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Research article

Promotor del crecimiento mejora calidad y reduce permanencia en vivero de *Acacia mangium* Willd.

Growth promoter in *Acacia mangium* Willd. improves quality and reduces permanence in nursery

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Abstract

Increasing the quality of seedlings in the nursery, reducing the permanence time and obtaining material that guarantees greater survival in the field is a concern of foresters today. Therefore, the objective of the research was to evaluate the effect of foliar application of a promoter based on amino acids on the growth, quality and residence time in the nursery of *Acacia mangium*. An experiment was established in a completely randomized design with four weekly foliar treatments: VA1 (1.2 mL L^{-1}), VA2 (1.5 mL L^{-1}), VA3 (1.8 mL L^{-1}) and VA0(0). At 90 and 120 days after sowing (das), attributes and morphological indices of quality and growth rates were evaluated. It was found that the foliar application of VIUSID Agro® improved the morphological characteristics with the VA1 dose because, among other variables, it surpassed the control in the length of the plants by 65 and 54 %, while in the active growth rate the increases were 65 %. The morphological indices benefited mainly from the VA1 dose (1.2 mL L^{-1}) where the Dickson index reached the average quality of 0.22 at 120 das with VA1. Findings suggest that the foliar application of the amino acid-based growth promoter improves morphological characteristics, growth rates and plays an important role in reducing the permanence of *A. mangium* seedlings in the nursery to a minimum time of 120 das when using the 1.2 mL L^{-1} dose.

Key words: *Acacia mangium* Willd., amino acids, foliar fertilization, growth rates, VIUSID Agro®, forest nurseries.

Resumen

Aumentar la calidad de las plántulas en el vivero, disminuir el tiempo de permanencia y obtener material que garantice mayor supervivencia en campo es preocupación de los forestales, en la actualidad. Por lo que el objetivo de la investigación fue evaluar el efecto de la aplicación foliar de un promotor a base de aminoácidos en el crecimiento, calidad y tiempo de permanencia en vivero de *Acacia mangium*. Se estableció un experimento en un diseño completamente aleatorizado, con cuatro tratamientos foliares semanales: VA1 (1.2 mL L^{-1}), VA2 (1.5 mL L^{-1}), VA3 (1.8 mL L^{-1}) y VA0 (0). A los 90 y 120 días de la siembra (dds) se evaluaron atributos e índices morfológicos de calidad y las tasas de crecimiento. La aplicación foliar de *VIUSID Agro*® mejoraron las características morfológicas con la dosis VA1 pues entre otras variables, superó al control en la longitud de las plantas en 65 y 54 %, mientras que en la tasa activa de crecimiento los incrementos fueron de 65 %. Principalmente, con la dosis VA1 (1.2 mL L^{-1}) el Índice de *Dickson* alcanzó la calidad media de 0.22 a 120 dds. Los hallazgos sugieren que la aplicación foliar del promotor del crecimiento a base de aminoácidos mejora las características morfológicas, las tasas de crecimiento y desempeña un rol importante en la reducción de la permanencia de plántulas de *A. mangium* en vivero, a un tiempo mínimo de 120 dds cuando se usa la dosis de 1.2 mL L^{-1}.

Palabras clave: *Acacia mangium* Willd., aminoácidos, fertilización foliar, tasas de crecimiento, *VIUSID Agro*®, viveros forestales.

Introduction

Acacia mangium Willd. is a fast-growing and high-economic value species, widely used in reforestation worldwide. Its cultivation not only helps the recovery of forested areas, but also has a positive impact on silvopastoral and agroforestry systems (Reid *et al.*, 2024). In addition, *A. mangium* acts as a nitrogen-fixing plant, which improves soil quality and favors the growth of other plant species (Oliveira *et al.*, 2021; Nirsatmanto *et al.*, 2022). In this context, increasing plantations of this species becomes a key objective for the Cuban forest sector, given its high potential for use and its ability to contribute to the economic and environmental development of the country (Pérez *et al.*, 2017).

