	56.0±9.97ab	3.6±0.24ab	18.8±4.11abc	5.9±0.13ab	5.2±0.21ab	0.8±0.02a	21.2±4.78a
23.7+14.1	11.6±1.03abc	9.3±1.05a	57.2±7.73ab	3.5±0.37ab	13.1±2.87abc	5.2±0.20ab	3.6±0.69ab	0.8±0.05a	12.2±2.49a
23.7+28.3	12.1±0.44abc	8.6±0.58a	63.9±8.00ab	3.7±0.35ab	15.6±4.60abc	4.6±0.24ab	4.6±0.95ab	0.9±a0.06	18.2±4.81a
23.7+42.5	13.7±0.55ab	9.9±0.52a	46.5±1.80ab	4.0±0.14ab	17.4±2.01abc	5.2±0.99ab	4.7±0.69ab	0.8±0.03a	18.5±2.50a
47.5+0	14.6±0.88a	10.8±0.60a	57.1±5.43ab	4.1±0.30a	22.9±2.72a	4.6±0.63ab	4.8±0.17ab	0.7±0.02a	20.2±4.97a
47.5+14.1	13.5±0.98abc	10.6±0.91a	56.7±11.74ab	4.3±0.24a	20.2±4.15ab	5.4±0.99ab	5.5±0.74ab	0.7±0.01a	23.7±3.47a
47.5+28.3	13.2±0.59abc	10.4±0.33a	71.7±10.55ab	3.9±0.20ab	17.7±2.72abc	6.1±0.03ab	4.4±0.87ab	0.7±0.04a	15.2±2.86a
47.5+42.5	12.7±1.06abc	9.2±0.55a	55.7±6.75ab	3.4±0.23abc	14.8±2.52abc	4.9±0.58ab	3.9±0.77ab	0.7±0.03a	16.0±3.93a
71.2+0	13.3±0.96abc	9.1±0.36a	45.8±1.52b	3.6±0.18ab	17.9±0.96abc	5.2±0.55ab	3.8±0.36ab	0.7±0.09a	18.5±3.50a
71.2+14.1	14.7±0.36a	8.1±0.46a	54.4±9.68ab	3.3±0.09abc	18.1±1.90abc	5.5±0.66ab	4.1±0.05ab	1.0±0.07a	14.5±3.72a
71.2+28.3	12.6±0.65abc	9.8±0.51a	42.3±3.49b	2.9±0.17bc	10.1±1.04abc	2.7±0.67b	2.0±0.17b	1.0±0.07a	7.6±1.62a
71.2+42.5	14.0±0.56ab	8.2±0.73ab	41.4±5.01b	3.7±0.27ab	18.0±3.27abc	5.8±0.68ab	3.0±0.14ab	0.9±0.06a	10.0±0.81a

Means with the same letters in each column are not significantly different (Tukey≤0.05).

RDW, RL and SD increased by 521.4%, 306.2%, 148.7% and 86.3%, respectively (Table 4). With 47.5 mg N per kg soil+0 mg P per kg soil, increases of 252.3% for LDW, 107.6% for PH and 89.6% for UL were obtained (Table 4). With 47.5 mg N per kg soil+14.1 mg P per kg soil, SD increased 95.4%, PH 103.8% and LP 84.1% (Tables 4 and 5). With 47.5 mg N per kg soil+28.3 mg P per kg soil, PH increased 100.0% (Table 4). With 47.5 mg N per kg soil+42.5 mg P per kg soil, TSS increased 77.4% (Table 5). With 71.2 mg N per kg soil+14.1 mg P per kg soil, LNO increased 112.6% and UL 90.9% (Tables 4 and 5). LRCC increased by 18.0% and 17.6% with 71.2 mg N per kg soil+28.3 mg P per kg soil and 47.5 mg N per kg soil+42.5 mg P per kg soil, respectively (Table 5).

Discussion

Nitrogen fertilization favored the UL, LRCC, PH, SD, LDW, LP and LNO contents in *A. potatorum*. Similar results were reported by Sánchez-Mendoza et al. (2020), who indicated that *A. angustifolia* plants fertilized for 12 months with Multigro 6® fertilizer (21–14–10 NPK + 2 MgO) increased in leaf fresh weight, stem fresh weight and SD. In the same manner, UL increased in *A. cocui* Trelease plants with the addition of 0.5 g NH_4NO_3 per plant (Díaz et al., 2011). Previous studies have also reported an increase in SD when *A. duranguensis* Gentry plants were fertilized with 0.02 kg N ha^{-1} (Orea-Lara et al., 2014). Martínez-Ramírez et al. (2013) found an increase in dry biomass accumulation in *A. potatorum* and *A. angustifolia* with 30-20-15, 60-40-30, and 90-60-45 kg N-P-K ha^{-1}. Zúñiga-Estrada et al. (2018) reported an increase in PH and UL in plants of *A. tequilana* fertirrigated with 0.0796 g L^{-1} N, 0.0454 g L^{-1} P2O5, 0.0892 g L^{-1} K2O, 0.0280 g L^{-1} CaO and 0.0224 g L^{-1} MgO. García-Martínez et al. (2020) reported increases of 13.2, 34.9, 36.1, and 21.5% in PH, leaf fresh weight, stem fresh weight and SD, respectively, in *A. potatorum* plants fertilized with 43.5 mg P kg^{-1}. Contrasting the results of the present study, Martínez-Ramírez et al. (2012) did not find significant differences in UL, PH or SD in *A. potatorum* plants fertilized with 50, 100 and 150 kg N ha^{-1}

