

## Osmotic potential and macronutrient uptake in *Matricaria recutita* L.

## Potencial osmótico y extracción de macronutrientes en *Matricaria recutita* L.

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### ABSTRACT

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The osmotic potential for higher total biomass and inflorescence production of chamomile was identified, and the nutrient requirement and extraction of N, P, K, and Ca during the growing season were determined. Four levels of osmotic potential ( $\Psi_o$ ) were tested: -0.036, -0.054, -0.072, and 0.090 MPa from Steiner's nutrient solution. The experimental arrangement employed a randomized complete block design with three replications; the experimental unit consisted of a pot containing a single plant. Means were compared using Tukey's test ( $\alpha = 0.05$ ). The evaluated variables were the number of inflorescences per plant, diameter, and dry weight of both inflorescences and plants, for which destructive sampling was carried out throughout the crop cycle. Nutrient chemical analyses were performed using standard procedures. The effect of the level of osmotic potential on dry weight and inflorescence production was identified; based on the best treatment, the nutrient requirement was calculated in the treatment with  $\Psi_o$  of -0.072 MPa. The nutrient requirement (kg) per ton of dried chamomile (branches, stems, and inflorescence) was N, 32.00; P, 3.67; K, 39.29; and Ca, 7.11, and nutrient extraction in chamomile cultivation was in the order  $K > N > Ca > P$ .

**KEY WORDS :** Osmotic pressure, production, dry inflorescences, nutrient requirements

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## RESUMEN

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Se evaluó el potencial osmótico para obtener mayor producción de biomasa total e inflorescencias de manzanilla y se determinó el requerimiento y extracción nutrimental de N, P, K y Ca durante el ciclo de cultivo. Se probaron cuatro niveles de potencial osmótico ( $\Psi_o$ ): -0.036, -0.054, -0.072 y -0.090 MPa de solución nutritiva Steiner. El arreglo experimental fue en bloques completos al azar con tres repeticiones, la unidad experimental consistió en una maceta con una planta. Se determinó el número de inflorescencias por planta, el diámetro, el peso seco de inflorescencia y de la planta, para lo cual se hicieron muestreos destructivos cada 15 días después del trasplante. La comparación de medias se realizó con la prueba de Tukey ( $\alpha= 0.05$ ). Los análisis químicos nutrimentales se realizaron mediante procedimientos estándar. Hubo efecto del nivel de potencial osmótico en el peso seco y en producción de inflorescencias destacando el tratamiento de  $\Psi_o$  de -0.072 MPa. y se realizó el cálculo de requerimiento nutrimental. El requerimiento nutrimental en (kg) por tonelada de manzanilla seca (ramas, tallos e inflorescencia) fue de: N: 32.00; P: 3.67; K: 39.29 y Ca: 7.11, y la extracción de nutrientes en el cultivo de manzanilla fue en el orden  $K>N>Ca>P$ .

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**PALABRAS CLAVE:** Presión osmótica, producción, inflorescencias secas, requerimiento nutrimental.

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## Introduction

Chamomile is an aromatic-medicinal plant belonging to the Asteraceae family (Kisić *et al.*, 2018). German chamomile (*Matricaria recutita*) together with Roman chamomile (*Chamaemelum nobile*) are the most representative species (Sharifi-Rad *et al.*, 2018). It is a species of global commercial importance due to its multiple uses and applications in the food, herbal, pharmaceutical, and cosmetic sectors (Chauhan *et al.*, 2022; Wu *et al.*, 2022). The variety *Matricaria recutita* L. is the most widely cultivated in Mexico (Milla-Escobar, 2008). In 2024, 597 hectares were planted, yielding an average of  $3.67 \text{ t}\cdot\text{ha}^{-1}$ , with the central producing states being Estado de México, Puebla, Morelos, San Luis Potosí, and Durango (SIAP, 2024). However, there are currently no data available regarding the varieties under cultivation or the proportion of production dedicated to organic and conventional chamomile in Mexico. The cultivation of aromatic and medicinal species represents a profitable alternative with a growing market and high added value, particularly when certified under Good Agricultural Practices and organic standards (Juárez-Rosete *et al.*, 2013), as production is targeted at consumers seeking to enhance their quality of life.