However, despite being a viable alternative for plantations in several provinces of Cuba, due to its adequate morphometric characteristics (straightness of the stem, characteristics of the crown, diameter) (Pérez *et al.*, 2017; Pérez *et al.*, 2019), it has been observed that the seedlings of this species usually remain in the nursery for between four and six months and do not reach the necessary quality, which affects their survival in the field.

One option to improve the growth and quality of the seedlings, as well as reduce their stay in the nursery, may be the use of growth promoters based on amino acids. It is known that these substances applied foliarly, alone or in combination, stimulate plant growth through the stabilization of processes such as photosynthesis, transpiration and stomatal conductance. In addition, they work as protein molecules, energy sources and chemical messengers (Peña *et al.*, 2022; Kawade *et al.*, 2023).

In this sense, it is known that in fruit trees the joint foliar application of glycine and tryptophan resulted in notable increases in shoot length and diameter, leaf area, total chlorophyll, as well as nitrogen assimilation (Mataffo *et al.*, 2020; Mosa *et al.*, 2021). On the other hand, amino acids applied in the nursery phase provide benefits in the quality of seedlings by preparing them for transplantation (Ozyhar *et al.*, 2019).

In forest species, the effect of this amino acid-based growth promoter has not been determined; there are only records of its use in agroforestry systems in crops such as coffee (*Coffea arabica* L.) (Posada-Pérez *et al.*, 2021; Bustamante-González *et al.*, 2023; Díaz *et al.*, 2023), in which foliar applications improved the morphological response of the crop.

Based on the above, the objective of this research was to evaluate the effect of foliar application of the commercial product VIUSID Agro® on the growth, quality and time spent in the nursery of *A. mangium* seedlings, under the following hypotheses: The application of amino acids increases the quality of *A. mangium* seedlings grown under controlled conditions, improves their morphological characteristics, increases growth rates and reduces the time spent in the nursery.

Materials and Methods

Experimental conditions and plant material

The research was developed under homogeneous semi-controlled conditions for the entire experimental area (substrate homogeneity, irrigation interval, weed and pest control, location of the experiment in relation to lighting and wind) in the *Espinal* nursery located in the *Santo Domingo* municipality, *Villa Clara* province, *Cuba*, located between 22°39'31.648" N and -80°17'48.527" W, at an altitude of 50 m. The nursery is of the permanent type with a production capacity of 198 000 seedlings in rigid plastic containers.

The seeds were obtained from the seed processing plant with registered origin from the seed mass of *Gabilanes*, *Coralillo* municipality. According to the Cuban Sampling Standards (GOC-2020 526-057), the lots had 96 % purity, 87 % germination (pre-germination treatment) and 65 000 seeds per kg. The dormancy was broken by scarification, according to the methodology used by Khurana and Singh (2001) and sown in a substrate with 50 % soil and 50 % organic matter, made from sheep and cattle manure and worm humus, with a humidity of 38.5 %, total organic Carbon (TOC) 25.3 %, total Nitrogen (TN) 17.7 g^{-1} kg^{-1}, Ammonium (NH_4^+)) 889 mg^{-1} kg^{-1} and Nitrate (NO_3^-) 520 mg^{-1} kg^{-1}.

Sowing was carried out on April 4th, 2023 at a rate of two seeds per tube (capacity: 280 cm^3, height: 173 mm); when the seedlings reached five cm in length, only one was left. The length of the trays with respect to the ground was 1.20 m and the shade control was through a *sarán* (60 % luminosity). Weed control was manual and daily irrigation was by sprinkling up to field capacity.

The data of the climatic variables were recorded daily with a model 30.3039.IT TFA® Thermohygrometer. The precipitation during the experimental phase was 59.29 mm, the average temperature was 31.81 °C and the relative humidity was 76.50 %.

