Growth and accumulation of macronutrients in arugula

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Abstract**—***In Brazil, arugula is a vegetable often consumed in salads because it provides a flavorful option when paired with blander lettuces and because it is considered rich in vitamins A and C, potassium, sulfur and iron. However, several aspects of fertilization management for this crop must be studied further. Thus, the objective of this work was to determine the growth and accumulation of macronutrients within arugula, under field conditions. The experiment was conducted in four parcels (vegetable beds) with dimensions of 5.0 x 0.2 x 1.3 m, located within an experimental area of 54 m² (6.0 x 9.0 m). The Arugula cv. Cultivated, with seedlings produced in a protected environment. Standard fertilization was performed with 160 kg ha^{-1} of N, 340 kg ha^{-1} of P_2O_5, 160 kg ha^{-1} of K_2O, 20 kg ha^{-1} of S and 1 kg ha^{-1} of B. The treatments were constituted by different collection times at 7, 14, 21, 28, 35 and 42 days after the arugula seedlings transplanting. Between 18 and 38 days after the transplanting of the seedlings, a significant increment in the accumulation of dry matter occurred. In the period between 20 and 30 days after the transplanting, the greatest demand for most macronutrients occurred. The order of macronutrient accumulation by arugula at 42 days was as follows: K > N >Ca> P > Mg > S.*

Keywords**—Eruca sativa Miller, Fertilization, Nutrient extraction.**

I. INTRODUCTION

Arugula is a small herbaceous plant with elongated leaves and deeply cut limbus showing an average height of 10 to 30 cm in the harvest period. It has favorable development in mild temperatures with the harvest performed between 35 to 50 days after planting being able to do even 3 cuts depending on management conditions and variety [8], [27].

Although this plant is more adapted to temperate climate [8], arugula has important requirements for performance in the northeast region of Brazil given that its cycle and form of conduction resemble those of species widely cultivated in the region, like lettuce and coriander. In addition to the sharp growth in consumption when compared to other vegetables with a planted area of 6000 ha year^{-1},being that 85% of this national production is concentrated in the southeast region [23].

Arugula production can be influenced by several factors linked to management strategies, as inappropriate irrigation blade, climate, cultural practices, pest and disease control, and, mainly, availability of nutrient for the plant due to adequate crop fertilization is one of the most important attributes for crop productivity [3]. In this sense, the knowledge of the number of nutrients accumulated in plants enables the adoption of strategies in the crop fertilization program [25].

A nutrient absorption march is a tool adopted in crops for informing in the form of response curves as a function of plant age, periods of higher nutrient absorption, as well as the largest quantities, indicating the times of greatest nutritional demand, thus constituting a tool of great importance for the management and fertilization of crops [32]. Some studies on growth and accumulation of nutrients in vegetables have been carried out on tomatoes [5], beet [25], eggplant [28], and lettuce [26].

Regarding the arugula, there is little information in the literature about the higher demand for nutrients required by the crop, as well as the total amount extracted of nutrients requiring research on the accumulation of nutrients, because this technique related to the productivity gain of the culture is understudiedin the country.

These surveys become even more important when carried out on soils that show wide variability in their physical characteristics, chemical and morphological. As is the case with QuartzarenicNeosols which according to the diversity of its source material and its low degree of pedogenetic development, there are soils that can have high, medium, and even low agricultural potential [24].

Given the above information, the present work was developed to determine the growth rate and accumulation of arugula macronutrients, during its production cycle, under field conditions.

II. METHODOLOGY

The experiment was carried out over February to April 2017 in an experimental area of the Soil Study Group at the Agricultural School of Jundiaí (EAJ), belonging to the Federal University of Rio Grande do Norte (UFRN), Macaíba/RN RN (5° 53' 35.12" latitude-S e 35° 21' 47.03" longitude-W).

The soil in the experimental area was classified in the Brazilian Soil Classification System as QuartzeneNeossol [24]. The chemical characterization of the soil (Table 1) was carried out following the procedures proposed by [30].The climate of the region, according to the Koppen classification is included between the types As' and BSh' featured with rainy and hot summer, and dry winter with an average annual temperature of 27.1 °C, an average maximum temperature of 32°C and an average minimum temperature of 21°C, and the average annual rainfall between 800 and 1,200 mm [10].

