

Dynamics of Nutrient Demand and Uptake with Chemical Fertilization Levels on Dry Matter Accumulation and Yield of Escabeche Chili Pepper

Roberto H. Tirado-Malaver ^{a,*}, Roberto Tirado-Lara ^b, Fredesvindo Fernández Herrera ^a

^aUniversidad Nacional José Faustino Sánchez Carrión, Huacho, Perú.

^bUniversidad Nacional Pedro Ruíz Gallo, Lambayeque, Perú.

hugotiradomalaver@gmail.com

The nutrient uptake curve identifies the nutrient supply that the plant demands and improves the fertilization programmer of the crop. The objective of this study was to determine the yield, dry matter production and macro and micronutrient uptake of escabeche chili pepper. A randomized block design with four replicates and four fertilization levels (kg ha⁻¹ of NPK): T0 (0-0-0), T1 (100-50-150), T2 (150-100-200), T3 (200-150-250). It has been shown that dry matter accumulation occurred from 72 to 180 days after transplanting (DAT) 48% in stem, 30% leaf and 22% in fruit. A significant effect was found in the T3 which reported higher macro and micronutrient uptake and yield (59.79 t ha⁻¹). Our study showed that in order to obtain this high yield, the escabeche chili pepper plant absorbed 201; 24,44; 331,7; 108,66; 31,03; 28,72; 9,93; 1,96; 1,72; 1,39 y 1,23 kg ha⁻¹ de N, P, K, Ca, Mg, S, Fe, B, Cu, Mn and Zn respectively. Therefore, it was found that the most suitable time for plants to find a higher availability of nutrients in the soil is from 72 to 180 DAT, in addition, the uptake pattern allows understanding nutritional demands and improving fertilizer management to increase yields without altering soil fertility and prevent both nutrient deficiency and excess, thus minimizing environmental impact and encouraging sustainable agriculture.

1. Introduction

The escabeche chili pepper (*Capsicum baccatum* var. pendulum) is a vegetable of great importance due to its high content of phenolic compounds, flavonoids and capsaicin, which have antioxidant activity and have favorable characteristics for gastronomy, as well as a source of natural coloring for the cosmetics industry (Guevara et al., 2023). The production of this chilli pepper is constantly growing. Thus, the crop needs adequate plant nutrition, both mineral and hydric since inadequate or disproportionate nutrition adversely influences yield and fruit quality and even affects soil fertility and therefore, it is necessary to provide nutrients to the plant through the application of fertilizers (Zydlik et al., 2022).

On the other hand, the overuse of fertilizers is one of the biggest problems in most crops, because it causes a negative effect on the environment and also in recent years the price of chemical fertilizers has increased, due to external factors such as the conflict between nations (Neugschwandtner et al., 2022). In studies Pereira et al. (2023). showed that farmers used fertilizer doses higher than those required by the crop, which caused a decrease in yield, soil contamination, increased production costs and proved toxic to plants, while low doses limit yield and fruit quality. However, to determine the nutritional disorders of plants, different diagnostic techniques are used to provide information about the deficiency, toxicity, concentration and quantity of nutrients in the plant and in fact, soil analysis, together with foliar analysis information, is recommended to guide fertilization programs (Beyer et al., 2021).

Due to the growing interest in conservation methods to improve soil fertility, increase yield and fruit quality, the interest of sustainable agriculture, it is necessary to quantify the amount of nutrients that the plant absorbs at different stages of development, using the technique of uptake curves (Arthur et al., 2023). Since uptake is the

plant's ability to extract mineral nutrients in order to form tissues, organs and organic compounds (Jiang et al., 2023). Also, Janket et al. (2021) indicate that several studies have found that nutrient uptake depends on the dynamics of plant growth, accumulation and distribution of dry matter. From this information, uptake curves can be developed, which are graphic representations of the extraction of each nutrient and represent the quantities of this element extracted by the plant during its phenological cycle, which is the appropriate way to fine-tune fertilization programs according to the needs of the plant. Therefore, the objective of this study was to determine the yield, dry matter production and macro and micronutrient uptake of escabeche chili pepper.