Although chamomile is a high-value medicinal and aromatic herb, its cultivation is generally limited to backyards, orchards, or small-scale farmers. Growers are not interested in large-scale production due to the lack of high-yield varieties adapted to the agroecological conditions of each region (Castro-Restrepo *et al.*, 2013), the limited knowledge of nutritional requirements necessary for developing fertilization plans, the absence of low-cost agrotechnologies for flower harvesting, and the lack of suitable machinery for crop collection (Milla-Escobar, 2008; Chauhan *et al.*, 2022). One of the main challenges in cultivating aromatic and medicinal species is the lack of precise information on mineral nutrition management (Pedraza & Henao, 2008). In this context, the growing demand and increasing quality requirements have driven the search for new and more effective methods in chamomile cultivation. Mineral nutrition management is a decisive factor that enhances the productive potential of plants (Sánchez-García *et al.*, 2016), influences inflorescence yield (Kisić *et al.*, 2019), and can be optimized if the crop's nutritional requirements are well understood.

Research on chamomile fertilization has focused on nitrogen fertilization rates and irrigation regimes that result in higher yields by increasing biomass production, flower yield (Alhasan *et al.*, 2022), and essential oil content (Alhasan *et al.*, 2022; Giannoulis *et al.*, 2020).

Furthermore, it has been reported that N-P-K fertilization increases the yield of dry inflorescences per plant (Mohammadreza *et al.*, 2012; Ahmad *et al.*, 2024), which is influenced by plant age and the type of fertilizer supplied (Juárez-Rosete *et al.*, 2011). However, Barbosa *et al.* (2015) reported no significant effect of potassium application on plant height, stem diameter, number and diameter of flower heads, or dry matter production. The use of organic fertilizers has also been reported (Alemán *et al.*, 2016; Rostaei *et al.*, 2024), showing positive effects on growth traits such as flower head diameter and essential oil content (Ahmed *et al.*, 2022; Singh *et al.*, 2011), as well as combinations of chemical and organic fertilization (Kisić *et al.*, 2019). Overall, chamomile does not require large amounts of fertilizers; depending on soil fertility, small amounts of N, P, and K can be applied before sowing (Singh *et al.*, 2011). Therefore, understanding the nutritional requirements of the crop enables rational fertilization practices, which in turn support optimal yield.

Nevertheless, in Mexico, no precise data are available on the fertilization levels applied to soils, nor on the ranges of deficiency, sufficiency, or excess of macronutrients in chamomile cultivation and their effect on yield. In this regard, nutrient uptake curves represent the amounts of an element extracted by plants throughout their life cycle (Sancho, 1999) and serve to define strategies in crop nutrition programs (Bertsch, 2005). One approach to obtaining such nutrient uptake curves is through hydroponic experiments in which the osmotic potential of the nutrient solution is varied to determine the level that maximizes biomass accumulation and flower production (Ebrahimi *et al.*, 2021). As osmotic potential becomes more negative, the free energy of water decreases, reducing nutrient uptake (Marschner, 2012) until reaching levels that limit the root's ability to absorb water and nutrients (Ben-Gal *et al.*, 2009; Pachepsky *et al.*, 2024). Therefore, the present study aimed to identify the osmotic potential of the nutrient solution within the range of -0.036 to -0.090 MPa that maximizes total biomass and inflorescence production per plant and to determine macronutrient uptake across phenological stages.

## Material and Methods

The study was conducted in a gothic-type greenhouse with passive roof and side ventilation. The structure was covered with Hals-type polyethylene film featuring UV and anti-drip technology, and a 35 % shade mesh was installed at a height of four meters. The greenhouse was located in the Ejido Colonia Seis de Enero, Tepic, Nayarit, at coordinates 21°32'16.9"N and 104°48'30.6"W. Seeds of the DC-1 variety (Plantamex®) were used and germinated in 200-cell polystyrene trays. The germination substrate consisted of a mixture of Sunshine® No. 3 peat and perlite in a 60:40 (v:v) ratio. During the germination and seedling stages, irrigation was applied with water adjusted to a pH of 6.0. Transplanting was carried out when the seedlings reached a height of 3 cm.