Table 5. Mean ± standard error of total soluble solids content (TSS) in the stem, leaf relative chlorophyll content (LRCC), leaf nitrate (LNO), and leaf P (LP), indicating the response of *Agave potatorum* Zucc to a combination of different doses of N and P.

N + P (mg nutrient per kg soil)	TSS °Bx	LRCC SPAD values	LNO	LP
			------------------mg kg^{-1}------------------	
0 + 0	11.1±1.01c	53.7±1.35b	195.5±16.86cd	14.5±1.50bcd
0+14.1	13.0±1.34abc	53.7±1.38b	232.5±11.15bcd	15.0±0.70bcd
0+28.3	15.0±1.77abc	59.6±1.80ab	155.7±16.15d	6.7±0.47efg
0+42.5	18.9±1.66ab	57.0±3.87ab	240.0±32.39bcd	4.5±0.86fg
23.7+0	15.9±0.56abc	56.7±1.02ab	246.0±24.24bcd	15.0±1.41bcd
23.7+14.1	12.9±0.64abc	56.4±0.21ab	282.2±34.56bc	21.7±1.03ab
23.7+28.3	11.7±0.59c	59.3±1.22ab	343.5±17.95ab	15.7±2.13bcd
23.7+42.5	12.0±0.35bc	57.9±1.55ab	245.7±27.28bcd	19.7±2.92abc
47.5+0	13.4±0.68abc	57.2±0.45ab	247.5±21.43bcd	22.0±3.10ab
47.5+14.1	13.6±1.12abc	59.2±0.92ab	276.5±35.31bc	26.7±0.85a
47.5+28.3	15.4±1.11abc	60.2±1.02ab	286.7±10.81bc	18.0±0.70bcd
47.5+42.5	19.7±2.35a	63.2±0.05a	253.0±0.00bcd	3.0±0.40g
71.2+0	16.3±1.35abc	62.0±1.35a	344.0±21.00ab	5.0±0.70efg
71.2+14.1	17.2±1.20abc	60.3±0.98ab	415.7±24.82a	12.5±0.64cde
71.2+28.3	17.3±1.66abc	63.4±0.38a	231.7±7.55bcd	11.5±0.64def
71.2+42.5	16.9±2.57abc	59.9±0.33ab	185.2±30.07cd	15.0±1.87bcd

Means with the same letters in each column are not significantly different (Tukey≤0.05).

under field conditions. Enríquez del Valle *et al.* (2009) reported that young *A. angustifolia* plants that grew 6 months in a nursery, during which different quantities of mineral (50 and 100% Steiner solution) or organic nutrients were available, had higher leaf contents of N and P than plants that were not fertilized. These results coincide with ours: leaf nitrate and P contents in *A. potatorum* improved with nitrogen fertilization. De la Torre-Ruiz et al. (2016) stated that plant nutrition, especially N content, affects agave plant productivity. The positive effect of N on plant growth is possibly due to a greater availability of N in the root zone because of fertilizer application. This nutrient intervenes in the synthesis of vitamins, amino acids, and some plant hormones (such as auxins, gibberellins and cytokinins), which stimulate cell elongation and division (Allahdadi & Raei, 2017). Kumar et al. (2021) indicated that N is an essential nutrient for plant growth, as it is required for the synthesis of starch in leaves, production of amino acids for protein synthesis, and thus yield of the crop. De la Torre-Ruiz et al. (2016) and Pereira et al. (2019) considered N to be the element with the greatest effect on the growth and metabolism of agave and CAM plants. The positive response in terms of the LRCC increase in *A. potatorum* is likely due to the greater N availability from the application of ammonium sulfate. Nitrogen fertilization promotes a higher content of leaf chlorophyll, as was found in maize (Rincón-Castillo & Ligarreto, 2010), oregano **(***Origanum vulgare* L.) (Calderón-Medellín *et al.,* 2011) and guava **(***Psidium guajava* L.) (Rodríguez-Larramendi *et al***.,** 2021). Bassi et al. (2018) mentioned that the amount of N applied favors the synthesis of chlorophyll, proteins, enzymatic activity and sugar content in the plant.

