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RESEARCH ARTICLE

Distribution dynamics of nutrient and biomass in yacon organs

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Abstract

Studies on nutrient absorption patterns allow for the identification of periods of peak nutritional demand, the amount of nutrients accumulated in each organ, the quantity exported by harvest, and the necessary replenishment to the soil. These insights are crucial for developing effective fertilization programs for crops. This study aimed to determine the nutrient absorption pattern of macro and micronutrients and the accumulation of biomass in various organs of yacon plants. The experiment was conducted under field conditions, following a randomized block design. The treatments consisted of different plant ages. Seven evaluations were conducted monthly, starting 30 days after transplanting. Twelve plants from the useful area were sampled for each evaluation. The plants were divided into five parts (leaves, stems, rhizophores, roots, and tuberous roots) to determine dry biomass. The samples were analyzed for N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn content. Yacon prioritized the allocation of photoassimilates for biomass production in the following order: tuberous roots, rhizophores, leaves, stems, and fine roots. Nutrient absorption by yacon plants followed this order: Ca > N > K > Mg > P > Fe > Mn > Zn > Cu. Tuberous roots were the main organ for nutrient accumulated, exporting from the system 71, 15, 57, 125, 11, 1.8, 0.87, 0.40, and 0.27 kg há⁻¹ of N, P, K, Ca, Mg, Fe, Zn, Mn, and Cu, respectively. These results provide critical physiological parameters for formulating evidence-based fertilization programs and modeling yacon growth, thereby advancing precision nutrient management. Moreover, integrating these data into agronomic models and sustainability assessments will facilitate the crop's development as a high-value functional food, supporting both productive and environmental goals.

Keywords: *Smallanthus sonchifolius*; biomass accumulation; nutrient export; nutrient absorption; plant physiology.

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1. Introduction

The yacon potato (*Smallanthus sonchifolius*) has been considered a nutraceutical food due to its designated components, such as soluble dietary fibers and prebiotics, which, because of their low digestibility by human gastrointestinal enzymes, selectively stimulate the growth and activity of health-promoting intestinal bacteria (Gusso et al., 2014; Sacramento et al., 2017). Currently, it is described as the food with the highest content of fructo-oligosaccharides (FOS) in nature (Brandão et al., 2014; Mendes et al., 2024). The prebiotic activity of the FOS contained in yacon has been associated

with health benefits, such as relief of constipation, increased mineral absorption, strengthening of the immune system (Vaz-Tostes et al., 2014), and reduction in the development of colon cancer (Moura et al., 2012; Verediano et al., 2020), which are scientifically proven when FOS is consumed in recommended doses.

These characteristics have driven yacon potato consumption worldwide, generating significant demand for knowledge regarding plant behavior with the aim of improving its cultivation. To achieve this, new research is necessary, including the generation of information on nutritional aspects, which requires

knowledge of the nutrient uptake dynamics, as well as the partitioning of photoassimilates and, consequently, biomass accumulation in the various plant organs.

Studying nutrient uptake dynamics allows for evaluating the relationship between nutrient supply, dry matter accumulation, and plant age. In this way, it is possible to identify the period of greatest nutritional demand, the quantity of nutrients required by the crop, the amount of nutrients accumulated in each organ, the amount exported at harvest, and the amount that must be replenished in the soil. These are crucial pieces of information that can aid in the crop fertilization program (Echer et al., 2009; Marschner, 2012).

Nutrient accumulation in plant tissues varies according to species, cultivar, tissue type, and plant age. Nutrient uptake in vegetables generally follows the pattern of growth or dry matter accumulation (Malavolta, 2006). It is worth noting that nutrient accumulation in the plant's dry biomass throughout the cycle exclusively demonstrates what the plant requires and not the amount that should be applied, as it is necessary to consider nutrient use efficiency, which varies depending on climatic conditions, water management, and cultivation environment, among other factors (Prado & Nascimento, 2003).

Understanding the factors influencing nutrient uptake and dynamics is fundamental to comprehending how they affect the biomass of plant tissues. Numerous studies have been conducted on various crops to elucidate the factors affecting nutrient dynamics and partitioning, and how this response translates into biomass, such as the critical demand period and soil moisture (Amissah et al., 2024; Ma et al., 2025). Temporal variation and phenological stage also play a key role in nutrient reallocation to different organs, as observed by Li et al., 2024 in blueberry crops. Mao et al., 2024 also demonstrated the patterns of nutrient accumulation and distribution in tobacco, where the total accumulation of N, P, and K over the entire growth period was 4.92 g/plant, 0.46 g/plant, and 5.43 g/plant, respectively.