Table 1. Soil chemical characterization of the experimental area before the implementation of the experiment.

Soilchemicalcharacterization	Collectiondepth (cm)	
	0-10	10-20
pH H_2O	4,9	4,28
P (mg dm^{-3})	19	14
K (mg dm^{-3})	166	117
Na (mg dm^{-3})	46	40
Ca (mg dm^{-3})	1,11	0,89
Mg (cmolc dm^{-3})	0,6	0,45
Al (cmolc dm^{-3})	0,05	0,1
H+Al (cmolc dm^{-3})	2,39	2,22
SB (cmolc dm^{-3})	2,34	1,81
CTC (cmolc dm^{-3})	4,73	4,03
V (cmolc dm^{-3})	49,42	44,97

The experiment was conducted in four plots with dimensions of 5.0 meters long, 0.2 meters high, and 1.30 meters wide, located within an experimental area of 54 m^2 (6.0 x 9.0 m). Arugula cv. Cultivated with seedlings produced in styrofoam trays of 200 cells, using organic compost as a substrate.

The seedlings remained in a protected environment, and at 21 days, counted from sowing, were transplanted in the definitive beds, using the spacing of 0.25 x 0.25 meters. The treatments consisted of different collection times (7, 14, 21, 28, 35 e 42 days after transplanting the seedlings), distributed based on the arugula cultivation cycle.

To increase the pH, it was necessary to correct (liming) the soil in the experimental area 30 days before the beginning of the experiment.The fertilization of foundation and cover was performed considering the analytical results of Table 1, applying in all experimental plots 160 kg ha^{-1} of N, 340 kg ha^{-1} of P_2O_5, 160 kg ha^{-1} of k_2O, 20 kg ha^{-1} of S and 1 kg ha^{-1} of B, in the form of urea, triple superphosphate, potassium chloride, ammonium sulfate and FTE BR 12 (source of micronutrients), respectively.

The foundation fertilization was carried out at the time of transplanting the seedlings, applying 20% of total nitrogen and potassium, and 100 % of phosphorus and boron. The cover fertilization was divided into two applications at 11 and 21 days after transplanting, applying 40% of the total nitrogen and potassium in each fertilization. Fertilization was carried out in furrows, made manually with the aid of three-tooth rakes, 5.0 cm from the seedlings.

Irrigation was performed daily using a micro-sprinkler system. The reach of the micro-sprinklers was around 4.5 m, being installed along the beds, every 3.0 m so that all plots were equally irrigated. For the irrigation depth and the irrigation shift, the type of soil, the arugula development stage, and the region's climate were taken into account, applying 3.8 mm day^{-1}.

The evaluation of dry matter accumulation and macronutrient accumulation (N, P, K, S, Ca e Mg) was carried out from the collection of six healthy plants from each plot. The first collection was performed at 7 days after transplanting the seedlings (DAT), and the remainder with

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an interval of 7 days for the next collection. Each collection was carried out randomly, always in the morning. In all, six collections were performed at 7, 14, 21, 28, 35, and 42 days after transplanting the seedlings. The plants were cut close to the ground with stainless scissors, placed in properly identified trays, and sent to the Gesolo laboratory. The estimate of the average height of the plants (cm) was made at all times of collection, measuring with the aid of a graduated ruler 6 plants in the central lines of each repetition.

In the laboratory, the plants were washed with distilled water, placed in paper bags identified according to the treatment, and then sent to the forced air circulation oven, at a temperature of 65 ºC, until reaching constant weight. After this period the samples had their dry matter estimated, using an analytical balance. With the dry matter values of each collection, together with the crop spacing used in this experiment, it was possible to determine the arugula dry matter accumulation in "t ha^{-1}" throughout its development cycle.