Product characteristics and experimental design

The commercial product VIUSID Agro® (VA) was used as a source of amino acids. The amino acids present in the solution were Aspartic acid (1.6 %), Arginine (2.4 %), Glycine (2.5 %) and Tryptophan (0.5 %). Three concentrations of VA were evaluated: VA1 (1.2 mL L^{-1}), VA2 (1.5 mL L^{-1}), VA3 (1.8 mL L^{-1}) and a control (without application) VA0 (0). The pH of the solution was adjusted to 5.7±0.2, with hydrochloric acid (HCl) or sodium hydroxide (NaOH) solution, both at 1.0 mol L^{-1}. To determine the concentrations, the manufacturer's recommendations, experiences in coffee cultivation (Bustamante-González *et al.*, 2023; Díaz *et al.*, 2023) and the authors' experiences were taken into account.

The experimental design was completely randomized (Equation 1) with four treatments and three replications. 15 seedlings were randomly marked and evaluated in the central or calculation area of the tray, for a total of 45 seedlings per treatment and 180 for the entire experiment.

$$Y_{ij} = m + t_i + e_{ij} \qquad (1)$$

Where:

Y_{ij} = Observed value

m = Mean

t_i = Effect of the i^{-th} treatment

e_{ij} = Random variation of the $i^{\text{-th}}$ treatment and the $i^{\text{-th}}$ observation of the replication (experimental error)

Description of applications

The applications were made in the morning hours with a calibrated 16-liter capacity backpack sprayer, taking into account possible wind drift and relative humidity above 60 %. The interval was seven days from May 4th, 2023 to July 27th of that same year.

Variables evaluated

The variables were evaluated at 90 and 120 days after sowing (das). Growth in length (cm) was measured from the root collar to the apex using a 1 500×30 mm stainless steel graduated ruler (7647511500 Format®). Root collar diameter (*RCD*) (mm) was measured at the junction point between stem and root using a model ACC115-006-11 Digite® brand digital caliper, with an accuracy of ±0.03 mm. Leaf area was calculated using the dimensional method described by Peña *et al.* (2018a) in which the following formulas were used:

$$AF = l \times a \times f \qquad (2)$$

$$f = Ah(l \times a) \qquad (3)$$

$$Ah = (Ar \times Bcl)Brc \qquad (4)$$

Where:

AF = Leaf area

l = Leaf length

a = Leaf width

f = Factor

Ah = Leaf blade area

Ar = Paper rectangle area

Bcl = Leaf blade contour biomass

Brc = Rectangle biomass

The seedlings segmented into their organs were washed to remove residues with a 0.2 % detergent solution, 0.1 % hydrochloric acid solution and distilled water (de Lima *et al.*, 2018). Root volume (cm^3) was determined by the water displacement method (Harrington *et al.*, 1994). On the other hand, the fresh biomass (g) of the seedlings segmented into their organs was determined with a model BS 124S

Sartorius® digital scale, with an accuracy of ±0.01 g. Fresh seedlings were placed in separate, labeled bags and placed in a model YRO5229-2 Kalstein® oven at 65 °C until constant biomass was obtained at 96 hours.

The following formula was used to determine the ratio (R) between the dry biomass of the aerial part (AP) and the dry biomass of the root part (RP).

$$R = \frac{AP}{RP} \qquad (5)$$

In addition, morphological indices were calculated as described below.

Robustness or slenderness index (RI):

$$RI = \frac{Total\ length\ (cm)}{RCD\ (mm)} \qquad (6)$$

Lignification index (LI):

$$LI = \left(\frac{\text{Total dry biomass of the seedling (g)}}{\text{Total fresh biomass of the seedling (g)}}\right)100 \qquad (7)$$

Dickson quality index (QI):

$$QI = \frac{Total\ dry\ biomass\ of\ the\ seedling\ (g)}{\frac{Total\ length\ (cm)}{RCD\ (mm)} + \frac{Dry\ aboveground\ biomass\ (g)}{Dry\ root\ biomass\ (g)}} \qquad (8)$$

Where:

RCD = Root collar diameter

To calculate the growth indices (Table 1) two evaluations were carried out, at 90 and 120 days, the methodology of Hunt (1990) was used.