Although information on these relationships exists for different cultivated plants, there is still scarce scientific literature available regarding yacon. Given the lack of information on this crop, especially regarding mineral nutrition, understanding the nutrient uptake dynamics in yacon, as well as biomass accumulation in various plant organs, will facilitate improvements in fertilization management, optimizing fertilizer use and thereby

significantly contributing to the crop's development and productivity.

Thus, the objective of this study was to determine the nutrient uptake dynamics of macro and micronutrients and biomass accumulation in the various organs of yacon potato plants.

2. Methodology

Area characterization

The experiment was conducted at Garganta's farm, Celina district, in the municipality of Alegre, state of Espírito Santo, Brazil, located at an altitude of 680 meters, latitude 20° 47' 1" south, and longitude 41° 36' 56" west. The local climate, according to Köppen's classification, is tropical humid with an average annual temperature of 24 °C (Pezzopane et al., 2012). A meteorological station, Irriplus® model E5000, was installed at the experimental site. During yacon cultivation, the following meteorological data were recorded: 406.93 mm of accumulated precipitation and an average air temperature of 20.10°C.

The soil was classified as Red-Yellow Latosol with medium texture (Santos et al., 2018). Soil samples were collected from the 0 - 20 cm depth layer, and after analysis, presented the following characteristics: pH (H₂O) 4.56; Mehlich 1 phosphorus (P): 27.42 mg dm⁻³; potassium (K): 103 mg dm⁻³; aluminum (Al): 0.70 cmolc dm⁻³; calcium (Ca): 1.25 cmolc dm⁻³; magnesium (Mg): 0.27 cmolc dm⁻³; sum of bases (SB): 1.82 cmolc dm⁻³; base saturation percentage (V%): 20.56; cation exchange capacity (CEC_{7.0}): 2.52 cmolc dm⁻³. Soil preparation involved plowing to a depth of 40 cm, followed by harrowing. Lime was applied using dolomitic limestone to raise base saturation to 70%, and a 60-day waiting period was observed before planting.

Propagation and fertilization

Yacon seedlings were produced from propagules formed by rhizophores weighing approximately 20 g (Pedrosa et al., 2020). Plastic bags measuring 10x18x21 cm were filled with a substrate composed of soil and manure in a 3:1 v/v ratio. The manure analysis showed concentrations of 5.53 g kg⁻¹ of P, 4.44 g kg⁻¹ of K, 13.81 g kg⁻¹ of Ca, 2.91 g kg⁻¹ of Mg, 7.10 g kg⁻¹ of N, 20.15 mg kg⁻¹ of Cu, 22,835.6 mg kg⁻¹ of Fe, 395.6 mg kg⁻¹ of Mn, and 56.02 mg kg⁻¹ of Zn. The bags were kept under a shade screen (50% light restriction), with two daily irrigations using 13 liters of water evenly distributed among the seedlings.

At 40 days of age, seedlings of uniform size were selected and transplanted at a spacing of 1.0 x 0.5

m on ridges approximately 30 cm in height (Quaresma et al., 2021), with each usable plant surrounded by four border plants. During the crop cycle, weed control and drip irrigation were performed with a fixed irrigation interval of two days. Fertilization consisted of the application of 50:80:60 kg ha⁻¹ of NPK, based on Kruger (2003), using urea (45% N), single superphosphate (18% P₂O₅, 16% Ca, and 8% S), and potassium chloride (60% K₂O) as sources. The total of the phosphorus and one-third of the nitrogen and potassium were applied at planting, with the remaining two-thirds of nitrogen and potassium applied as topdressing 30 days after seedling transplanting.

Experimental design and treatments

The experimental design was a randomized block design with seven treatments corresponding to evaluation times (plant ages), based on preliminary observations to capture the complete growth cycle dynamic of yacon. Evaluations were conducted monthly, starting 30 days after transplanting. At each evaluation, 12 plants were removed from the usable area for analysis. To carry out the analysis, the plants were divided into five parts (leaves, stems, rhizophores, roots, and tuberous roots). Each part was dried in a forced air circulation oven at 70 ± 5°C until a constant mass was achieved, followed by dry mass measurement. Possible leaf drops were disregarded. From these samples, P, K, Ca, Mg, Cu, Fe, Mn, and Zn contents were determined in each plant organ after nitric-perchloric digestion. Nitrogen was determined after sulfuric digestion (Carmo et al., 2000).