With the estimated dry matter, the rocket samples were ground in a Willey mill; and then sent to the plant tissue analysis laboratory of the Agricultural Research Corporation of Rio Grande do Norte (EMPARN), where they were subjected to chemical analysis to quantify the levels of macronutrients (N, P, K, S, Ca e Mg), following the methodology proposed by [17]. The accumulation of arugula nutrients over the growing cycle was calculated by multiplying the macronutrient (N, P, K, S, Ca e Mg) contents by the accumulation of dry matter.

The effects of the collection periods on the growth and accumulation of macronutrients were evaluated by regression analysis, using the statistical software Sisvar, version 4.6 [7]. To explain the behavior of the analyzed variables, non-linear regression models were used, using the sigmoidal function $\hat{y} = a/(1+e-(x-xo/b))$, where: $\hat{y}$ = dependent variable; a = maximum point of the curve; e = base of the Neperian logarithm, b = adjustment parameter; x = independent variable; and, xo = inflection point (point at which the maximum rate of variation of the function occurs).

The curves with the macronutrient accumulation rates were obtained using the first-order derivative of the equation, equal to zero [19], [6]. The points of minimum curvature (PCmin) and maximum (PCmax) were also evaluated, according to the method mentioned by [31], using the parameters of non-linear equations, where: PCmin = xo - 2b; e, PCmax = xo + 2b. The PCmim indicates the moment on the curve when expressive gains begin in each analyzed variable. On the other hand, PCmax expresses the moment when these gains start to stabilize.

III. RESULTS

Mineral fertilization showed good productive performance for the plant height and dry matter accumulation variables. When analyzing the growth variables along the productive cycle, it is observed, from the second day after transplanting the seedlings (DAT), a considerable increase in the height of the arugula plant up to 27 DAT, and after that period there was stabilization in the height increase, with an average of 25.82 cm $plant^{-1}$ (Figure 1A).

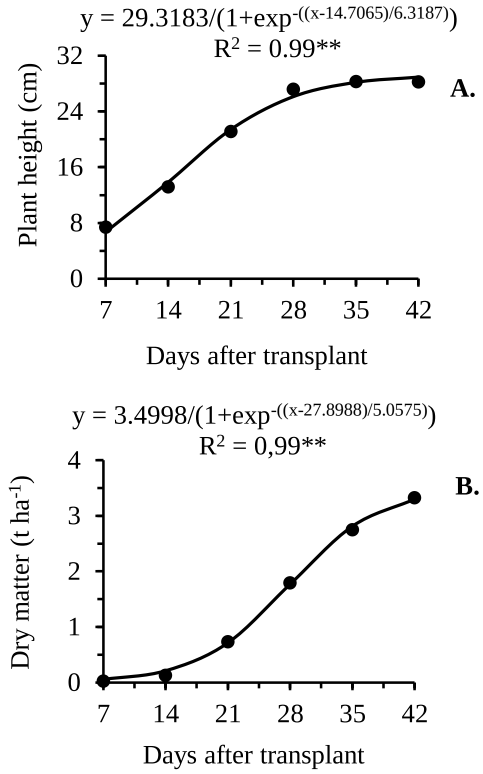

Fig.1: Height (A) and dry matter accumulation (B) of arugula plants, as a function of different collection times

In general, the number of nutrients accumulated by the rocket plants was directly related to the increase in height and accumulation of dry matter. It was observed that in the first days after the transplant, the accumulations are modest and similar. From the 20 DAT onwards, there was a marked increase in the accumulation of these nutrients, which increased considerably until the end of the cycle, with larger leaves and darker color.

At the beginning of the arugula development, dry matter gains occurred slowly, with relatively low values being observed up to 18 DAT(Figure 1B). After this period it was possible to observe a rapid increase in the accumulation of dry matter (PCmin), with an average production of 416.88 kg ha^{-1}. At 38 DAT, the arugula dry matter accumulation began to stabilize (PCmax), with production around 3,080.33 kg ha^{-1}. During this period (18 to 38 DAT), there was an increase of 86% in the arugula dry matter accumulation.