Table 1. Growth rate and indices in plants

Growth rate and indices	Formulas	Units
Absolute growth rate (*AGR*)	$AGR = \frac{W2 - W1}{t2 - t1}$	g^{-1} day^{-1}
Net assimilation rate (*NAR*)	$NAR = \frac{2(W2 - W1)}{(AF2 + AF1)(t2 - t1)}$	g^{-1} cm^{-2} day^{-1}
Relative growth rate (*RGR*)	$RGR = \frac{2(W2 - W1)}{(W2 + W1)(t2 - t1)}$	mg^{-1} g^{-1} day^{-1}
Crop growth rate (*CGR*)	$CGR = \frac{1}{As} \frac{W2 - W1}{t2 - t1}$	g^{-1} cm^{-2} day^{-1}
Leaf area ratio (*LAR*)	$LAR = ½ \frac{AF1}{W1} + \frac{AF2}{W2}$	cm^{-2} g^{-1}
Leaf area duration (*LAD*)	$LAD = \frac{(IAF1 + IAF2)(t2 - t1)}{2}$	cm^{-2} day^{-1}
Leaf efficiency index (*LEI*)	$LEI = \frac{Wc}{AF}$	
Leaf area index (*LAI*)	$LAI = \frac{AF2 - AF1}{As}$	

W1 = Dry biomass at 90 das; *W2* = Dry biomass at 120 das; *t1* = Initial time; *t2* = Final time; *LF* = Leaf area; *As* = Area of the substrate occupied by the plant in its tube (cm^2); Wc = Leaf dry biomass (g).

Seedling quality classification

A seedling quality classification was carried out according to Rueda-Sánchez *et al.* (2014) for tropical broadleaf species (Table 2).

Table 2. Plant quality intervals (broadleaf) for morphological attributes.

Variable	Quality		
	Low "B"	**Medium "M"**	**High "A"**
Length (cm)	<12.0	12.0-14.9	≥15.0
Diameter (mm)	<2.5	2.5-4.9	≥5.0
Robustness index (slenderness)	≥8.0	7.9-6.0	<6.0
AP/RP relation	≥2.5	2.4-2.0	<2.0
Dickson index	<0.2	0.2-0.4	≥0.5
Lignification index	<10.0	10.0-11.3	≥11.4

AP = Dry biomass of the aerial part; RP = Dry biomass root.

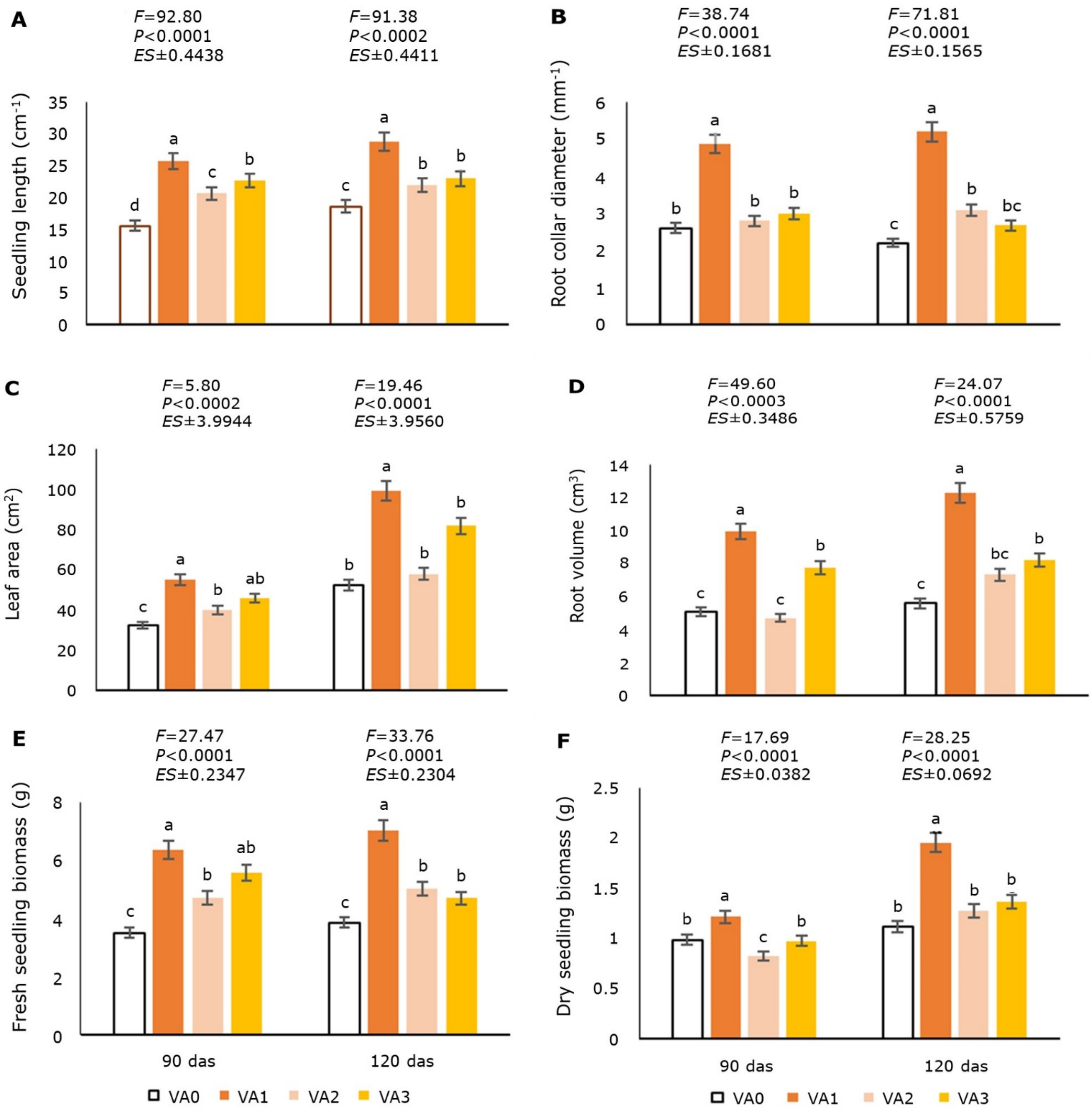
Data analysis

The data were processed with the AgroEstat statistical package (Barbosa and Maldonado, 2015) independently for each evaluation (90-120 das). For normality, the Kolmogorov-Smirnov test (Stephens, 1992) was performed and the Levene test (Correa *et al.*, 2006) for homogeneity of variance. Normality and homogeneity were checked, therefore, a one-way analysis of variance (ANOVA) and the Tukey multiple range test ($P<0.05$) were performed.

Results and Discussion

Effect of treatments on growth variables

With the VA1 treatment, greater seedling length was obtained for both dates (90 and 120 das) with significant differences with respect to the other treatments and an increase of 65 and 54 % compared to VA0. VA2 and VA3 treatments also differed from each other and exceeded the control (VA0) at 90 das by 33 and 46 %, respectively. At 120 das, the increases relative to the control were 18 % with VA2 and 24 % with VA3 (Figure 1A).



A = Seedling length; B = Root collar diameter; C = Leaf area; D = Root volume; E = Seedling fresh biomass; F = Dry biomass of *Acacia mangium* Willd. seedlings. Uneven letters indicate significant differences within each independent time point (90 and 120 das), according to Tukey's multiple range test (P<0.05).

Figure 1. Effect of treatments on growth variables.

Regarding root collar diameter (Figure 1B), it was observed that seedlings treated with the VA1 dose (1.2 mL L^{-1}) were significantly superior to the control by 87 %. In the first evaluation, no significant differences were found between the control and the VA2 and VA3 doses. However, at 120 das, the least favorable response was detected in the VA0 treatment seedlings.

Regarding leaf area, at 90 das all treatments with the amino acid solution significantly exceeded VA0. The increases compared to the latter were 71 % with VA1, 24 % with VA2 and 42 % with VA3. While at 120 das, the VA2 and VA3 treatments did not differ from the control; VA1 had an increase of 16 % compared to the control (Figure 1C).