The increase in LP content can be attributed to an acidification process in the rhizosphere. Fertilizers such as ammonium sulfate release acidifying hydrogen ions when ammonium is transformed to nitrate by microorganisms (Domenech & Peral, 2006), and this acidification process promotes the solubilization of phosphorus (Beltrán, 2014). Studies that have evaluated the effect of phosphorus fertilization on agave growth are scarce. Like our study, Mota-Fernández et al. (2011) assessed three concentrations of P (0.3, 0.6 and 0.9 mM) on *Aloe vera* growth; they did not find significant differences in PH, UL, or plant dry weight. However, at a concentration of 0.6 mM, they obtained a higher plant fresh weight. The increase in the TSS content with the application of P is most likely because this element forms part of molecules, such as adenosine triphosphate, guanine triphosphate and cytosine triphosphate, which are required for the synthesis of sugars in the photosynthesis process, phospholipids, and ribonucleic acids (Stigter & Plaxton, 2015).

The N+P interaction increased SDW, RDW, RL, LDW, PH, SD, LP, TSS, LNO, UL and LRCC in *A. potatorum*. Similar results were reported by Garnica-García et al. (2020) in nursery *A. angustifolia* plants. In this case, the agave plants increased their values of PH, SD, UL, LDW and SDW when they were irrigated with Steiner solution (12 meq L^{-1} NO_3^-, 1 meq L^{-1} $H_3PO_4^-$, 7 meq L^{-1} SO_4^{2-}, 9 meq L^{-1} Ca^{2+}, and 4 meq L^{-1} Mg^{2+}).

Previous studies have also demonstrated that the application of nitrogen and phosphorus fertilizers, alone or in combination, significantly increases plant stem growth (Oskarsson et al.*,* 2006).

Likewise, Razaq et al. (2017) reported an increase in *Acer mono* PH after the simultaneous application of 10 g N + 8 g P. Akpojotor et al. (2019) also reported that the combined application of N and P favored PH in *Helianthus annuus*. Firew et al. (2016) indicated that PH in potato plants increased with the application of 168 kg N ha^{-1} + 138 kg P ha^{-1}. Opposite results were reported by Umeri et al. (2016), with no significant differences in PH or leaf number in maize when N and P were applied in combination. Wen et al. (2016) found that the combined application of N and P increased grain yield and RL in maize. These findings are consistent with our results for RL and RD.

Conclusions

The application of N and P to soil favors growth, nutrition, and TSS in *A. potatorum*. Therefore, this could be a key element in the agronomic management of this agave species under nursery conditions. However, further field research is required to confirm the response of *A. potatorum* to N and P fertilization.

Resumen

S. Sánchez-Mendoza, G. Bautista-Aparicio, y A. Bautista-Cruz. 2022. La fertilización inorgánica mejora el crecimiento y la nutrición de *Agave potatorum* Zucc. Int. J. Agric. Nat. Resour. 147-156. *Agave potatorum* Zucc es un agave silvestre usado para la producción de mezcal (una bebida alcohólica tradicional) en Oaxaca, México, sin embargo, la información disponible sobre su respuesta a la fertilización nitrogenada y fosforada es escasa. El efecto de diferentes dosis de N (0, 23.7, 47.5, y 71.2 mg N por kg de suelo) y P (0, 14.1, 28.3, y 42.5 mg P por kg de suelo) sobre el crecimiento, nutrición y contenido de sólidos solubles totales en el tallo (TSS) de *A. potatorum* en condiciones de vivero fue evaluado utilizando un diseño bifactorial completamente al azar. Con respecto al control, el mayor incremento en las variables respuesta fue: número de hojas desplegadas (UL) 37.3%, contenido relativo de clorofila (LRCC) 9.6%, contenido foliar de nitrato (LNO) 42.7% con 71.2 mg N por kg de suelo; altura de planta (PH) 39.1%, diámetro de tallo (SD) 17.2%, peso seco de hojas (LDW) 70.2% con 47.5 mg N por kg de suelo; contenido foliar de P (LP) 78.2% con 23.7 mg N por kg de suelo; densidad radicular (RD) 28.5%, LRCC 5.5% con 28.3 mg P por kg de suelo; LP 34.7%, LNO 16.8% con 14.1 mg P por kg de suelo; TSS 19.0% con 42.5 mg P por kg de suelo. La aplicación combinada de N y P también mejoró el peso seco del tallo, el peso seco de raíces, la longitud radicular, SD, LDW, PH, UL, LP, TSS, LNO y LCRR. La aplicación de N y P favorece el crecimiento, nutrición y el TSS en *A. potatorum*, por lo que, podría ser una importante alternativa para el manejo agronómico de este agave en condiciones de vivero. Es recomendable realizar investigaciones en campo para evaluar la respuesta de *A. potatorum* a la fertilización nitrogenada y fosforada.

Palabras clave: Agave, crecimiento vegetal, fertilización fosforada, fertilización nitrogenada, nutrición vegetal.

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