2. Materials and Methods

This research was conducted in the experimental field of the Universidad Nacional Agraria La Molina (UNALM), located in the district and province of Cañete, Lima, Peru (13°05'53.03" South Latitude and 76° 21'34. 10" West longitude, 49 m above sea level. Also in this research soil samples were taken randomly at a depth of 0 to 50 cm being the effective depth of the root system of the escabeche chili pepper plant which determined the physical and chemical properties of the soil, indicating that the soil in the study site is sandy loam, slightly basic reaction (7.62), without salinity problems (0.85 dS/m); apparently well drained, organic matter (0.01). Soil P content (ppm) was 4.9, obtained using the Olsen method (Olsen & Sommers, 1982). that of K (ppm) was 113, that of Ca²⁺ (meq/100 g) was 9.14, that of Mg²⁺ (meq/100 g) was 2.15, and that of Na⁺ (meq/100 g) was 0.08, which were obtained using the Houba et al. (1994) using ammonium acetate followed by spectrophotometry. No deficiency of microelements was found. The field experiment was conducted under a completely randomised block design with four treatments and four blocks, resulting in 16 experimental plots. The experimental plot consisted of four rows, and 10 plants were transplanted in each row at a distance of 50 cm between plants. The form of application for the different nutrients was localized, considering the changes of furrow and respective hilling. Irrigation, weed, pest and disease control were carried out according to the degree of incidence of these pests and diseases and to the needs of the crop. The treatments used were four fertilization levels (kg ha⁻¹ of NPK): T0 (0-0-0), T1 (100-50-150), T2 (150-100-200), T3 (200-150-250) for determining the uptake curve. Tukey's significance test was used to compare the averages.

The experimental process was carried out in two stages: Stage 1 consists of the elaboration on dry matter (DM) accumulation and distribution, for each experimental plot, 10 plants were periodically sampled every 36 days, obtaining a total of five samplings: 36, 72, 108, 144 and 180 days after transplanting (DAT) obtaining the fresh weight of the whole plant and then the weight of each organ (leaves, stem and fruit). Likewise, the samples obtained were placed in the oven for 72 hours at a temperature of 70°C. Once dried, they were weighed to determine the dry weight, to determine the accumulation and distribution of dry matter, were expressed in kg ha⁻¹. Stage 2 consists on dry samples from each part of the plant were ground using a gang mill followed by a one millimeter diameter mesh in sieves, then these samples were stored in plastic bags. The samples were then taken to the soil and water analysis laboratory of the UNALM where samples of 0.5 to 1 g were taken to determine the nutrient content through chemical analysis according to that proposed by Janket et al. (2021). Macro and micronutrient uptake was calculated individually by multiplying the dry weight of each plant part by its nutrient concentration, then all parts were summed to obtain the total plant uptake and the results were expressed in kg ha⁻¹. Finally, the statistical application was carried out with the data collected from field and laboratory were processed through one-way analysis of variance (ANVA) with SPSS v.23.0 (IBM, Armonk, NY, USA) and comparison of means was calculated with Tukey's test at $\alpha \leq 0.05$. Graphical presentation was performed with Microsoft Excel 2013.

3. Results and Discussion

3.1 Dry matter formation and accumulation and yield

The analysis of variance shows high statistical significance (Table 1 and Figure 1) from 72 DDT due to the exponential growth of the plant and the response of the application of fertilizers until 180 DDT, being T3 the one who recorded the highest DM production with 1345.92 kg ha⁻¹, statistically exceeding the observed with the other fertilization levels. At 108 to 180 DDT, the highest DM production was observed again in T3 statistically superior to all other fertilization levels. The results found are similar to those reported by Huang et al. (2020) who found that the accumulation of DM is lower since the plant at the beginning of its vegetative period grows slowly and then presents a rapid accumulation, due to its exponential growth and the response to the application of fertilizers. Table 1 highly significant differences are shown between the treatments. It was found that T3 reported higher total yield with 59.79 t ha⁻¹. Although the increase in the yield of the escabeche chili pepper has been significant when using the T3 dose, farmers with this information on the uptake of macro and micronutrients have a model to provide nutrients at the time the plant needs, thus improving and refine the fertilization program. Similar reports are registered in chili by Janket et al. (2021) who argue that the pattern of nutrient uptake during

the growth cycle helps to understand nutritional demands and identify management practices to prevent both nutrient deficiency and excess.

Table 1: Periodic accumulation of total dry matter (kg ha^{-1}) and total yield (t ha^{-1}) in escabeche chili pepper, Peru.

Treatments	Days after transplant					Yield ...t ha^{-1} ...
	36	72	108	144	180	
 kg ha^{-1}					
T3 (200N– 150P–250K)	179.04 a ¹	1345.92 a	5987.50 a	8455.29 a	9017.52 a	59.79 a
T2 (150N –100P–200K)	192.83 a	1183.83 b	5332.92 b	7426.77 ab	7526.43 ab	44.05 b
T1 (100N – 50P–150K)	181.00 a	1011.46 c	4213.58 c	4811.15 b	5080.40 b	31.33 c
T0 (0 N – 0P – 0K)	195.58 a	948.29 c	3105.29 d	3599.97 b	2338.20 c	20.06 d
Average	187.12	1122.38	4659.82	6073.3	5990.60	38.81
ANVA	n.s.	**	**	**	**	**
C.V. (%)	15.04	5.52	4.54	12.8	16.74	10.53

Note: **Highly significant ($p < 0.01$), ns=not significant, CV= Coefficient of variability. ¹The means in the columns marked with different letters are significantly different at the $p = 0.05$ level, according to Tukey's test.

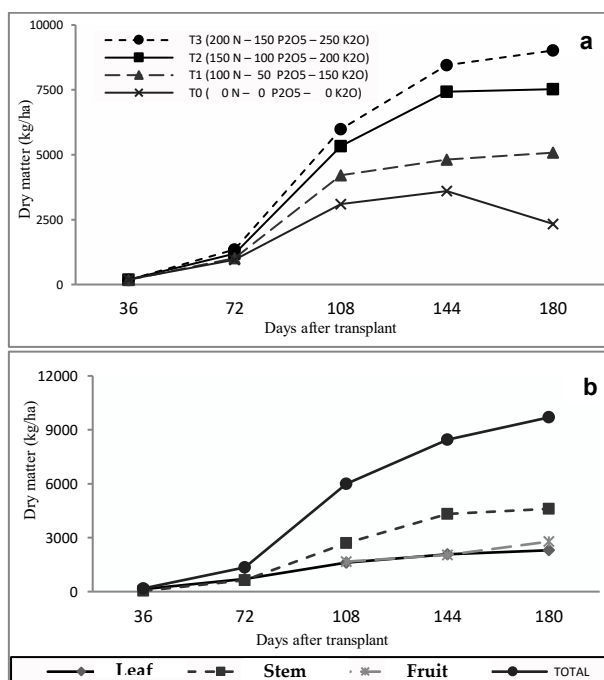


Figura 1: (a) Periodic accumulation of dry matter (kg ha^{-1}) in pickled peppers in the different treatments and (b) dry matter (kg ha^{-1}) in different organs for T3 (200 N - 150 P - 250K).

3.2 Accumulation of dry matter in the different organs of the plant

Figure 2 shows the values of periodic accumulation of DM in plant organs for T3. It was found that the leaf shows an increasing trend from 36 to 180 DAT, where it reaches the highest accumulation value with $2301.92 \text{ kg ha}^{-1}$ of DM, it should be noted that from 144 DAT it begins to stabilize due to translocation to the fruit. A similar case occurs in the stem, where at 180 DAT it reaches the highest uptake value with $4607.10 \text{ kg ha}^{-1}$ of DM. Likewise, DM uptake in the fruit starts from 108 to 180 DAT and the stem registered a higher value with 48%, 30% in the leaf and the remaining 22% towards the fruits, due to the fact that the escabeche chili pepper has a cycle long life span and fruit production cycles continually overlap. These results are similar to those reported by Arthur et al. (2021) who found that the increase in DM in the fruit occurs from 90 to 180 DAT as seen in the different levels of fertilization evaluated. Likewise, this result is corroborated by Yu et al. (2021) who found that DM accumulation and distribution patterns of plants are important to optimize nutrient uptake efficiency and production.

3.3 Analysis Nutrient uptake

Table 2 and Figure 2 (a) how that N, P and K uptake at 36 DAT was very similar at all fertilization levels. At 72 DAT, significant statistical differences were observed in the uptake between the different fertilization levels, being T3 the one that reported the highest accumulation with 65.40 kg ha⁻¹ of N, 6.18 kg ha⁻¹ of P and 37.08 kg ha⁻¹ of K, 42.03, 9.88 and 3.35 kg ha⁻¹ of de Ca, Mg and S statistically surpassing the other treatments, in the same way it can be seen at 108, 144 and 180 DAT, with 140.58, 213.91 and 201.85 kg ha⁻¹ of N, 17.06, 23.64 and 24.44 kg ha⁻¹ of P and 200.61 and 331.70 kg ha⁻¹ of K, 69.96, 100.43 and 108.66 kg ha⁻¹ of Ca, 11.57, 30.07 and 31.03 kg ha⁻¹ of Mg and 11.57 a 28.72 kg ha⁻¹ of S respectively. Regarding the percentage increase of the nutrients in the treatments, it can be seen in Table 2, it varied between 80.59 and 86.81% of the total N absorbed by the plant, as well as, from 90.11 and 93.69% of the total P, 85.54 and 91.48% of the total K, 80.66 and 90.64% by the plant and occurs between 36 and 144 DAT, for all fertilization levels evaluated and then declined at 180 DAT in all macronutrients.

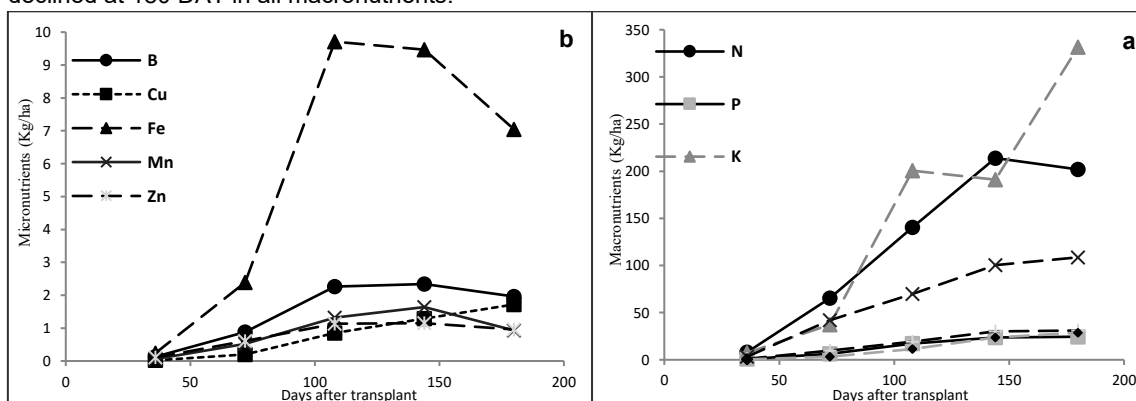


Figure 2: Periodic uptake of macro (a) and micronutrients (b) using the fertilization level (200 N - 150 P - 250 K) in escabeche chili pepper.

The results obtained are similar to those reported by Subedi et al. (2023) who obtained averages of N in peppers 225 and 207.4 kg ha⁻¹ of N. Foliage development favours N uptake (Jiaying et al. 2022). Regarding the uptake of P, the results show T3 with the highest absorption whose results are within the ranges reported by Żurawik et al. (2020). Highest level of uptake at 112 DAT in leaf and in the stem and then tends to decrease, this decrease for both organs may be due to translocation to the fruit. Veazie et al. [25] indicate that P favour the beginning of fruit formation and in the fruit set stage, due to high cell division. In the case of K is uptake and stored in the stem, to later help distribute the photosynthates to the new shoots (Subedi et al., 2023). Corroborated by Pereira et al. (2023) who indicate that the uptake of K in the fruit follows an increasing trend and reaches the highest value at 180 DAT, that K during the periods of fruit formation and maturation is mainly expressed in the metabolism of carbohydrates and translocation from vegetative organs to developing organs. If the expected yield is higher, the escabeche chili pepper will demand a greater amount of K.

The case of Ca, the results obtained are within the ranges reported by Bonomelli et al. (2021). The Ca maintains the integrity of the membrane cell, favors growth and activates a large number of enzymes involved in cell division. Regarding Mg uptake, it shows that the results obtained are similar to those reported by Żurawik et al. (2020) who reported that an average of 32.14 kg ha⁻¹ of Mg is obtained in pepper at 120 DAT and is the center of the chlorophyll molecule in the leaves that is in charge of capturing the energy supplied by the sun, necessary for photosynthesis. Regarding S, the results were similar to what was reported by Galvão et al. (2022) indicate that the leaf follows a growing trend where it reaches its maximum value after this date, the uptake declines due to the translocation of sulfur compounds to the fruit due to the synthesis of the capsaicin alkaloid, which is a substance that confers the characteristic pungency of the fruit.

Figure 2(b) shows the uptake of micronutrients which vary greatly in their distribution within plants and their ability to be remobilized from source and sink organs. Also, the results report that T3 obtained greater uptake of micronutrients and was significantly superior to the other treatments, showing that the nutrient with the greatest uptake was iron (Fe) which varied of 0.24 and 9.71 kg ha⁻¹, followed by boron (B) which varied from 0.13 and 2.26 kg ha⁻¹, manganese (Mn) which varied from 0.06 and 1.64 kg ha⁻¹, zinc (Zn) that varied from 0.11 and 1.15 kg ha⁻¹ and copper (Cu) that varied from 0.02 and 21.29 kg ha⁻¹, in addition, the maximum uptake value occurred at 108 and 144 DAT and then declined at 180 DAT in all micronutrients. Regarding the uptake of micronutrients, the results vary greatly in their distribution within the plants and their ability to be remobilized from the source and sink organs, as indicated Żurawik et al. (2020). The organic matter content is the determining factor to provide micronutrients to the escabeche chili pepper plant. In addition, micronutrients are

commonly added to NPK fertilizers during the manufacturing process and can significantly contribute micronutrient supply to crops according to Elshamly & Nassar (2023). The results identified that Fe was the micronutrient with the highest absorption, followed by B, Mn, Zn and Cu. The results were similar to those reported in pepper by Malik et al. (2020).

Table 2: Accumulation rate and percentage increase of macronutrients in five samples of escabeche chili pepper.

Muestre o	Macron utrients	Fertilization levels								F- test
		T3 (200 N–150 P– 250K)		T2 (150 N– 100P– 200 K)		T1 (100N –50 P – 150K)		T0 (0 N – 0 P – 0K)		
		AR kg ha ⁻¹	PI %	AR kg ha ⁻¹	PI %	AR kg ha ⁻¹	PI %	AR kg ha ⁻¹	PI %	
36 DDT	N	8.03 a	3.98	8.96 a	6.08	8.20 a	10.68	6.84 a	19.42	ns
	P	0.74 a	3.03	0.79 a	4.35	0.72 a	6.33	0.78 a	9.93	ns
	K	7.37 a	2.22	9.54 a	3.90	7.64 a	4.83	8.10 a	11.76	ns
	Ca	3.29 a	3.02	3.37 a	3.58	3.26 a	4.41	2.86 a	62.34	ns
	Mg	1.02 a	3.28	1.08 a	4.08	1.04 a	5.80	1.19 a	16.80	ns
	S	0.37 a	1.30	0.38 a	1.78	0.34 a	2.56	0.38 a	6.40	ns
72 DDT	N	65.40 a	28.42	52.81 b	29.74	36.78 c	37.23	28.79 d	46.02	**
	P	6.18 a	22.26	4.65 b	21.09	3.22 b	21.88	3.22 b	45.34	**
	K	37.08 a	8.96	37.29ab	11.35	33.50ab	16.37	29.21 b	30.63	**
	Ca	42.03 a	35.65	32.73 a	31.17	33.89 a	41.45	30.50 a	62.34	**
	Mg	9.88 a	28.54	10.00 a	33.11	8.52 a	41.43	7.86 a	30.05	**
	S	3.35 a	10.35	3.09 a b	12.63	2.50 b	16.12	2.49 b	35.45	**
108 DDT	N	140.58 a	33.08	124.48 a	37.31	103.12 b	38.45	67.94 c	32.23	**
	P	17.06 a	45.51	15.84a	51.23	13.68 b	61.22	9.39 c	40.54	**
	K	200.61 a	49.30	174.72ab	56.20	135.82 b	64.74	85.40 c	55.54	**
	Ca	69.96 a	25.71	61.58a b	30.63	45.27 bc	15.41	36.65 c	20.16	**
	Mg	19.23 a	30.15	18.29 a	32.01	16.48 a	41.43	13.17 b	30.05	**
	S	11.57 a	28.63	10.78 a	35.87	8.91 b	47.89	6.86 c	39.73	**
144 DDT	N	213.91 a	20.35	157.22 b	13.55	110.09 c	11.13	63.79 d	2.34	**
	P	23.64 a	23.93	19.51a b	18,12	14.65 bc	8.49	10.55 c	4.23	**
	K	291.10 a	27.28	229.40 b	22,36	152.21 c	10.37	82.61 d	2.12	**
	Ca	100.43 a	28.04	79.35 a	18.87	50.50 b	7.07	34.92 b	8.14	**
	Mg	30.07 a	34.92	27.66ab	25.32	19.14 bc	12.65	13.90 c	10.35	**
	S	23.70 a	42.24	18.95ab	38.07	11.42 b c	18.80	7.95 c	18.44	**
180 DDT	N	201.85 a	14.17	147.44 b	13,33	76.76 c	2.55	35.22 c	0.00	**
	P	24.44 a	3.28	18.29a b	5.21	11.42 bc	2.12	7.85 c	0.00	**
	K	331.70 a	12.24	244.53 ab	6.19	158.04 ab	3.69	68.92 b	0.00	**
	Ca	108.66 a	7.57	94.19 ab	15.76	73.90 b	31.67	30.50 c	0.00	**
	Mg	31.03 a	3.10	26.43 a	5.53	17.94 b	0.00	7.06 c	0.00	**
	S	28.72 a	17.48	21.45 ab	11.65	13.38 bc	14.63	5.94 c	0.00	**

Note: **Highly significant ($p < 0.01$), *significant ($p < 0.05$), ns: not significant; AR: Accumulation rate; PI: Percentage increase.

¹ The means with a common letter are not significantly different ($p < 0.05$) according to Tukey's test.

4. Conclusions

The present study indicated that T3 (200 N - 150 P - 250 K) shows a significant effect on the uptake of macro and micronutrients of the plant and on the yield of the pickled chili pepper crop (59.79 t ha⁻¹). Regarding the DM accumulation rate, it occurred from 72 to 180 DAT, its distribution being this way: 48 % in the stem, 30% in the leaf and the remaining 22 % towards the fruits. The uptake of macronutrients in descending order was: K > N > P > Ca > Mg > S and of micronutrients was: Fe > B > Mn > Zn > Cu. According to the accumulation of nutrients in the different organs of the escabeche chili pepper plant, the stem was the organ that presented the highest concentration of nutrients, especially: N, K, S, Cu, Fe and Zn, followed by the leaf: N, Ca, Mg and Mn, and the fruit: P, B, Cu, respectively. Based on the results of this study, it was found that the use of a fertilization of 200 N - 150 P - 250 K, the plant absorbs 201; 24,44; 331,7; 108,66; 31,03; 28,72; 9,93; 1,96; 1,72; 1,39 y 1,23 kg ha⁻¹ de N, P, K, Ca, Mg, S, Fe, B, Cu, Mn and Zn respectively. The results of this study are useful as information to understand nutritional demands and improve fertilizer management to increase yields without altering soil

fertility and prevent both nutrient deficiency and excess, thus minimizing environmental impact and encouraging a sustainable agriculture.

References

- Arthur, J.D. Li, T., & Bi, G., 2023, Plant Growth, Yield, and Quality of Containerized Heirloom Chile Pepper Cultivars Affected by Three Types of Biostimulants. *Horticulturae*, 9, 12.
- Beyer, C. P., Cuneo, I. F., & Alvaro, J. E., & Pedreschi, R., 2021, Evaluation of aerial and root plant growth behavior, water and nutrient use efficiency and carbohydrate dynamics for Hass avocado grown in a soilless and protected growing system. *Science Horticulture*, 277, 109830.
- Bonomelli, C., Alcalde, C., