e-ISSN: 2954-4440

SCIENTIFIC ARTICLE

Current Topics in Agronomic Science

https://doi.org/10.5154/r.ctasci.2025.04.006

EN Section: Agricultural Science

Growth curves and nutrient uptake of a cannabis cultivar (*Cannabis sativa* L.)

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Article history:

Received: April 20, 2025

Accepted: April 21, 2026

Published online:

August 26, 2026

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Abstract

Understanding the dynamics of nutrient uptake in crops is essential for optimizing agronomic management, improving fertilizer use efficiency, and minimizing environmental impact. The legal prohibition on cultivating *Cannabis sativa*, derived from its classification as a narcotic drug by the United Nations (UN) in 1961, has limited agronomic research, including knowledge of its growth kinetics and nutrient uptake, which in turn limits efforts to meet the pharmaceutical flower market's expectations regarding efficacy, innocuousness, standardization, and traceability. The objective of this research was to determine the dynamics of macronutrient, secondary nutrient, and micronutrient uptake in *C. sativa* and its growth curve in a protected production environment with a plastic cover and a fertigation system. Allometric growth and nutrient uptake variables were evaluated at 19, 34, 47, 61, 75, and 89 days after transplanting (dat), in plants grown from rooted cuttings, in each case, with three independent replicates consisting of five plants. Growth variables followed a third-degree polynomial pattern. The highest dry matter accumulation rate was recorded at 75 dat, reaching 6.04 $g \cdot d^{-1}$. The period of greatest macronutrient uptake occurred between 47 and 61 dat, while the period of micronutrient uptake occurred between 61 and 75 dat. Flowering was recorded at 47 dat. The nutrients taken up in the greatest quantities, both during the vegetative and reproductive phases, are nitrogen, calcium, potassium, and iron. Guidelines are proposed for designing a specific nutrition plan for this non-psychoactive cultivar of *C. sativa*

Keywords: Hemp, growth and development, agronomic management, nutrition.

Introduction

Cannabis sativa is a herbaceous plant of the Cannabaceae family, native to Asia, with an ethnobotanical history dating back more than 10,000 years. Its earliest medicinal uses were documented in ancient texts such as the pharmacopoeia of Emperor Shen Nung in China and are evidenced in Egyptian writings (Covarrubias-Torres, 2019). Applications of the plant include the manufacture of rope, textiles, food, and paper (Ángeles et al., 2014), ecomaterials for construction and biofuels (Pérez et al., 2023). However, the classification of *C. sativa* by the United Nations as a narcotic in 1961, and as a psychoactive substance in 1971, has limited research with the plant. Although Colombia has had a regulatory framework since 2016 aimed at ensuring safe and informed access to the medical and scientific uses of *Cannabis* and its derivatives (Congreso de Colombia, 2016; Ministerio de Salud y Protección Social, 2017; Ministerios de Justicia y del Derecho, Agricultura y Desarrollo Rural y Salud y Protección Social, 2022), knowledge gaps remain regarding the agronomic management of the plant, including nutritional criteria adjusted to the growth kinetics and nutrient uptake (Ángeles et al., 2014). Insufficient nutrient supply compromises the cultivation's potential yield. On the other hand, excessive nutrient supply, in addition to high costs, causes soil and water source contamination (Johnston & Bruulsema, 2014). The objective of this research was to understand the growth and nutrient uptake curves of the

Please cite this article as follows (APA 7): Alzate-Cataño L. Y., Mejía-Montoya, J. W., & de los Ríos-Muñoz, J. P. (2026). Curvas de crecimiento y extracción de nutrientes de un cultivar de cannabis (*Cannabis sativa* L.). *Current Topicsin Agronomic Science, 6*. e25006. https://doi.org/10.5154/r.ctasci.2025.04.006

non-psychoactive *C. sativa* cultivar "Colombia CBD", in order to contribute criteria for defining cultivation nutrition plans which optimize productivity, with minimal financial cost and environmental impact, aligned with the purpose of greater production of high-quality flowers, free of heavy metals, pesticide residues and microbial load, therefore safe for the production of phytopharmaceuticals (García & Chamorro, 2021).

Materials and methods

The study was conducted at the facilities of Green Element S.A.S., located in Las Toldas district of the municipality of Guarne, Antioquia, at an altitude of 2140 m.a.s.l, with an average temperature of 16 °C, an accumulated annual rainfall of 2958 mm, and a low montane humid forest life zone. The company holds a license for the cultivation of non-psychoactive cannabis plants, including for research purposes, granted by the Ministry of Justice and Law through Resolution 1961 of November 29, 2019, valid for 10 years. The evaluation was performed using the non-psychoactive *C. sativa* cultivar identified in the national cultivar registry as "Colombia CBD." After two weeks of rooting, the rooted cuttings were planted individually in plastic pots with a capacity of 5 kg of planting substrate, resulting from mixing soil (40 %), coconut substrate (25 %), chicken manure (15 %), vermicompost (10 %) and rock grinding (10 %).

The planting density was 4 plants $\cdot$ m^{-2}. In addition to the nutrients in the substrate, the plants received three daily nutrient doses via fertigation, for a total of: 2.0, 0.3, and 1.2 g $\cdot$ $plant^{-1}$ of N, P_2O_5 and K_2O during the vegetative period; 9.0, 2.0, and 4.4 g $\cdot$ $plant^{-1}$ of N, P, and K during the reproductive period. All plants received the same light, phytosanitary, and formative pruning (4 branches per plant) supplements during the first 47 da**ys afte**r transplanting (dat).The reproductive growth period, from flower differentiation to maturity, was 43 d.

Plant growth and the uptake of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), manganese (Mn), zinc (Zn), iron (Fe), and boron (B) were evaluated at 19, 34, 47, 61, 75, and 89 days after transplanting (dat). These points were established based on prior knowledge of the cultivar's life cycle under the farm's agroecological conditions and the availability of resources to cover the costs of the determinations. Each evaluation consisted of three replicates, each comprising five plants in full competition. During sampling, aerial tissue (leaves, branches, and flowers in equal parts by weight) and root tissue were collected, and the following variables were evaluated:

- Stem length (cm): the distance between the root crown and the apex was measured with a measuring tape.
- Stem base diameter (mm): the evaluation was performed at the root crown using a Vernier caliper.
- Fresh weight (g) of the roots and aerial tissue: was evaluated using a digital scale.
- Dry weight (g) of roots and aerial tissue: the roots were washed with running water, then rinsed with distilled water, the plants were oven dried at 70 °C until a constant weight was reached, the evaluation was carried out in the Plant Physiology laboratory of the Faculty of Agricultural Sciences of the Universidad Nacional de Colombia.

Using these data, growth curves and best-fit mathematical models were constructed. From the plant dry biomass records, the index for the absolute growth rate (AGR) in g $\cdot$ d^{-1} was estimated using Equation (1), where W_2 is plant biomass at evaluation time 2 (T_2) and W_1 is plant biomass at evaluation time 1 (T_1).

$$AGR = \frac{W_2 - W_1}{T_2 - T_1} \tag{1}$$

For each evaluation time, the relationships between the growth parameters were established, expressed as stem length per plant dry weight and stem base diameter per plant dry weight.

To quantify the tissue content of nutrients, a 20 g subsample of the dry weight of the tissues was analyzed. For N, the method established by Kjeldahl (AOAC, 2019) was followed, involving the digestion of plant material with sulfuric acid (H_2S0_4) and the determination of concentration by redox volumetry. For the other determinations, the Colombian Technical Standard NTC-5752 of 2010 (ICONTEC, 2010) was followed, which establishes the procedure for the digestion and mineralization of samples in plant tissue análisis. Uptake was performed using the microwave method with a mixture of nitric acid (HNO_3) and hydrogen peroxide (H_2O_2), nutrient concentrations were determined by atomic absorption spectrophotometry for K, Ca, Mg, Cu, Mn, Fe, and Zn. For P and B, concentrations were determined by colorimetry, and for S, by turbidimetry. The analyses were conducted at the Soil Laboratory of the Faculty of Sciences at the Universidad Nacional de Colombia, Medellín Campus

To establish the nutrient uptake curve, the total dry weight of the tissue (Ps tissue) was measured at each sampling time and, with the percentage concentration of nutrients in the plant tissue the uptake of each nutrient was calculated using equation (2), following the modified methodology of Quesada-Roldán and Bertsch-Hernández (2013).

$$Nutrient\ uptake\ (g \bullet plant^{-1}) = \frac{Ps\ tissue\ (g \bullet plant^{-1})\ x\ Nutrient\ content\ (\%)}{100} \tag{2}$$

Statistical analysis

The data were processed using R software (R Core Team, 2024; RStudio Team, 2023) and Microsoft Excel (Microsoft Corporation, 2025). Normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was assessed using Levene's test. Since the data did not meet the assumption of normality, the non-parametric Kruskal-Wallis test was applied. Subsequently, Dunn's test was performed to conduct multiple comparisons between groups. In defining the mathematical model that best fit the growth curve, the statistically significant model *($P < 0.05$)* with the highest coefficient of determination was selected using RStudio software. The correlation between variables was analyzed using Pearson's correlation coefficient *($p < 0.001$)*.

Results and discussion

Growth curves

The growth variables were fitted to a third-degree polynomial model (Figure 1). This was a non-linear growth characteristic of the species, with marked phenological transitions. The fitted model allowed the definition of the critical period for biomass accumulation. The vegetative growth stage lasted 46 d; the appearance of floral primordia occurred at 47 dat. The highest growth rate in stem length and diameter occurred at 61 dat (at the end of the second week after flowering); regarding fresh and dry weight, it was obtained between days 47 and 75 (at the end of the fourth week after flowering). The maximum values in the evaluated parameters correspond to 119.9 cm height (Figure 1a), 18.5 mm basal diameter (Figure 1b), 766.0 g fresh weight (Figure 1c) and 236.3 g dry weight (Figure1d). Ladino (2023) reported that the height of three non-psychoactive varieties of *C. sativa* (Souce Cauca, Highcol, and Calotoweed) ranged from 128 to 146 cm, with fresh weights of 750 to 900 $g \cdot plant^{-1}$. The differences in height and biomass compared to the values obtained in this study could be attributed to the genetic variation of the evaluated cultivars, as well as the environmental and agronomic management conditions. This genotype-environment interaction determined the biomass accumulation pattern.

Identifying the intervals with the highest growth rate provides valuable information for adjusting nutrition programs, irrigation, and protection of the photosynthetic area, aimed at optimizing the productivity and quality of dried flower or cannabinoid and terpenoid extract as a final product.

Correlations of growth variables

Figure 2 shows a positive and significant correlation among the evaluated growth variables. Among the quantified non-destructive variables, height showed the strongest correlation (r = 0.907***) compared to stem diameter (r = 0.853***). This suggests that, in this cultivar and under the study conditions, height is a more robust predictor of accumulated biomass. Other authors have reported that plant height and stem diameter are early indicators of yield in *C. sativa* (Naim-Feil et al., 2021).

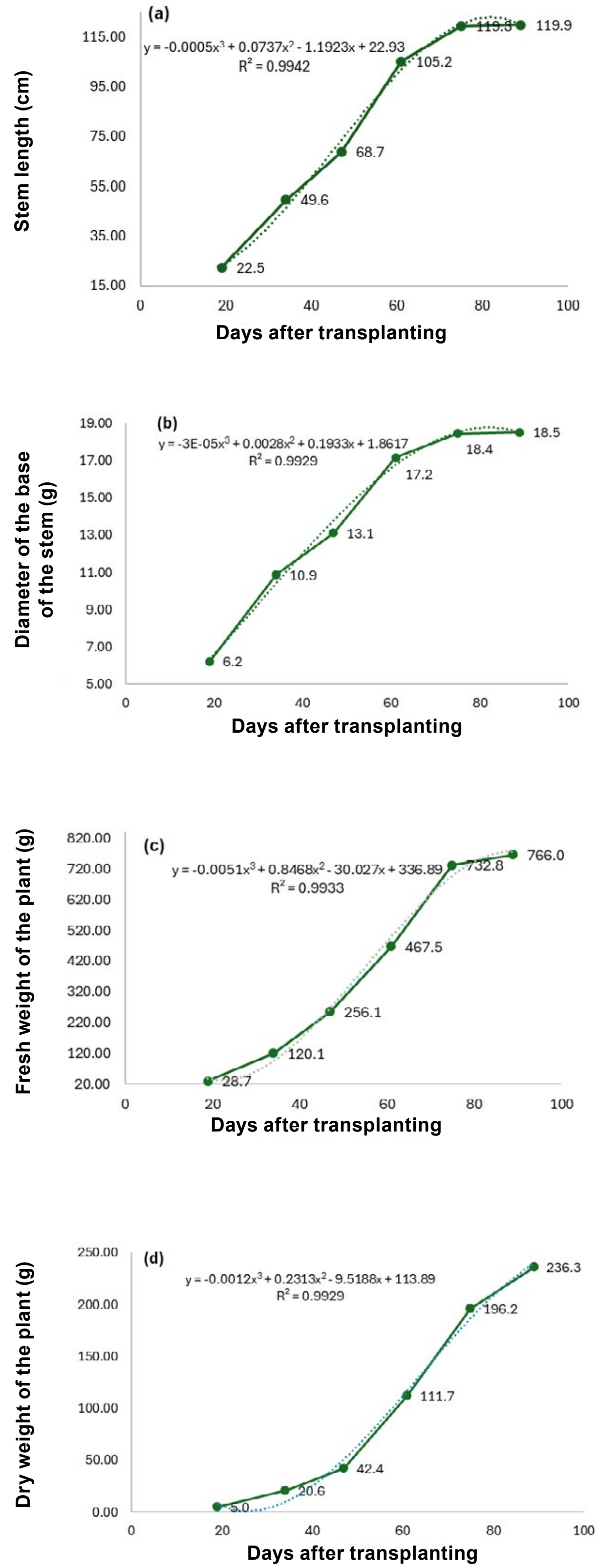

Figure 1. Growth curves of *C. sativa* cultivar "Colombia CBD" with third-degree polynomial model equations and their corresponding R^2 with significance at the 0.05 level.
*** The solid line represents the average observed values. The dashed line indicates the fit of the polynomial model. Number of observations: n = 3.**