The containers used for transplanting were black flexible plastic pots (20 x 20 cm) with pleats for greater stability, a capacity of 1.5 L, and drainage holes. The substrate consisted of volcanic basaltic rock (black tezontle) with a particle size of 0.3 to 0.8 cm, disinfected with quaternary ammonium salts. An analytical determination of the irrigation water was conducted to characterize its chemical composition and adjust the formulations of the nutrient solutions accordingly. The water analysis data were as follows: pH 7.08, EC 0.21 dS·m<sup>-1</sup>; K<sup>+</sup> 0.11, Ca<sup>2+</sup> 0.54, Mg<sup>2+</sup> 0.92, and Na<sup>+</sup> 0.50 meq·L<sup>-1</sup>; SO<sub>4</sub><sup>2-</sup> 0.03, NO<sub>3</sub><sup>-</sup> 0.12, Cl<sup>-</sup> 0.10, and HCO<sub>3</sub><sup>-</sup> 1.78 meq·L<sup>-1</sup>. Based on these results, adjustments were made to each osmotic potential treatment.

The treatments evaluated corresponded to four osmotic potential levels in a standard nutrient solution (Steiner, 1984), expressed as osmotic potential ( $\Psi_o$ ): -0.036, -0.054, -0.072, and -0.090 MPa (Table 1). The experimental design was a randomized complete block design with three replications. The experimental unit consisted of 24 pots, each containing one plant. Pots were spaced 0.10 m apart, with 0.50 m between experimental units. Nutrient solutions were prepared separately in 200 L containers using soluble fertilizers. Irrigation with the nutrient solution was carried out manually daily until harvest. Plants were watered twice a day: in the morning with nutrient solution and in the afternoon with tap water to prevent salt accumulation in the substrate.

**Table 1. Ionic composition of the nutrient solutions used in the treatments.**

Osmotic potential (MPa)	NO <sub>3</sub> <sup>-</sup>	H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	SO <sub>4</sub> <sup>-</sup> meq.L <sup>-1</sup>	K <sup>+</sup>	Ca <sup>+2</sup>	Mg <sup>+2</sup>
-0.036	6	0.50	3.5	3.5	4.50	2.0
-0.054	9	0.75	5.25	5.25	6.75	3.0
-0.072	12	1.00	7.00	7.00	9.00	4.0
-0.090	15	1.25	8.75	8.75	11.25	5.0

After transplanting, destructive sampling was performed every 15 days until the end of flowering. At each sampling, whole plants were randomly collected and cut at the substrate surface. The vegetative part was separated from the inflorescences, which were dried in a forced-

air oven at 60 °C until a constant weight was reached, following the procedure described by Sánchez-Prado *et al.* (2018). In this way, the accumulated dry matter of each organ was quantified throughout the crop's growth and production cycle, and a growth curve was constructed.

Inflorescence production per plant was recorded considering both weight and diameter. Inflorescences were harvested manually every five days, starting from the onset of flowering and continuing throughout the entire cultivation period. This practice maintained continuous production and prevented the senescence of inflorescences and the plant itself (Doni *et al.*, 1999). According to Sánchez-Prado *et al.* (2018), once the best treatment in terms of dry flower production was identified, analytical determinations of macronutrients were conducted in both the vegetative parts and the inflorescences.

Dry samples were ground using an IKA® A11 basic mill. Total nitrogen (N) content was determined by the Micro-Kjeldahl method. Phosphorus (P) was determined by colorimetry using a spectrophotometer (DR2800, Hach®). Potassium (K) and calcium (Ca) were quantified with a flame photometer (Flame Photometer 410, Sherwood®), following standard laboratory procedures described by Alcántar and Sandoval (1999).

Nutrient accumulation during the different sampling times in the chamomile growth cycle was calculated based on the percentage concentration and the total dry matter accumulated in the vegetative part and the inflorescences (Sánchez-Prado *et al.*, 2018). Macronutrient extraction at each sampling was expressed per plant (g). Extraction curves were constructed for each macronutrient considered: N, P, K, and Ca.

The data obtained for each response variable were analyzed by analysis of variance (ANOVA). Statistical differences were determined using the F-test, and when significant, mean comparisons were performed using Tukey's test ( $\alpha = 0.05$ ) with the SAS statistical software.

## Results and Discussion

Crop growth was evaluated as a function of osmotic potential treatments ( $\Psi_o$ ): -0.036, -0.054, -0.072, and -0.090 MPa. According to the analysis of variance, nutrient solutions had a significant effect on yield, and mean comparison tests indicated that the osmotic potential of -0.072 MPa resulted in the highest inflorescence yield. No statistical differences were observed among the -0.036, -0.054, and -0.090 MPa treatments.

Table 2 shows that inflorescence production began 86 dat (days after transplanting) and tended to increase until 105 dat. From 123 dat onwards, inflorescence yield began to decline, possibly due to plant age. These findings are similar to those reported by Al-Karaki and Otman (2009), who obtained up to 44.5 g plant<sup>-1</sup> of inflorescences in soilless cultivation.

Mohammadreza *et al.* (2012) evaluated the effect of different N, P, and K levels. They reported up to 17.50 flowers per plant when supplying 100 kg N·ha<sup>-1</sup> through urea application,

together with 50 kg  $P_2O_5 \cdot ha^{-1}$  as triple superphosphate, and 50 kg  $K_2O \cdot ha^{-1}$  as potassium sulfate. However, the study did not specify how many days after transplanting the harvest began, nor the number of harvests performed. In another study, Gandomi *et al.* (2021) assessed the response of different levels of chemical and organic fertilization on chamomile yield and quality, reporting up to 67.37 flowers per plant when 100 kg  $N \cdot ha^{-1}$  was supplied.

**Table 2. Number of inflorescences in chamomile (*Matricaria recutita* L.) in four nutrient solutions at different osmotic potential ( $\Psi_0$ ).**

Osmotic potential (MPa)	Days after transplant			
	86	91	105	125
-0.036	17.700 <sup>ab</sup>	40.480 <sup>ab</sup>	62.770 <sup>a</sup>	53.300 <sup>a</sup>
-0.054	12.070 <sup>b</sup>	29.790 <sup>b</sup>	56.870 <sup>b</sup>	51.660 <sup>a</sup>
-0.072	32.500 <sup>a</sup>	48.220 <sup>a</sup>	76.350 <sup>a</sup>	37.250 <sup>a</sup>
-0.090	31.930 <sup>ab</sup>	27.940 <sup>b</sup>	72.980 <sup>a</sup>	57.590 <sup>a</sup>
Pr >F	0.0294	0.0114	0.235	0.159
CV	30.480	14.800	16.870	19.470
HSD	20.331	15.337	32.248	27.524

CV: Coefficient of variation; HSD: Honestly Significant Difference. Different letters within columns indicate that they are statistically different in the Tukey test ( $\alpha \leq 0.05$ ).

Inflorescence diameter is a morphological variable that was not affected by the osmotic potential of the nutrient solutions at 86 and 91 dat (Table 3), but differences among treatments were observed at 105 dat, with the osmotic potential of -0.072 MPa producing the most significant values.

Inflorescence diameters ranged from 10.76 to 12.63 mm, which are smaller than those reported by Gandomi *et al.* (2021), who obtained inflorescences with a diameter of 19.85 mm. In a study conducted by Juárez-Rosete *et al.* (2011), inflorescence diameters were 10.71 mm under organic fertilization, whereas inorganic fertilization and semi-hydroponic cultivation produced diameters of 11.22 mm. The results were attributed to the genetic origin of the seed used and the cultivation conditions.

**Table 3. Inflorescence diameter in chamomile (*Matricaria recutita* L.) grown with nutrient solution with different osmotic potential ( $\Psi_o$ ).**

Osmotic potential (MPa)	Days after transplant			
	86	91	105	125
	----- mm -----			
-0.036	10.953 <sup>a</sup>	10.957 <sup>a</sup>	11.863 <sup>b</sup>	11.734 <sup>a</sup>
-0.054	11.059 <sup>a</sup>	10.726 <sup>a</sup>	12.027 <sup>b</sup>	11.208 <sup>a</sup>
-0.072	10.763 <sup>a</sup>	11.257 <sup>a</sup>	12.634 <sup>a</sup>	11.415 <sup>a</sup>
-0.090	11.018 <sup>a</sup>	11.174 <sup>a</sup>	11.947 <sup>b</sup>	11.820 <sup>a</sup>
Pr >F	0.667	0.104	0.005	0.166
CV	2.740	1.900	1.400	2.700
HSD	2.740	0.650	0.480	0.898

CV: Coefficient of variation; HSD: Honestly Significant Difference. Different letters within columns indicate that the values are statistically different according to the Tukey test ( $\alpha \leq 0.05$ ).

Regarding the dry weight of inflorescences, values below 1.0 g plant<sup>-1</sup> were obtained (Table 4), with the highest values corresponding to osmotic potentials of -0.072 and -0.090 MPa. These results are lower compared to those reported by Al-Karaki and Otman (2009), who obtained an average of 3.0 g plant<sup>-1</sup> in Jordanian chamomile and up to 9.75 g plant<sup>-1</sup> in German chamomile cultivated in a soilless system.

At 105 days after transplanting, no significant differences were observed among treatments in inflorescence dry weight. This may be explained by the fact that flower yield is highly influenced by plant age and the type of fertilizer supplied (Juárez-Rosete *et al.*, 2011), as was evident at 125 days, when the -0.036 MPa treatment showed the highest dry weight. In this regard, Mohammadreza *et al.* (2012) reported that the accumulation of chamomile dry matter is affected by environmental factors, including temperature, humidity, nutrient availability, and genetic factors, as well as their interactions. Nitrogen directly influences dry matter accumulation (Mohammadreza *et al.*, 2012). In this context, osmotic potential treatments of -0.072 and -0.090 MPa provided adequate NO<sub>3</sub><sup>-</sup> concentrations for the plant to perform its vital processes. In contrast, at  $\Psi_o$  levels of -0.036 and -0.054 MPa, the concentrations were insufficient to achieve significant dry matter accumulation.

**Table 4. Weight of dried inflorescences in chamomile (*Matricaria recutita* L.) using nutrient solutions with different osmotic potential.**

Osmotic potential (MPa)	Days after trasplant			
	86	91	105	125
			g	
-0.036	0.173	0.439 a	0.530 a	0.532 a
-0.054	0.100	0.289 ab	0.596 a	0.507 b
-0.072	0.265	0.441 a	0.726 a	0.439 c
-0.090	0.286	0.374 ab	0.726 a	0.515 b
Pr >F	0.014	0.171	0.103	0.562
CV	24.200	19.900	13.700	15.400
HSD	0.438	0.224	0.263	0.006

CV: Coefficient of variation; HSD: Honestly Significant Difference. Different letters within columns indicate that the values are statistically different according to the Tukey test ( $\alpha \leq 0.05$ ).

The variables analyzed showed a positive trend under the osmotic potential ( $\Psi_o$ ) of -0.072 MPa, where the plants achieved higher yield, which could be attributed to efficient nutrient assimilation and, consequently, greater accumulation of inflorescence biomass in chamomile. It is important to note that the economic yield, or the helpful part of chamomile, lies in its inflorescences, as these are utilized in the various industries that process this aromatic plant (Singh *et al.*, 2011; Giannoulis *et al.*, 2020).

The most significant accumulation of chamomile dry matter (g plant<sup>-1</sup>) (Table 5) was obtained with treatment number four (-0.090 MPa) at 86 dat. Beyond this period, the accumulation tended to decrease, a trend also reported by other researchers. In this regard, Rahmati *et al.* (2011) found that an adequate nitrogen supply can lead to greater dry weight accumulation per plant. This effect is associated with increased photosynthetic activity and carbohydrate storage (Chen *et al.*, 2019). Although higher applications of nitrogen fertilizers can increase plant fresh biomass production, this does not necessarily lead to greater quality or yield of inflorescences. Therefore, it is advisable to maintain a balanced supply of macronutrients (N, P, K, and Ca). This observation is consistent with Chauhan *et al.* (2021), who emphasized that a balanced nutrient supply is required throughout the chamomile crop cycle for commercial cultivation.

**Table 5. Dry matter accumulation in chamomile plants (*Matricaria recutita* L.) using nutrient solutions with different osmotic potential.**

Osmotic potential (Mpa)	Days after transplant			
	86	91	105	125
	----- g -----			
-0.036	8.113 a	8.451 a	7.168 a	7.597 a
-0.054	10.570 a	7.242 a	6.654 a	6.941 abc
-0.072	8.325 a	5.768 a	6.829 a	7.251 ab
-0.090	10.924 a	7.898 a	7.683 a	6.294 c
Pr >F	0.0474	0.0745	0.5303	0.0025
CV	3.90	13.80	12.30	0.03
HSD	3.256	2.995	2.457	0.6574

CV: Coefficient of variation; HSD: Honestly Significant Difference. Different letters within columns indicate that the values are statistically different according to the Tukey test ( $\alpha \leq 0.05$ ).

Table 6 presents the values of nutrient requirements for N, P, K, and Ca, expressed as kilograms of nutrient per ton of dry chamomile biomass. These values provide a basis for adjusting fertilization to the crop cycle, thereby optimizing input use (Valdez-Aguilar *et al.*, 2015) and establishing yield and quality targets in chamomile production. The results obtained in this study suggest that the nutrient requirement for chamomile cultivation is relatively low. However, nutrient solutions with an osmotic potential lower than -0.072 MPa will not adequately meet the crop's demands.

**Table 6. Nutritional requirement of N, P, K, and Ca in chamomile (*Matricaria recutita* L.) expressed per kg of nutrient per ton of dried chamomile plants (branches, stems and inflorescences).**

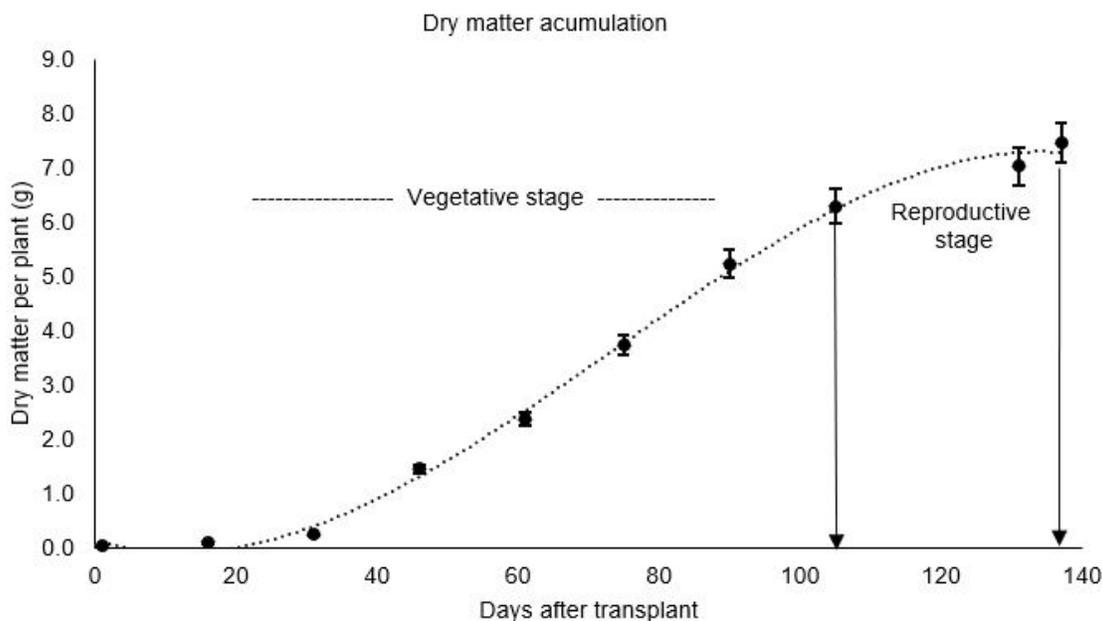
Nutrient	kg
N	32.00
P	3.67
K	39.29
Ca	7.11

Growing chamomile without adequate fertilization is not a viable option; it is essential to understand the crop's nutritional requirements to achieve optimal yields (Kisić *et al.*, 2019). When compared with data from other crops, such as Stevia (*Stevia rebaudiana* Bertoni), the maximum nutrient uptake rate occurs from 60 to 105 days for N and P, with values of 1.41 and 0.09 kg ha<sup>-1</sup>

day<sup>-1</sup>, respectively, and at 75 days for K and Ca<sup>2+</sup>, with 1.71 and 2.05 kg ha<sup>-1</sup> day<sup>-1</sup>, respectively (Chamorro & Calvache, 2018).

The nutrient extraction by chamomile plants over time is illustrated in Figure 1. The order of nutrient extraction was K>N>Ca>P. Among the macronutrients, N and K were present at higher concentrations, making them the most important for the production of aromatic and medicinal plants. Since N deficiency inhibits the growth of shoots/flower buds (Kováčik *et al.*, 2008), it reduces yield.

In the case of K, this effect may be explained by its role as a cofactor for more than 40 enzymes and as a regulator of cell turgor (Mengel & Kirkby, 2001). The absorption dynamics of potassium in sunflower (*Helianthus annuus*) can be compared with those of chamomile, as the behavior of this nutrient within the plant is similar. Potassium plays a critical role during the flowering stage, accounting for 65 % of the total uptake throughout the crop cycle. In sunflowers, potassium reaches its maximum concentration in the stem at the onset of flowering, and along with the leaves, constitutes the main sink for this nutrient.



**Figure 1. Dry matter accumulation per plant (g) during the life cycle in chamomile plants (*Matricaria recutita* L.) grown at a  $\Psi_o$  of -0.072 Mpa in the nutrient solution.**

Own elaboration based on the data obtained.

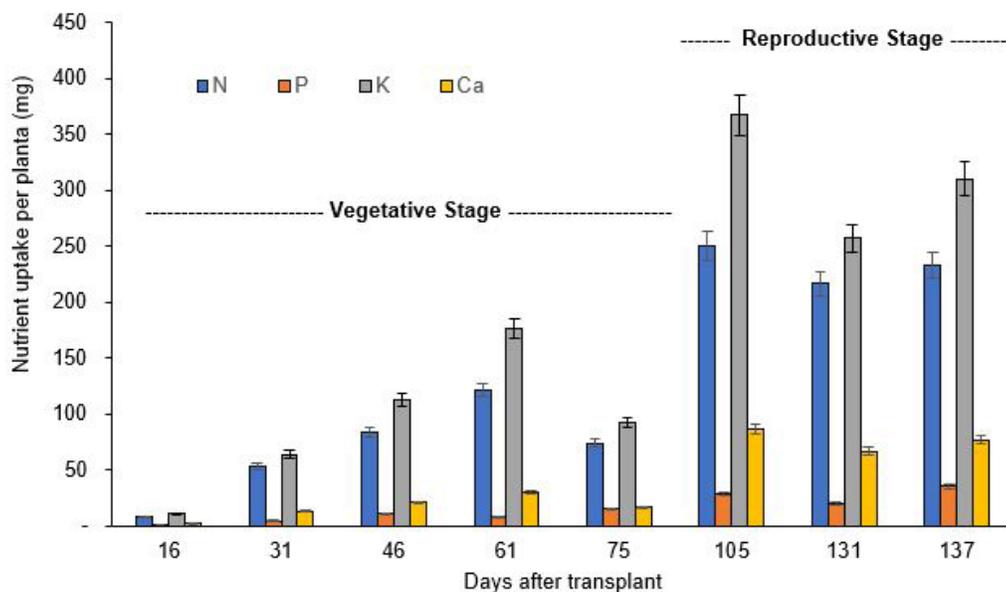
Subsequently, potassium migrates to the receptacle and later to the seeds. At the end of plant development, 50 % of the potassium is found in the stems, 25 % in the receptacles, and only 7 % in the seeds (Cortijo & Gimeno, 2012). From the beginning of the vegetative stage to the end of the reproductive stage, the highest accumulation of N, K, and Ca was recorded at 105 dat, and for P at 137 dat, which is consistent with the findings of Juárez-Rosete *et al.* (2011). The highest extraction of Ca and Mg was observed at 108 dat, considering the structural and positional differences within the plant. In contrast, various studies evaluating the application of inorganic and organic fertilizers (Morais *et al.*, 2006; Kisić *et al.*, 2019; Gandomi *et al.*, 2021) did not include Ca in their analyses. Phosphorus extraction was lower compared to the other nutrients and was not detected at the beginning of the vegetative stage. This behavior could be explained by the possibility that, during the first days of cultivation, P accumulation occurred primarily in the roots (Valdez-Aguilar *et al.*, 2015).

The results obtained in this study are consistent with those reported in other cultivars belonging to the Asteraceae family, where N and K are the nutrients with the highest accumulation and extraction throughout the crop cycle, as observed in chrysanthemum (*Chrysanthemum morifolium* Ramat), marigold (*C. officinalis* L.) cultivated in clay-loam soil (Valdez-Aguilar *et al.*, 2015), and Stevia (*Stevia rebaudiana*), in which the highest absorption rate was also recorded at 105 dat (Chamorro & Calvache, 2018).

Understanding crop nutrient needs and the dry matter accumulation curve enables the refinement of crop nutrition strategies, provided that soil nutrient supply and recovery efficiency are considered. With these factors in mind, it becomes possible to design fertilization plans that maximize fertilizer efficiency, reduce costs, and prevent soil and groundwater contamination. The improper use of mineral fertilizers, whether in excess or deficiency, especially nitrogen and phosphate fertilizers, has damaged the functionality of many productive soils, as indicated by chemical, physical, and biological indicators (Krasilnikov *et al.*, 2022).

An aspect not addressed in this study was the buildup of nutrients in the root zone. For chrysanthemum, for instance, the highest accumulation of P has been found in the root rather than in the flower (Valdez-Aguilar *et al.*, 2015). A similar outcome might be expected for chamomile cultivation; thus, examining this organ could provide more detailed data on nutrient uptake and assimilation across different plant structures. The exclusion of root analysis in this study suggests an underestimation of nutrient needs by about 4.7 %, since in this crop, root dry matter makes up that portion of total biomass, as noted by Hassan *et al.* (2025).

Figure 2 displays the nutrient extraction values per plant, measured in mg for N, P, K, and Ca. These results can guide the development of fertilization programs for chamomile cultivation. To determine the correct fertilizer amount, it is important to evaluate the soil's nutrient supply and the fertilizer's recovery efficiency (Sánchez-Prado *et al.*, 2018). Specifically, for potassium (K), it is crucial to consider the ppm levels already present in the soil, as once K reaches 350 ppm, additional potassium fertilization is unnecessary for increasing yield. In fact, applying extra K at this point may harm the quality of chamomile production (Mohammadreza *et al.*, 2012).



**Figure 2. Extraction of N, P, K, and Ca mg plant<sup>-1</sup> in the chamomile crop (*Matricaria recutita* L.) obtained in the treatment with an osmotic potential  $\Psi_o$  of -0.072 MPa during the crop cycle.**

Own elaboration based on the data obtained.

The results show that applying different amounts of nutrients to chamomile crops will influence the production and quality of the inflorescence, affecting its weight and size. Fractional fertilization tailored to the crop's phenological stage can optimize its production and yield. A critical moment in chamomile production is when the inflorescences are harvested, as more mature inflorescences tend to lose weight and therefore quality.

## Conclusions

An osmotic potential of -0.072 MPa with a 100 % Steiner concentration yielded the highest dry chamomile inflorescences. Nutrient extraction per plant followed the order  $K > N > P > Ca$ , which can help estimate nutrient needs for fertilization plans.

The nutrient requirement (kg) of *Matricaria recutita* per ton of dry matter was: N, 32.00; P, 3.67; K, 39.29; and Ca, 7.11.

## Author Contributions

Work conceptualization, JMM, CRJR; methodology, JMM, CRJR, JAAC, and GAS; software management, JMM, JAAC, and GAS; experimental validation, CRJR, JAAC, and GAS; data analysis, JAAC, GAS; data curation, JMM, CRJR, and JAAC; original draft writing, JMM, CRJR; review and editing, GAS, CAAG; project administration, CRJR, CAAG; funding acquisition, CRJR.

All authors have read and approved the final version of the manuscript.

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## Ethical statements

Not applicable.

## Informed consent statement

Not applicable.

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## Conflicts of interest

The authors declare no conflicts of interest.

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