Statistical analysis

Data were analyzed through regression, and significant equations were adjusted up to a 5% probability using the F-test with the highest determination

coefficients (R²), with the aid of the R software, version 4.3.0 (R Core Team, 2020).

3. Results and discussion

The yacon allocates the majority of its photosynthates to storage organs (tuberous roots and rhizophores). At harvest, dry biomass accumulation in tuberous roots (7985 kg ha⁻¹) and rhizophores (3805 kg ha⁻¹) were significantly higher than in leaves (269 kg ha⁻¹), stems (476 kg ha⁻¹), and fine roots (146 kg ha⁻¹), as shown in Figure 1.

The storage process, through biomass accumulation in tuberous roots and rhizophores, began 30 days after transplanting (DAT) and increased linearly until 210 DAT. Biomass accumulation in fine roots also followed a linear pattern throughout the growth cycle, but at a lower investment level. Biomass accumulation in leaves and stems, however, better fit a quadratic model, with maximum biomass accumulation in leaves (734 kg ha⁻¹) occurring around 110 DAT, and in stems (545 kg ha⁻¹) around 150 DAT, as shown in Figure 1 and detailed in Table 1. When observing biomass accumulation behavior throughout the growth cycle across different plant organs (Figure 1), it becomes evident that yacon allocates the majority of its photosynthates to storage organs (tuberous roots and rhizophores). The onset of storage accumulation at 30 DAT in yacon can be considered early for a plant of Andean origin. Common potatoes (*Solanum tuberosum*), which share a similar origin, typically start storing reserves around 60 DAT. Some genotypes that begin this process earlier are considered early maturing genotypes (Lyra et al., 2015). This earlier accumulation is more common in tropical plants, such as sweet potatoes (*Ipomoea batatas*), which usually start reserve accumulation at around 30 DAT (Echer et al., 2009).

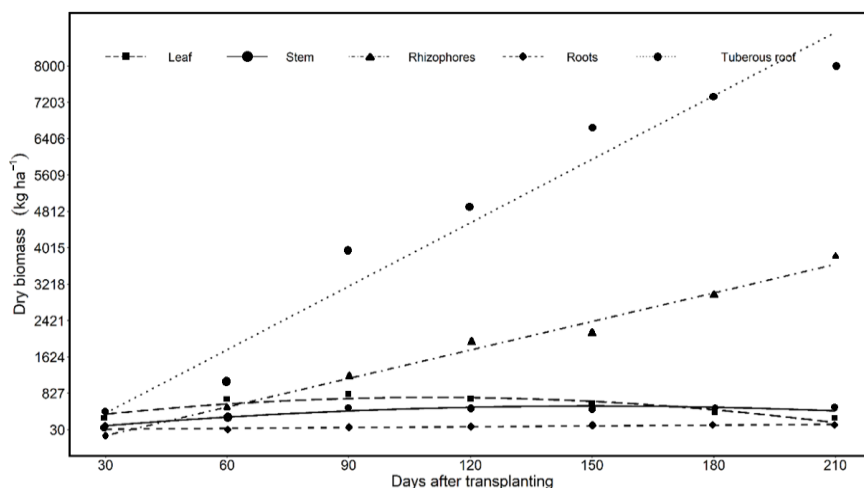


Figure 1. Dry biomass accumulation in yacon potato organs throughout the growth cycle.

Table 1

Regression equations for biomass accumulation in yacon potato organs

Yacon	Model	Equation	R ² (%)	P-value (%)
Leaves	Quadratic	$Y = 45.4285 + 12.45476X - 0.0563X^2$	77.70	4.97
Stem	Quadratic	$Y = -125.5858 + 8.95674X - 0.0299X^2$	94.63	0.28
Rhizophores	Linear	$Y = -724.5143 + 20.8311X$	98.20	0.00
Roots	Linear	$Y = 21.4571 + .5867X$	94.12	0.02
Tuberous root	Linear	$Y = -1002.8715 + 46.366X$	95.84	0.01

R²: Coefficient of determination.

Regarding micronutrient absorption, yacon followed a general absorption order of Fe > Mn > Zn > Cu, with iron being absorbed in much larger quantities, as shown in **Figure 2**. The absorption curves for Fe, Mn, and Zn showed similar behavior, with a better fit to a quadratic model in leaves and stems, indicating increasing demand during the initial growth phase and a decline during the final phase. Both in leaves and stems, peak absorption occurred around 120 DAT. For other organs, a linear growth model provided a better fit. For copper (Cu), absorption followed a quadratic model across all plant parts, with increasing demand during the initial growth phase and a decrease in the final phase. Peak absorption of Cu in leaves, stems, and fine roots occurred around 120 DAT, while in rhizophores and tuberous roots, it occurred around 150 DAT, as shown in **Figure 2** and detailed in **Table 2**. Tuberous roots absorbed the most Zn and Cu, in quantities significantly higher than other organs.

They also had the second-highest Fe absorption, close to that of rhizophores. For Mn, leaves absorbed the most during the cycle, but at the end of the cycle, larger quantities were found in tuberous roots as well, as shown in **Figure 2**.

Yacon tuberous roots absorbed 1.8, 0.87, 0.40, and 0.27 kg ha⁻¹ of Fe, Zn, Mn, and Cu, respectively, as shown in **Figure 2**. Given that tuberous roots are the primary marketable product and, therefore, the main nutrient exporters, these values indicate the minimum quantities of these micronutrients that would be removed from the production system.

This pattern is similar to what has been observed in other tuberous vegetables, such as carrots, beets, radishes, and turnips, where iron is the primary micronutrient absorbed, followed by manganese and zinc (Furlani et al., 1978). However, this is different from sweet potatoes, which exhibit the following absorption order: Mn > B > Zn > Fe > Cu (Echer et al., 2009).

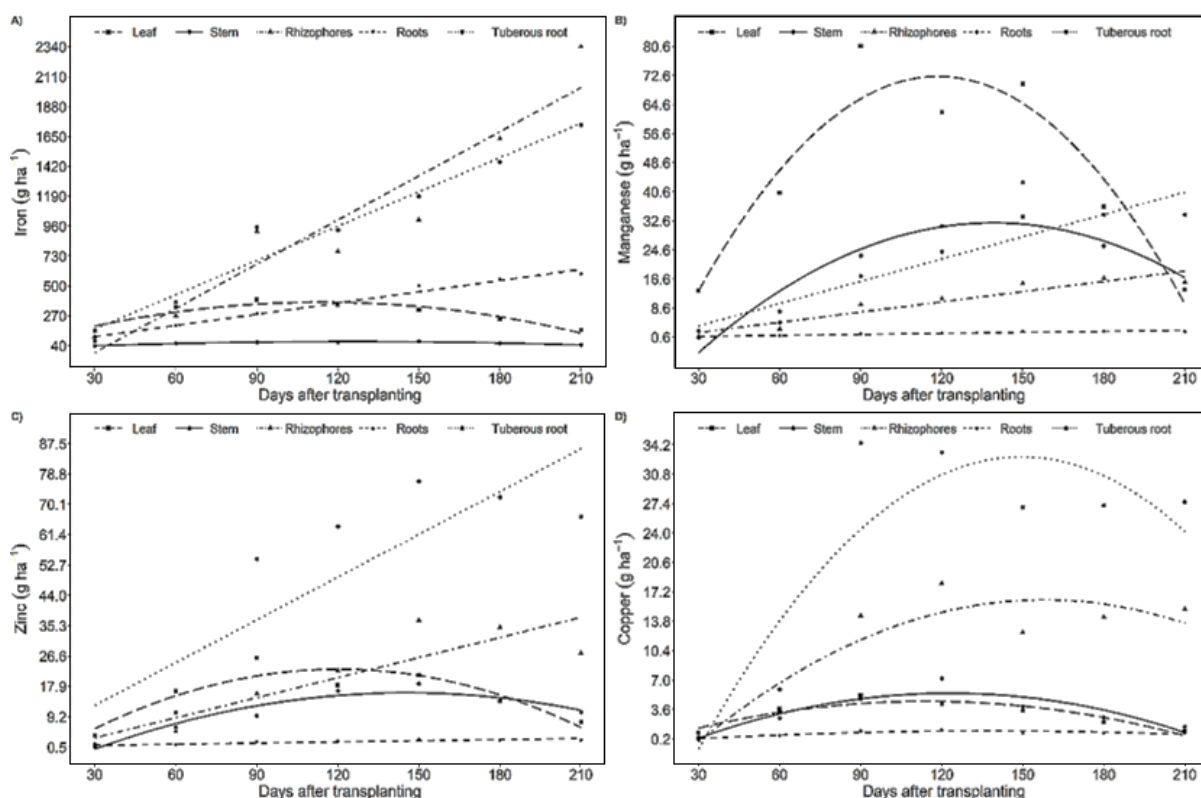
**Figure 2.** Micronutrient uptake dynamics in yacon potato organs throughout the growth cycle.

Table 2

Regression equations for micronutrient uptake in yacon potato organs

Iron (Fe)				
Yacon	Model	Equation	R ² (%)	p-value (%)
Leaves	Quadratic	$Y = 37.1971 + 5.90947X - 0.0259X^2$	88.39	1.34
Stem	Quadratic	$Y = 16.4642 + 0.8723X - 0.0035X^2$	95.08	0.24
Rhizophores	Linear	$Y = -352.3115 + 11.3261X$	90.06	0.10
Roots	Linear	$Y = 22.9199 + 2.8775X$	98.15	0.00
Tuberous root	Linear	$Y = -95.2029 + 8.7896X$	96.00	0.01
Maganese (Mn)				
Yacon	Model	Equation	R ² (%)	p-value (%)
Leaves	Quadratic	$Y = -33.2672 + 1.78078X - 0.0076X^2$	89.62	1.07
Stem	Quadratic	$Y = -25.9601 + 0.83407X - 0.003X^2$	77.96	4.85
Rhizophores	Linear	$Y = -0.9572 + 0.0938X$	89.93	0.11
Roots	Linear	$Y = 0.4871 + 0.0093X$	88.90	0.14
Tuberous root	Linear	$Y = -2.4272 + 0.2042X$	86.75	0.22
Zinc (Zn)				
Yacon	Model	Equation	R ² (%)	p-value (%)
Leaves	Quadratic	$Y = -7.3772 + 0.5014X - 0.0021X^2$	83.23	2.81
Stem	Quadratic	$Y = -9.5301 + 0.352X - 0.0013X^2$	90.54	0.89
Rhizophores	Linear	$Y = -2.5872 + 0.1916X$	78.50	0.79
Roots	Linear	$Y = 0.6571 + 0.0109X$	78.42	0.79
Tuberous root	Linear	$Y = 0.1871 + 0.4085X$	74.16	1.27
Copper (Cu)				
Yacon	Model	Equation	R ² (%)	p-value (%)
Leaves	Quadratic	$Y = -1.1243 + 0.0992X - 0.0005X^2$	91.95	2.06
Stem	Quadratic	$Y = -3.5872 + 0.14763X - 0.0007X^2$	81.49	3.42
Rhizophores	Quadratic	$Y = -8.7429 + 0.31698X - 0.0011X^2$	81.92	3.26
Roots	Quadratic	$Y = -0.3372 + .0209X - 0.0001X^2$	80.01	3.22
Tuberous root	Quadratic	$Y = -20.0629 + 0.7072X - 0.0024X^2$	79.26	4.34

R²: Coefficient of determination.

The absorption of macronutrients (N, P, K, Ca, and Mg) followed similar patterns, with a better fit to a quadratic model in leaves and stems, showing increasing demand during the initial growth phase and decreasing in the final phase. In leaves, peak absorption for N, P, and K occurred around 90 DAT, while for Ca and Mg, it occurred around 120 DAT. In stems, maximum absorption for N, P, and K occurred around 120 DAT, and for Ca and Mg, around 150 DAT. For other organs, a linear growth model provided a better fit, as shown in **Figure 3** and detailed in **Table 3**.

Tuberous roots absorbed the most macronutrients, in much higher quantities than other organs. Yacon tuberous roots absorbed 71, 15, 57, 125, and 11 kg ha⁻¹ of N, P, K, Ca, and Mg, respectively, as shown in **Figure 3**. Since these are the primary marketable organs of yacon and, therefore, the main nutrient exporters, these values indicate the minimum nutrients that would be removed from the production system, with an average tuberous root yield of 68.6 t ha⁻¹ in this study.

Overall, yacon followed the nutrient absorption order of Ca > N > K > P > Mg (**Figure 3**). This result is similar to what has been observed in sweet potatoes (**Echer et al., 2009**), but differs from other tuberous vegetables, such as carrots, beets, radishes, and turnips, which show potassium as the primary macronutrient absorbed, followed by nitrogen and calcium (**Furlani et al., 1978**).

To estimate the nutrient replenishment demand through NPK fertilization, solely to replace nutrient exports, 142 kg ha⁻¹ of N would need to be supplied, considering that plants typically utilize 50% of applied nitrogen. For P, the demand would be 150 kg ha⁻¹, considering a 10% use efficiency. For K, the demand would be 142.5 kg ha⁻¹, assuming a 40% use efficiency (**Baligar et al., 2001**).

Therefore, it is evident that yacon tuberous roots represent the primary source of nutrient export from the system, highlighting the need for careful attention to nutrient replenishment through fertilization.

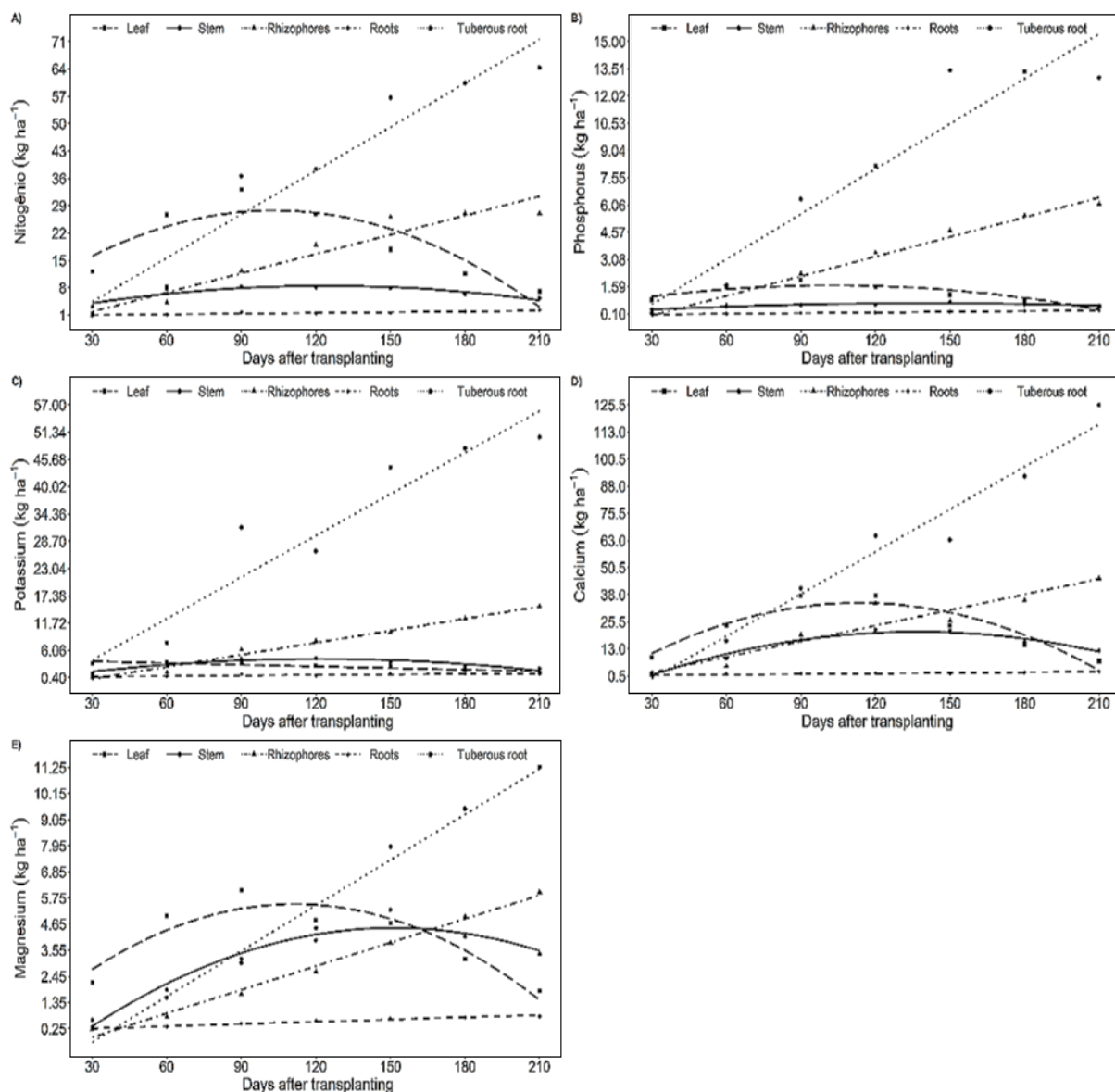


Figure 3. Macronutrient uptake dynamics in yacon potato organs throughout the growth cycle.

4. Conclusions

This study delivers the first detailed profile of biomass allocation and nutrient dynamics in yacon, revealing tuberous roots as the primary storage organ ($7,985 \text{ kg ha}^{-1}$) and a calcium-dominated uptake sequence ($\text{Ca} > \text{N} > \text{K} > \text{Mg} > \text{P} > \text{Fe} > \text{Mn} > \text{Zn} > \text{Cu}$). Quantified nutrient exports (71 kg N , 15 kg P , 57 kg K , 125 kg Ca , 11 kg Mg ha^{-1}) underpin

precision fertilization recommendations. These insights support development of targeted N-P-K regimes and cultivar-specific management. Future research should explore fertilizer optimization, genetic variation in nutrient use, and environmental interactions to enhance yacon sustainability and place it as a high-value functional food, contributing to sustainable agriculture and nutritional security.

Table 3

Regression equations for macronutrient uptake in yacon potato organs

Nitrogen (N)				
Yacon	Model	Equation	R ² (%)	P-value (%)
Leaves	Quadratic	$Y = 4.5799 + 0.44832X - 0.0022X^2$	80.26	3.89
Stem	Quadratic	$Y = 0.7242 + 0.12511X - 0.0006X^2$	83.97	2.56
Rhizophores	Linear	$Y = -3.0886 + .1642X$	92.72	0.04
Roots	Linear	$Y = 0.7457 + 0.0064X$	83.18	0.41
Tuberous root	Linear	$Y = -6.7772 + 0.3729X$	92.92	0.04
Phosphorus (P)				
Yacon	Model	Equation	R ² (%)	P-value (%)
Leaves	Quadratic	$Y = 0.4371 + 0.0237X - 0.0002X^2$	82.77	2.96
Stem	Quadratic	$Y = 0.1171 + 0.00792X - 0.0001X^2$	89.44	1.11
Rhizophores	Linear	$Y = -1.0743 + 0.0358X$	98.15	0.00
Roots	Linear	$Y = 0.0185 + 0.0012X$	98.94	0.00
Tuberous root	Linear	$1.8529 + 0.0823X$	90.65	0.09
Potassium (K)				
Yacon	Model	Equation	R ² (%)	P-value (%)
Leaves	Linear	$Y = 4.1028 - 0.0114X$	89.70	0.11
Stem	Quadratic	$Y = -0.3486 + 0.07629X - 0.0004X^2$	85.29	2.16
Rhizophores	Linear	$Y = -2.3158 + 0.0832X$	98.49	0.00
Roots	Linear	$Y = 0.4885 + 0.0039X$	69.11	2.04
Tuberous root	Linear	$Y = -4.5743 + 0.287X$	90.73	0.09
Calcium (Ca)				
Yacon	Model	Equation	R ² (%)	P-value (%)
Leaves	Quadratic	$Y = -8.8601 + 0.7583X - 0.0034X^2$	87.21	1.63
Stem	Quadratic	$Y = -11.7101 + .4762X - 0.0018X^2$	96.45	0.12
Rhizophores	Linear	$Y = -5.0829 + 0.2397X$	89.68	0.12
Roots	Linear	$Y = 0.5328 + 0.0092X$	87.17	0.21
Tuberous root	Linear	$Y = -20.3458 + 0.6513X$	96.70	0.00
Magnesium (Mg)				
Yacon	Model	Equation	R ² (%)	P-value (%)
Leaves	Quadratic	$Y = 0.3414 + 0.09247X - 0.0005X^2$	87.05	1.67
Stem	Quadratic	$Y = -1.9572 + 0.08513X - 0.0003X^2$	93.81	0.38
Rhizophores	Linear	$Y = -1.1029 + 0.0331X$	99.13	0.00
Roots	Linear	$Y = 0.1585 + 0.0031X$	97.00	0.00
Tuberous root	Linear	$Y = -2.2315 + 0.0638X$	98.15	0.00

R²: Coefficient of determination.

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