On the other hand, in root volume (Figure 1D), the treatment with the best response was VA1 at 90 das and this behavior was maintained until 120 das with increases in relation to the control of 4.84 and 6.67 cm^3. The VA3 treatment also showed a stimulating effect on root volume with respect to VA0 with increases of 2.64 and 2.63 cm^3; however, VA2 did not cause any response in this variable.

In the fresh biomass of the plants (Figure 1E), in both evaluations the most favorable response was achieved with the VA1 dose with increases in relation to the control of 82 %. The rest of the treatments with the product also differed significantly from the VA0 control and exceeded it by 35 and 59 %, respectively.

In terms of dry biomass, the response was similar, as the VA1 treatment exceeded VA0 by 23 % at 90 das and by 77 % at 120 das. However, VA3 did not differ significantly from the control in any of the evaluations. The VA2 and VA3 doses had the least favorable response, with no differences in relation to the control in the last evaluation (Figure 1F).

These results show that the foliar application of the amino acid combination impacted variables such as seedling length, root collar diameter, dry biomass accumulation, and root volume. With the lowest dose (VA1), adequate mean values were obtained in these variables for transplanting at 90 das (Rueda-Sánchez *et al.*,

2014) (Table 2). These reactions are important considering that diameter is a better predictor than length in terms of field survival, while a greater root volume will enable seedlings to achieve greater fixation and water absorption, which benefits their post-transplant establishment (Morris *et al.*, 2020).

This response is attributed to the effect of the growth promoter, which provides amino acids, which have been associated with antioxidant and growth-stimulating effects, both under normal conditions and under abiotic stresses such as salinity and drought (Sabagh *et al.*, 2019). For example, Glycine, when applied independently or in combination with Tryptophan, plays a fundamental role in the formation of total chlorophylls and vegetative growth (Souri and Hatamian, 2019). Furthermore, foliar-applied amino acids improve crop yield and quality and increase root volume, which is associated with better nutrient absorption and increased growth (Souri and Hatamian, 2019; Mosa *et al.*, 2021).

No data were found on the use of foliar application of this amino acid-based solution in forest species. Applications in coffee improve germination, initial seedling growth, and the acclimatization phase (Posada-Pérez *et al.*, 2021; Bustamante-González *et al.*, 2023; Díaz *et al.*, 2023).

On the other hand, in agricultural crops, such as radish (*Raphanus sativus* L.) and tobacco (*Nicotiana tabacum* L.) in which this growth promoter has been widely used, it led to increases in the number of leaves, fresh and dry biomass of seedlings, root length and leaf area (Peña *et al.*, 2018a; 2018b).

Effect of treatments on physiological rates

Treatments with the amino acid solution generated increases in the dry biomass of seedlings per unit of time. Significant increases were observed in the Absolute growth rate (*AGR*) compared to the control of 65 % for VA1, 45 % for VA2 and 22 % for VA3. Regarding the Net assimilation rate (*NAR*), treatments with lower doses exceeded VA0, with increases of 52 % with VA1 and 58 % with VA2 (Table 3). The response of the seedlings in this variable triggered a greater photosynthetic efficiency in treatments VA1 and VA2, as well as a greater increase in dry matter per unit of leaf area in a unit of time. Amino acids, when applied in combination, promote stability in the production of pigments and in the functioning of photosystem II, which generates greater efficiency of photosynthesis and stomatal conductance in the vegetative phase of plants (Peña *et al.*, 2022).

Table 3. Effect of treatments on the indices and growth rates of *Acacia mangium* Willd. seedlings.

Treatments	***AGR*** **(g^{-1} day^{-1})**	***NAR*** **(g^{-1} cm^{-2} day^{-1})**	***RGR*** **(mg^{-1} g^{-1} day^{-1})**	***CGR*** **(g^{-1} cm^{-2} day^{-1})**
VA0	0.01029 c	0.00019 b	0.00983 c	0.00009 c
VA1	0.01760 a	0.00029 a	0.01524 a	0.00017 a
VA2	0.01487 b	0.00030 a	0.01427 a	0.00010 b
VA3	0.01256 b	0.00020 b	0.01054 b	0.00011 b
F=	46.46	19.87	85.97	46.46
P<	0.0001	0.0001	0.0001	0.0001
ES	0.0012	0.00002	0.0006	0.000008
Treatments	*LAR* (cm^{-2} g^{-1})	*LAD* (cm^{-2} day^{-1})	*LEI*	*LAI*
VA0	49.663 b	4.4287 b	0.004783 b	0.2952 b
VA1	45.439 a	8.1935 a	0.007189 a	0.5462 a

VA2	45.005 a	5.2592 b	0.006790 a	0.3006 b
VA3	45.214 a	7.0415 a	0.005339 b	0.4694 a
F=	9.91	12.14	59.46	13.14
P<	0.0001	0.0001	0.0001	0.0001
ES	2.0222	0.4698	0.0001	0.0313

AGR = Absolute growth rate; *NAR* = Net assimilation rate; *RGR* = Relative growth rate; *CGR* = Crop growth rate; *LAR* = Leaf area ratio; *LAD* = Leaf area duration; *LEI* = Leaf efficiency index; *LAI* = Leaf area index. Unequal letters in the same column indicate significant differences within each variable, according to Tukey's multiple range test ($P<0.05$).

In the Relative growth rate (*RGR*) the response was favorable with the VA1 and VA2 treatments, which differed from VA0 by 55 and 45 %, respectively. The VA3 treatment also surpassed control by 7 %. This means that the seedlings treated with amino acids had a greater gain in dry biomass per unit of time.

In the Crop growth rate (*CGR*), the VA1 treatment stood out over the other treatments with an accumulation of 0.00007 (g^{-1} cm^{-2} day^{-1}) more than VA2 and 0.0006 more than VA3 with increases of 88 % with respect to control (Table 3). This result demonstrates that there was a greater increase in dry biomass per unit area in the evaluated time interval when the combination of amino acids was applied.

Regarding the Leaf area ratio (*LAR*), it was observed that VA0 reached a value of 49.663 (cm^{-2} g^{-1}) with significant differences in contrast to the other treatments. This means that seedlings treated with any of the options need between 9 and 10 % less area to produce a unit of biomass compared to VA0 (Table 3). On the other hand, the Leaf area duration (*LAD*) was significantly greater in the treatments with the amino acid solution, except with VA2 which did not differ from the control. A longer Leaf area duration implies a greater use of solar radiation over time. In the Leaf efficiency index (*LEI*), VA3 did not provide significant benefits, while VA1 and

VA2 surpassed VA0 by 50 and 42 %, respectively. In the Leaf area index (*LAI*), VA1 and VA3 were the best responders (Table 3).

These responses are associated with the foliar application of the amino acid solution, which in forest nurseries improves seedling growth rates through a greater accumulation of dry biomass per unit of time (Ozyhar *et al.*, 2019). Previous research in herbaceous plants has shown that weekly application of this product results in increases in growth rates and dry biomass accumulation (Peña *et al.*, 2018a; 2018b).

Effect of treatments on morphological variables

In the Robustness index (*RI*), the best response was observed with the VA1 treatment, with differences with respect to VA0, with increases of 16 and 54 % at 90 and 120 das, respectively. On the other hand, in the AP/RP ratio (Dry biomass of the aerial part to dry root biomass ratio), no differences were observed between the treatments (Table 4).

Table 4. Effect of treatments on morphological indices of *Acacia mangium* Willd. seedlings.

	First assessment 90 (das)			
Treataments	***H/D***	**AP/RP**	***QI***	***IL***
VA0	6.18 b	2.15 a	0.12 b	29.05 a
VA1	5.32 a	1.85 a	0.17 a	19.83 b
VA2	7.72 bc	1.88 a	0.08 c	17.59 b
VA3	8.01 c	2.15 a	0.10 bc	17.90 b
F=	10.45	1.95	28.10	17.75

P<	0.0001	0.1327	0.0001	0.0001
ES	0.3946	0.1181	0.0067	1.2805
Second assessment 120 (das)				
Treatments	*H/D*	AP/RP	*QI*	*IL*
VA0	8.64 bc	1.99 b	0.10 b	28.84 a
VA1	5.62 a	3.27 a	0.22 a	27.78 ab
VA2	7.32 b	2.30 b	0.14 b	25.28 b
VA3	9.15 c	2.19 b	0.12 b	29.04 a
F=	15.42	23.23	33.79	5.65
P<	0.0001	0.0011	0.0003	0.0019
ES	0.4014	0.1174	0.0087	0.7271

H/D = Robustness index; AP/RP = Dry biomass of the aerial part to dry root biomass ratio; *QI* = Dickson index; *LI* = Lignification index. Uneven letters in the same column indicate significant differences within each variable, according to the Tukey multiple range test ($P<0.05$).

The Dickson quality index values are below the average quality (Rueda-Sánchez *et al.*, 2014) with all treatments except with the VA1 treatment at 120 das, since it is located within the range established as average quality (0.2-0.4). The best response in the Lignification index (*IL*) was at 120 das, although no differences were identified in relation to control (Table 4).

It was observed that the length of seedlings was classified as high quality when 1.2 mL L^{-1} of VIUSID Agro® was applied, while VA2 and VA3 presented a medium quality, and the control a low quality. In relation to the Robustness index and the AP/RP ratio, only the VA1 treatment reached a high quality, while in the Dickson index the quality was low for all treatments (Table 5). At 120 das, the length remained in the high quality range, but in diameter and robustness only VA1 was considered high quality. In the other variables, including the Dickson index, an average quality was recorded with the VA1 treatment.

Table 5. Assessment of the quality of seedlings for morphological attributes.

		First assessment 90 (das)			
Treatments	**Length (cm)**	**Diameter (mm)**	**Robustness**	**AP/RP ratio**	**Dickson index**
VA0	A	B	M	M	B
VA1	A	A	A	A	B
VA2	A	M	M	A	B
VA3	A	M	B	M	B
		Second assessment 120 (das)			
Treatments	Length (cm)	Diameter (mm)	Robustness	AP/RP ratio	Dickson index
VA0	A	B	B	A	B
VA1	A	A	A	M	M
VA2	A	M	M	M	B
VA3	A	M	B	M	B

A = High quality; M = Medium quality; B = Low quality; AP = Dry biomass of the aerial part; RP = Dry root biomass ratio.

Length was the variable highlighted in the evaluation; however, Rueda-Sánchez *et al.* (2014) suggest that length does not always directly correlate with survival, since tall but thin plants can be vulnerable to wind.

The product has not been evaluated in *Acacia* Mill. seedlings, but positive results were detected in coffee seedlings in which the combined foliar application of amino acids led to notable improvements in the quality of the seedlings, especially in biomass production and morphological indices (Posada-Pérez *et al.*, 2021; Díaz *et al.*, 2023).

On the other hand, Álvarez *et al.* (2022) state that foliar application of organic biostimulants and growth promoters with an abundance of amino acids favor the growth of seedlings of forest species produced in nurseries and also increase survival in the field.

Conclusions

Foliar application of the growth promoter favors the morphological characteristics, growth rates, and quality indices of *A. mangium* seedlings. The effective dose of VA1 (1.2 mL L^{-1}) in all the variables evaluated was the lowest. These results suggest that with this application it is possible to reduce at least 60 days the time the plant remains in the nursery, which coincides with the last stage of nursery development. This should be considered in the management strategies of this species in forest nurseries to optimize its production. After 120 das, quality patterns between high and medium emerge with the VA1 treatment, which indicates that an effective transplant could be performed at this point in the crop cycle.

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Conflict of interest

The authors declare that there are no conflicts of interest.

Contribution by author

Kolima Peña Calzada and Ana Gertrudis Trocones Boggiano: conceptualization and design of the study, statistical analysis and writing of the final manuscript; Luis Delgado Fernández: data analysis and writing of the original manuscript; Yarlenis Martínez Alonso and Yandy Martín Conesa: field data collection and data analysis; Alexander Calero Hurtado: preparation of figures, review of data and writing of the final manuscript; Juan Carlos Rodríguez Fernández: statistical analysis and writing of the original manuscript.

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