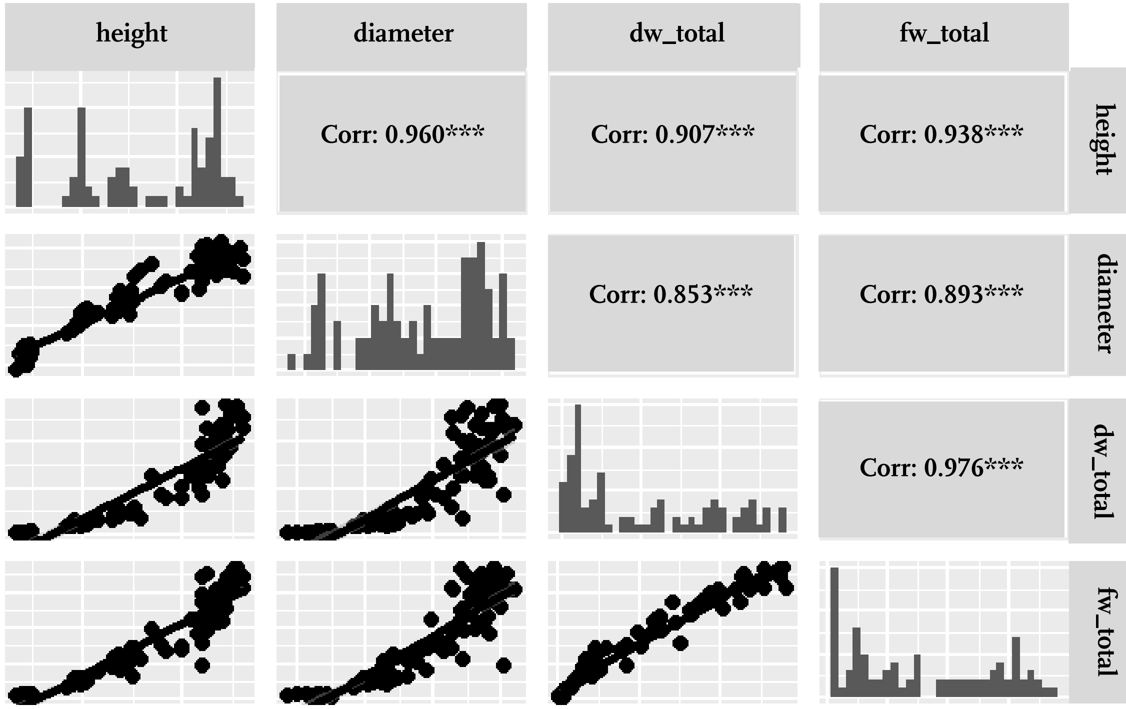

Figure 2. Pearson correlation matrix among the variables height, diameter, dry weight of the plant (dw_total) and fresh weight of the plant (fw_total) for the non-psychoactive cultivar of *C. sativa*. "Colombia CBD".
*** The diagonal shows the histograms of the distribution of each variable, below it are the scatter plots, and above it are the Pearson correlation coefficients. *** significance of $p < 0.001$.**

Absolute growth rate (AGR)

Growth curves of non-perennial species based on dry biomass as a function of time (days after sowing), usually follow a characteristic sigmoidal pattern (Lipovetsky, 2010). The use of logistic regressions allows modeling the behavior of variables related to crop growth (Feller et al., 2015; Genard & Huguet, 1996). The instantaneous accumulation of dry matter of *C. sativa* cultivar "Colombia CBD" showed a non-linear behavior, fitting a third-degree polynomial model (Figure 3). The absolute growth rate (AGR) registered its lowest values during the vegetative growth stage, when the plant prioritizes the formation of support structures. Between 47 and 61 dat, coinciding with the beginning and consolidation of the flowering stage, the most pronounced increase in AGR was observed. Reaching a maximum value at 75 dat (6.04 $g \cdot d^{-1}$) and reflected the period of greatest physiological efficiency in terms of biomass accumulation. The subsequent reduction to 2.87 $g \cdot d^{-1}$ could be associated with the culmination of the flowering stage and the decrease in photosynthetic activity, a phenomenon already described in studies of the species during floral maturity, when the senescent plant redirects energy towards final metabolite accumulation processes (Alden & Faust, 2025).

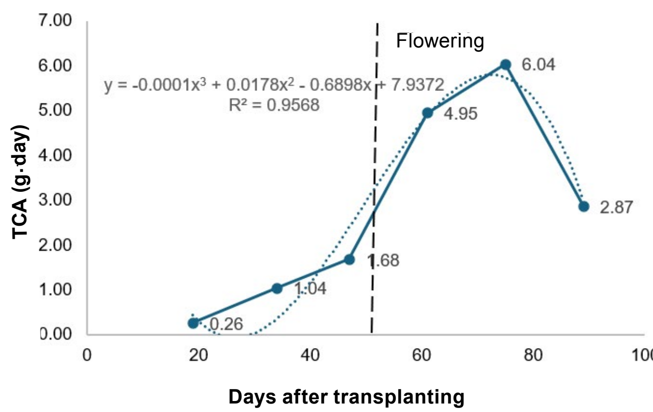

Figure 3. Absolute growth rate for the non-psychoactive cultivar of *C. sativa* "Colombia CBD", polynomial model and its corresponding R^2 with significance of 0.05.
*** The dashed line indicates the beginning of flowering at 47 dat.**

Nutrient uptake curves

Table 1 presents the physicochemical analysis of the planting substrate used in the crop, which is characterized by a sandy loam texture, a pH close to neutral, and high levels of organic matter, Ca, Mg, and K.

Macronutrient uptake curves (Figure 4) show marked differences between the vegetative growth and flowering stages. During the vegetative growth stage, Ca showed the highest uptake, which is consistent with its structural role in the formation and stability of cell walls, processes

Table 1. Results of physicochemical analysis of the planting substrate.

Texture				pH	MO	Ca	Mg	K	CICE	P	S	$N\text{-}NO_3$	$N\text{-}NH_4$	Fe	Mn	Cu	Zn	B
A%	L%	Ar%	Type		%		cmol c · kg^{-1}						mg · kg^{-1}					
72	22	6	FA	6.8	14.8	38.8	2.7	1.4	42.8	224	599	329	17	120	9	8	38	3

that dominate this growth stage, these values were also observed for N, K, P, Mg, and S. This pattern coincides with previous studies in *C. sativa*, where optimal macronutrient concentrations have been estimated during the vegetative stage, with a high demand for structural calcium and nitrogen (Kpai et al., 2024). In research conducted by Ladino (2023), Ca was also found to be the mineral with the highest uptake rate as of day 46 dat in the non-psychoactive cultivar "Souce Cauca".

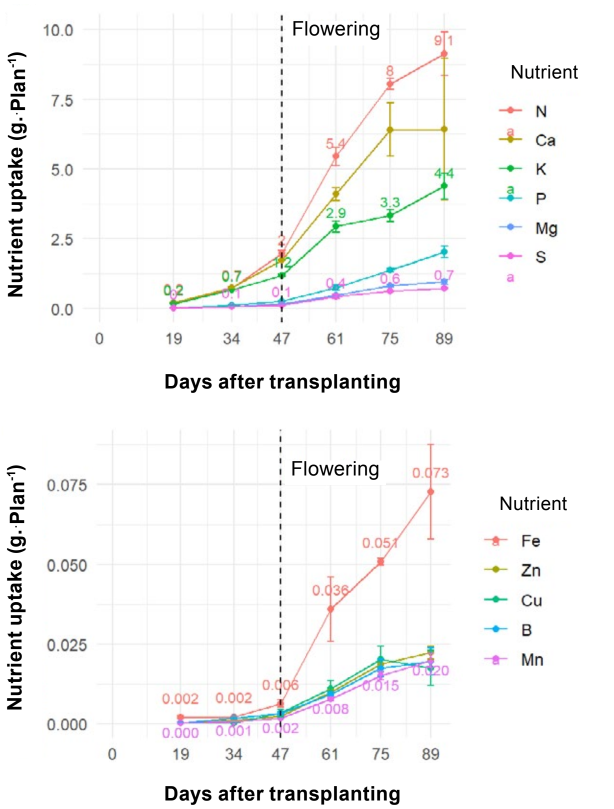

Figure 4. Macronutrient uptake curves (g·plant^{-1}) in the non-psychoactive cultivar *C. sativa* "Colombia CBD".
*** The bars denote the standard deviation.**

During the flowering stage, N became the most extracted nutrient, reflecting its importance in the synthesis of proteins, enzymes, and compounds associated with floral development and increased reproductive biomass (Niazi & Monib, 2023). Ca remained the second most demanded macronutrient, while the relative order of the remaining elements was similar to that of the vegetative growth stage. N is typically the most absorbed macronutrient in crops, due to its abundance in essential biomolecules, such as proteins and nucleic acids (Azcón-Bieto & Talón, 2013; Epstein & Bloom, 2004; Li et al., 2019).

During the vegetative growth stage, the demand for micronutrients was relatively low (Figure 4), and upon entering the flowering stage, uptake accelerated, especially for Fe, which showed the greatest increase. Other elements which exhibited this trend were Cu, Zn, B, and Mn, indicating that they are particularly required during the biosynthesis of reproductive structures and the formation of floral tissues. This pattern suggests that nutrition programs for *Cannabis* cultivation should consider increasing the availability of micronutrients from the beginning of flowering, especially Fe and Cu, to ensure adequate floral development and potentially maximize secondary metabolites.

Fitting the uptake curves to a third-degree polynomial model (Table 2), shows a nonlinear variation in the dynamics of nutrient absorption throughout the plant's growth cycle.

Table 2. Equations and R^2 values with significance of 0.05 for the foliar macro and micronutrient uptake curves of the non-psychoactive cultivar of *C. sativa*.

Nutrient	Equation	R^2
N	$y = -7E\text{-}05x^3 + 0.0123x^2 - 0.4921x + 5.6747$	0.996
P	$y = -3E\text{-}06x^3 + 0.0008x2 - 0.037x + 0.4556$	0.998
K	$y = -2E\text{-}05x^3 + 0.0029x^2 - 0.0888x + 0.9182$	0.979
Ca	$y = -6E\text{-}05x^3 + 0.0103x^2 - 0.4059x + 4.7193$	0.992
Mg	$y = -6E\text{-}06x^3 + 0.0012x^2 - 0.0493x + 0.5995$	0.991
S	$y = -5E\text{-}06x^3 + 0.0009x^2 - 0.0388x + 0.4596$	0.988
Fe	$y = -4E\text{-}07x^3 + 7E\text{-}05x^2 - 0.0032x + 0.0401$	0.987
Zn	$y = -2E\text{-}07x^3 + 3E\text{-}05x^2 - 0.0013x + 0.0154$	0.989
B	$y = -1E\text{-}07x^3 + 2E\text{-}05x^2 - 0.001x + 0.0122$	0.985
Cu	$y = -3E\text{-}07x^3 + 5E\text{-}05x^2 - 0.002x + 0.0241$	0.981
Mn	$y = -9E\text{-}08x^3 + 2E\text{-}05x^2 - 0.0009x + 0.0106$	0.992

The Kruskal–Wallis analysis revealed significant differences in nutrient absorption among the different assessment times (dat) (Table 3). A non-linear behavior of the absorption phenomenon was observed, with dependence according to the phenological stage. Simonutti et al. (2025) reported significant variations in the absorption of macronutrients (N, P, K) according to the phenological stage under different fertilization treatments, which reinforces the hypothesis that the nutrient absorption process, far from being constant, is dynamic.

Table 3. Kruskal-Wallis statistics for the evaluated nutrient uptake.

Nutrient	Ch-squared	Degrees of freedom	*P* Value
N	16.579	5	0.00537
P	16.613	5	0.00529
K	16.392	5	0.00581
Ca	15.807	5	0.00742
Mg	16.613	5	0.00529
S	16.648	5	0.00522
Fe	16.158	5	0.00641
B	16.158	5	0.00641
Zn	16.579	5	0.00537
Mn	16.579	5	0.00537
Cu	15.69	5	0.00779

Table 4. Results of Dunn's test comparing nutrient extraction for each mineral at the six evaluation times.

Nutrient	dat	Average absorption (value)	Statistical group	Adjusted *P* value
N	19	0.207	a	19 - 75 (0.0295), 19 - 89 (0.0087)
	34	0.716	ab	-
	47	1.91	abc	-
	61	5.45	abc	-
	75	8.05	bc	19 - 75 (0.0295)
	89	9.14	c	19 - 89 (0.0087)
P	19	0.03	a	19 - 75 (0.0293), 19 - 89 (0.0086)
	34	0.12	ab	34 - 89 (0.0293)
	47	0.27	abc	-
	61	0.74	abc	-
	75	1.38	bc	19 - 75 (0.0293)
	89	2.03	c	19 - 89 (0.0086), 34 - 89 (0.0293)
K	19	0.17	a	19 - 75 (0.0372), 19 - 89 (0.0087)
	34	0.67	ab	34 - 89 (0.0372)
	47	1.19	abc	-
	61	2.94	abc	-
	75	3.34	bc	19 - 75 (0.0372)
	89	4.39	c	19 - 89 (0.0087), 34 - 89 (0.0372)
Ca	19	0.21	a	19 - 75 (0.0167), 19 - 89 (0.0167)
	34	0.75	ab	-
	47	1.74	ab	-
	61	4.10	ab	-
	75	6.42	b	19 - 75 (0.0167)
	89	6.43	b	19 - 89 (0.0167)
Mg	19	0.03	a	19 - 75 (0.0293), 19 - 89 (0.0086)
	34	0.08	ab	34 - 89 (0.0293)
	47	0.16	abc	-
	61	0.48	abc	-
	75	0.82	bc	19 - 75 (0.0293)
	89	0.96	c	19 - 89 (0.0086), 34 - 89 (0.0293)

Table 4. Results of Dunn's test comparing nutrient extraction for each mineral at the six evaluation times.

Nutrient	dat	Average absorption (value)	Statistical group	Adjusted *P* value
S	19	0.02	a	19 - 75 (0.0290), 19 - 89 (0.0085)
	34	0.07	ab	34 - 89 (0.0290)
	47	0.12	abc	-
	61	0.43	abc	-
	75	0.61	bc	19 - 75 (0.0290)
	89	0.72	c	19 - 89 (0.0085), 34 - 89 (0.0290)
Fe	19	0.0020	a	19 - 89 (0.0198)
	34	0.0022	a	34 - 89 (0.0214)
	47	0.0064	ab	-
	61	0.0360	ab	-
	75	0.0509	ab	-
	89	0.0727	b	19 - 89 (0.0198), 34 - 89 (0.0214)
B	19	0.0004	a	19 - 75 (0.0214), 19 - 89 (0.0198)
	34	0.0017	ab	-
	47	0.0033	ab	-
	61	0.0094	ab	-
	75	0.0175	b	19 - 75 (0.0214)
	89	0.0196	b	19 - 89 (0.0198)
Zn	19	0.0003	a	19 - 75 (0.0295), 19 - 89 (0.0087)
	34	0.0010	ab	-
	47	0.0024	abc	-
	61	0.0099	abc	-
	75	0.0187	bc	19 - 75 (0.0295)
	89	0.0223	c	19 - 89 (0.0087)
Mn	19	0.0003	a	19 - 75 (0.0295), 19 - 89 (0.0087)
	34	0.0008	ab	34 - 89 (0.0295)
	47	0.0017	abc	-
	61	0.0077	abc	-
	75	0.0151	bc	19 - 75 (0.0295)
	89	0.0199	c	19 - 89 (0.0087), 34 - 89 (0.0295)
Cu	19	0.00028	ab	19 - 75 (0.0372)
	34	0.0002	a	34 - 75 (0.0257), 34 - 89 (0.0372)
	47	0.0034	abc	-
	61	0.0111	abc	-
	75	0.0203	c	19 - 75 (0.0372), 34 - 75 (0.0257)
	89	0.0176	bc	34 - 89 (0.0372)

dat: days after transplant

Table 4 presents the results of the Dunn test, with the multiple comparisons (six assessments) corresponding to the uptake of each nutrient.

Percentage distribution of minerals throughout the cycle

The percentage distribution of mineral uptake (Figure 5) showed a pattern of progressive accumulation throughout the crop cycle, with a notable increase starting at 61 days after transplanting (dat) for all nutrients evaluated. At 47 dat, the transition from vegetative to reproductive growth, nutrient uptake represented between 9 and 27 % of the total accumulated. Adequate nutrient availability in the planting substrate must be ensured during both growth stages, especially the reproductive, to achieve optimal cultivation growth and development.

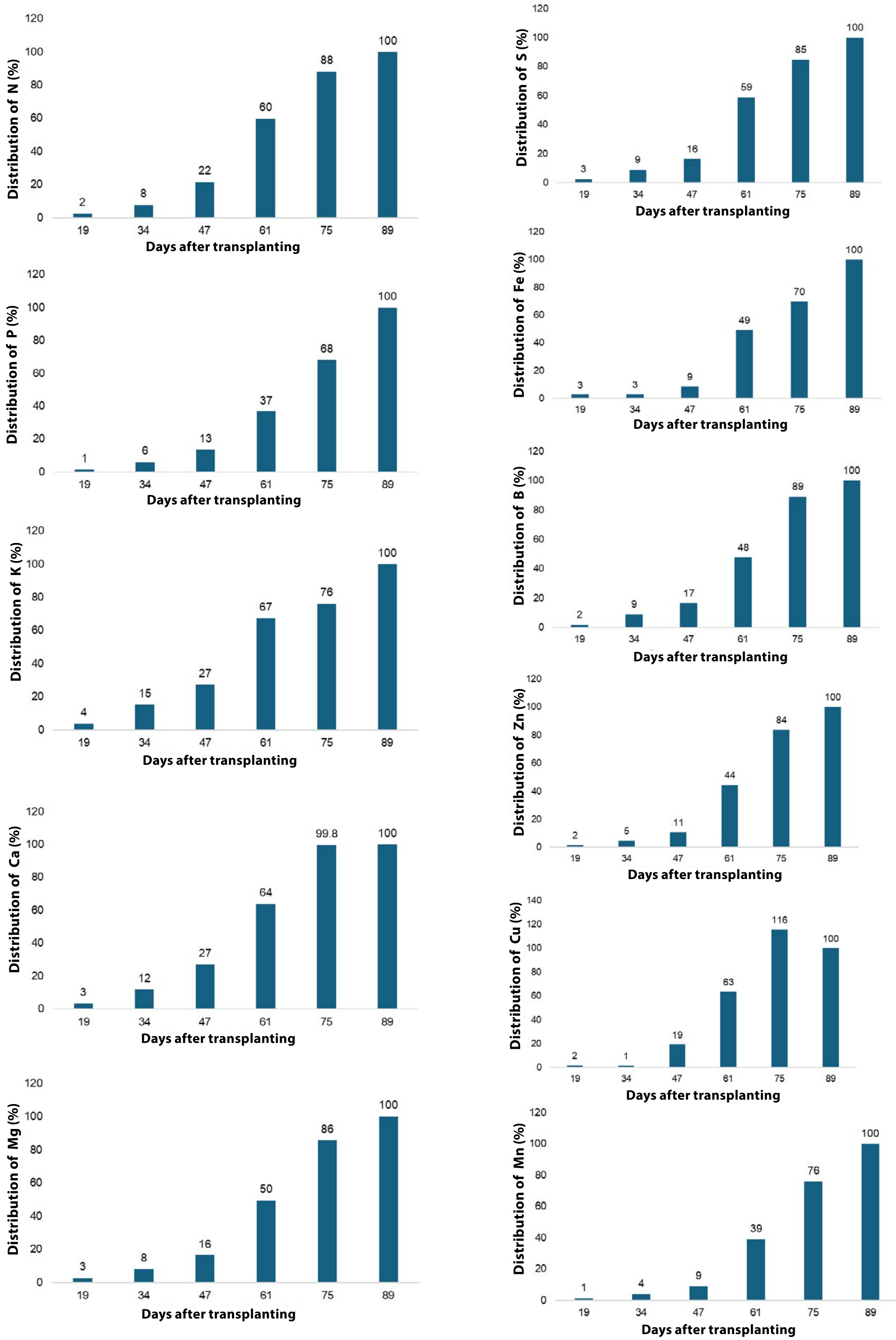

Figure 5. Percentage distribution of nutrient uptake in the non-psychoactive *C. sativa* cultivar "Colombia CBD" during its growth cycle.

Table 5. Ratio of Ca:Mg:K uptake over the life cycle of the non-psychoactive *C. sativa* cultivar "Colombia CBD."

Days after transplanting(dat)	Ca	Mg	K
19	4.3	0.12	0.8
34	3.7	0.10	0.9
47	4.1	0.09	0.7
61	3.7	0.12	0.7
75	3.3	0.13	0.5
89	2.7	0.15	0.7
Average	**3.6**	**0.12**	**0.72**

Figure 6. Photographic record of the non-psychoactive cultivar of *C. sativa* "Colombia CBD" at 19, 47 and 75 dat, with no visible symptoms of phytotoxicity or nutritional deficiencies.

Table 5 shows the Ca:Mg:K ratios at different evaluation time points during the life cycle of the "Colombia CBD" cultivar. The average Ca:Mg:K ratio throughout the growth cycle was 3.6:0.12:0.7.

During the evaluated growth period, the *C. sativa* plants did not show visible deficiency symptoms (Figure 6).

Zafeiraki et al. (2021) reported high foliar concentrations of Cu, Ca, Mg, Mn, Zn, Fe, and K in *C. sativa*. Similarly, Milan et al. (2024) found elevated concentrations of Fe, Mn, Zn, and Cu in this species. According to Bing et al. (2011), *C. sativa* has the capacity to absorb metals and metalloids from the soil. However, its accumulation levels are influenced by both natural and anthropogenic sources. On the other hand, Placido and Lee (2022) noted that hemp, due to its deep root system, is tolerant to the accumulation of several metals. The plant has the capacity to regulate the accumulation of elements in its different organs (Angelova et al., 2004), which allows it to grow without showing any obvious symptoms of phytotoxicity (Shi et al., 2012). The capacity of *C. sativa* leaves to accumulate metals should be considered when using them for medicinal purposes, as it could influence their safety and quality (Placido & Lee, 2022).

Efficient, sustainable, and environmentally friendly management is fundamental to maximizing cultivation yields (Fageria & Baligar, 2005). The use of fertilizers plays a crucial role in this process, as it allows plants to complete their life cycle (Verzeaux et al., 2017). In this regard, it is estimated that between 40 and 60% of global agricultural production depends on the addition of nutrients to the soil (Johnston & Bruulsema, 2014).

Conclusions

The research allowed us to understand the growth dynamics and nutrient uptake of the non-psychoactive *C. sativa* cultivar "Colombia CBD", under a protected production system with plastic covering and fertigation, under the agroecological conditions of the study. According to the growth kinetics, the highest absolute growth rate was observed between days 47-61 dat, immediately after flowering. During the same period, the steepest slope in the nutrient uptake curve was observed. During this interval of the cultivation cycle, the greatest care should be taken with fertigation and phytoprotection. To validate the growth kinetics and nutrient uptake found in this research, further evaluations should be conducted with different substrates, fertilizer doses, and application schedules. Further evaluations are needed to determine critical nutrient levels, based on data regarding the dry flower yield of *C. sativa* or the amount of cannabinoid extract at a defined concentration per unit of cultivated area, and nutrient concentration.

Acknowledgments

The authors would like to thank the Universidad Nacional de Colombia, Medellín Campus, for its institutional support. They would also like to thank Green Element S.A.S. for allowing this work to be carried out at its facilities and for its financial support.

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