Nitrogen was the second most accumulated nutrient by rocket plants, reaching a maximum of 536.16 kg ha^{-1} at the end of the cycle (42 DAT). The accumulation of nitrogen was initially very slow, similar to that observed with the accumulation of dry matter (Figure 1B), but after 16 DAT (PCmin) nitrogen extraction was accentuated, tending to stabilize at around 29 DAT (PCmax) (Figure 2A). At around 23 DAT, the highest nitrogen accumulation rate occurred (45.64 kg ha^{-1} day^{-1}) (Figure 2B).

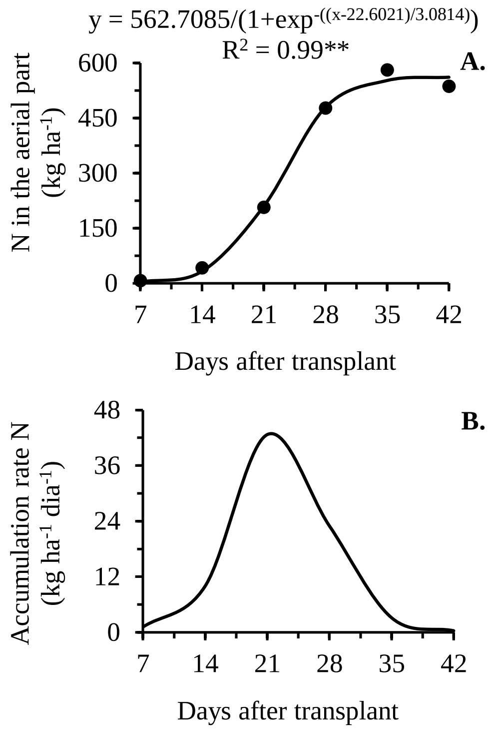

Fig.2: Accumulation (A) and daily accumulation rate (B) of nitrogen from arugula plants, as a function of different seasons collections

In decreasing order of accumulation of macronutrients in the aerial part of the arugula, analyzed in this work, phosphorus occupies the fourth place. PCmim and PCmax for this nutrient occurred at 21 and 41 DAP (Figure 3A), accumulating an average of 24.83 and 183.44 kg ha^{-1}, respectively. The highest demand for phosphorus by arugula plants occurred at 31 days (Figure 3B), with an accumulation rate of 10.49 kg ha^{-1} day^{-1}; in that period the plant accumulated 104.13 kg ha^{-1}, corresponding to 55% of the total accumulated by the plants at the end of the cycle at 42 DAT (Figure 3A).

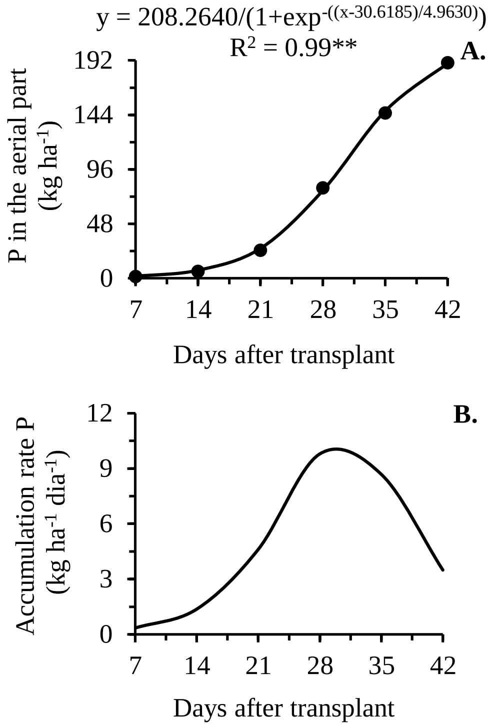

Fig.3: Accumulation (A) and daily accumulation rate of phosphorus (B) from arugula plants, as a function of different seasons collections

Throughout the development of arugula, potassium was the nutrient most extracted by plants (Figura 4A). Similar to that observed in Figure 2A, initially the accumulation of potassium was very slow, with the expressive gains starting at around 20 DAT (PCmim), accumulating about 153.23 kg ha^{-1}. At 33 DAT the accumulation of potassium started to stabilize (PCmax), with production around 1,132.32 kg ha^{-1}. The highest accumulation rate for this nutrient occurred around 27 DAT, accumulating an average of 99.12 kg ha^{-1} day^{-1} (Figure 4B).

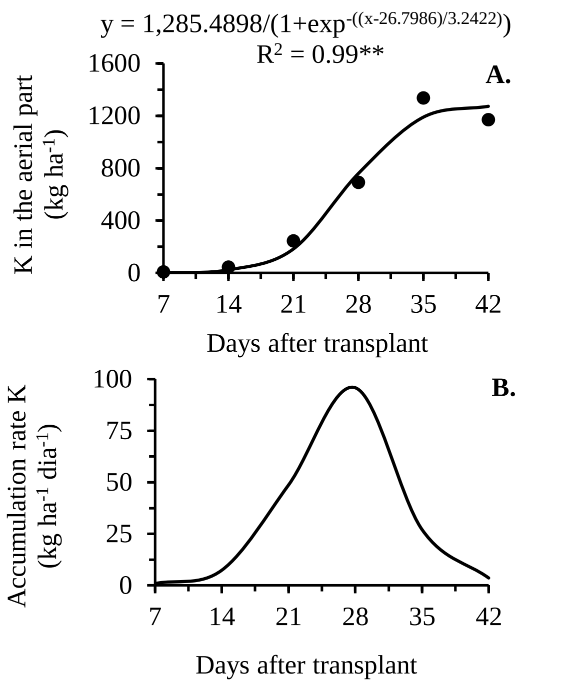

Fig.4: Accumulation (A) and daily accumulation rate of potassium (B) from arugula plants, as a function of different seasons collections

At the end of the cycle, at 42 DAT, sulfur was the least exported macronutrient by arugula plants. The largest accumulations of sulfur were observed in the period from 18 to 36 DAT, corresponding, respectively, to 15.99 and 118.18 kg ha^{-1} (Figure 5A).

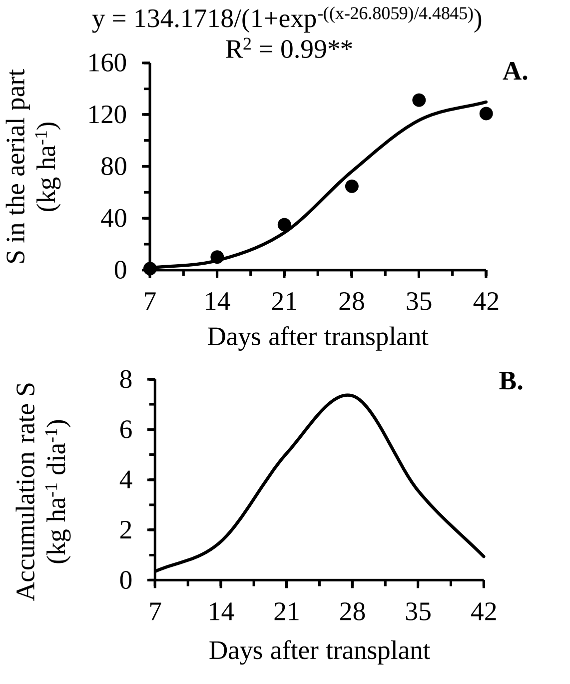

Fig.5: Accumulation (A) and daily accumulation rate of sulfur(B) from arugula plants, as a function of different seasons collections

The highest demand for sulfur by arugula plants occurred at 27 DAT, with an accumulation rate of 7.48 kg ha-1 day^{-1}(Figure 5B). At that time, at 27 DAT, the arugula plants accumulated 67.09 kg ha^{-1}, which corresponds to 55% of the total accumulated at the end of the cycle.

PCmim and PCmax for calcium occurred at 20 and 38 DAT (Figure 6A), accumulating an average of 42.42 and 313.46 kg ha^{-1}, respectively. The highest rate of calcium accumulation by arugula plants occurred at 29 DAT (20.34 kg ha^{-1} day^{-1}) (Figure 6B), and at that time, around 53% of the calcium needed for the development of the crop accumulated (177.94 kg ha^{-1}) (Figure 6A); from that moment, the accumulation gradually decreased, reaching the end of the cycle (42 DAT) with 331.69 kg ha^{-1}, occupying the third place of the most accumulated macronutrient in the aerial part of the arugula.

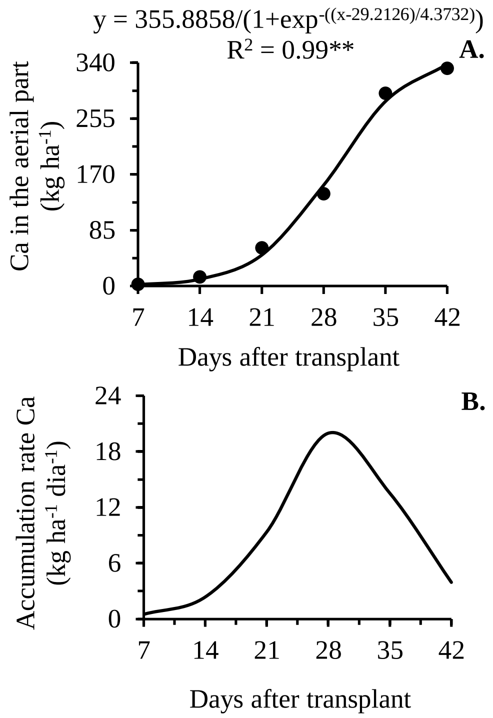

Fig.6: Accumulation (A) and daily accumulation rate of calcium (B) from arugula plants, as a function of different seasons collections

At 42 days after transplanting the seedlings, magnesium was the fifth macronutrient that most exported by arugula plants, with an average accumulation of 134.79 kg ha^{-1} (Figure 7A). The significant increases in magnesium accumulation started at 21 DAT (PCmin), extracting about 17.15 kg ha^{-1}, and started to stabilize by 36 DAT, with 126.73 kg ha^{-1}. At 28 DAT, the largest export of magnesium to the aerial part of the arugula plants was observed, approximately 9.59 kg ha^{-1} day^{-1} (Figure 7B).

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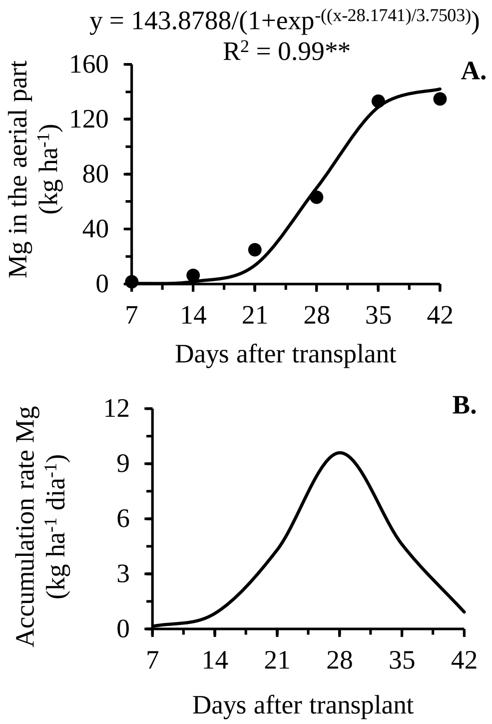

Fig.7: Accumulation (A) and daily accumulation rate of magnesium (B) from arugula plants, as a function of different season's collections

IV. DISCUSSION

The positive performance of the plant height and dry matter accumulation variables was possibly due to the application of nitrogen since although arugula is not a large crop, it requires a large number of nutrients at the end of the cycle. Therefore, nitrogen fertilization promoted greater development of arugula plants, ensuring better characteristics of commercial interest to the vegetable such as the size and color of the leaves [25].

According to [12], it is common in leafy vegetables, the plants initially present a slow phase of dry matter accumulation, intensifying at the end of the cycle. [22], also found a low accumulation of dry matter at the beginning of the arugula cycle and intensified until 43 days after sowing. This behavior can be explained, probably, because at the beginning of the development, the leafy vegetables present a low supply of leaves and roots, consequently, a lower production of photoassimilates and absorption of nutrients, resulting in lower accumulation of dry matter.

The availability of nitrogen in the soil is almost always a limiting factor that influences plant growth more than any other nutrients [4]. This is because nitrogen is an essential constituent of many proteins and directly interferes with the photosynthetic process, due to its participation in the chlorophyll molecule [16], hence the similarity between the nitrogen accumulation rate (Figure 2B) and the dry matter accumulation rate (Figure 1B).

Phosphorus is one of the essential nutrients for plant growth [11], as it plays a structural role and is linked to several important metabolic processes, such as energy transfer and storage, which can affect several others, such as protein and nucleic acid synthesis [29]. [14]when evaluating the effects of phosphorus doses on the arugula production, found that this nutrient provides an increase in the vegetative growth and productivity of this vegetable since P stimulates the growth and formation of the root system at the beginning of the development of cultivated plants.

Potassium, being the most accumulated macronutrient in vegetables [8], plays important roles, such as enzyme activation, photosynthesis, translocation of assimilates and protein synthesis, thus making it fundamental to plant growth and nutrition [12]. In general, the absorption of potassium, as well as nitrogen and phosphorus, follows the same trend as the biomass accumulation rate of the crop [13].

Sulfur influenced leaf color, playing a crucial role in the growth of arugula plants and adaptation to stress, also acting on the activation of the nitrate reductase enzyme, improving nitrogen metabolism, due to the synergistic action of sulfur and nitrogen [9], [27]. However, sulfur is considered to be an immobile nutrient in the plant, with a very low rate of redistribution after reaching some plant organs, such as old leaves [29].

When studying the sulfur cover fertilization in the arugula culture, similar to the present study, [27] observed that sulfur fertilization caused the greater intensity of green color in the arugula leaves, providing better product quality, making the arugula more attractive to the consumer, corroborating with [12] when studying the growth and accumulation of nutrients in coriander and arugula.

In agreement with what was found in this work, [12] reported that calcium was the third most exported macronutrient by arugula plants. As calcium is an element that has low mobility in the plant [20], its availability in the soil solution for plants, as well as its absorption by plants, is essential for maintaining the integrity of the plasma membrane [33]. Also, it plays a critical role in cell division and development, in the structure of the cell wall and, the formation of the middle lamella [15].

Magnesium is one of the most widely used macronutrients by plants, but in smaller portions than nitrogen and potassium. In general, it is similar to phosphorus, sulfur, and calcium, as observed in this work. Of the existing nutrients, magnesium is essential in photosynthesis, since its main function is to be the central atom of the chlorophyll molecule, in the green leaves of plants. The amount of magnesium in the central atom of chlorophyll corresponds to 2.7% of its weight and represents around 15 to 20% of the total magnesium present in the plant [29].

In general, the results obtained in the present study show a greater demand for nutrients by the arugula plant as the end of the cycle approaches. This fact occurs due to the increase of matter and accumulation of nutrients that occur in hardwoods after the initial phase of the culture, whose period corresponds to about 2/3 of the cycle [12], as observed by [1] when studying the growth and accumulation of macronutrients in vegetables.

V. CONCLUSION

Between 18 and 38 days after transplanting the arugula seedlings, there was a significant increase in dry matter accumulation from 0.42 to 3.08 t ha-1. The period of greatest demand for arugula in nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium was 23, 31, 27, 27, 29, and 28 days after transplanting the seedlings, respectively. Arugula plants accumulate nutrients in their shoot at 42 days after transplanting the seedlings in the following order: K (1.169,29 kg ha^{-1}) > N (536,16 kg ha^{-1}) >Ca (331,60 kg ha^{-1}) > P (189,95 kg ha^{-1}) > Mg (134,79 kg ha^{-1}) > S (120,91 kg ha^{-1}).

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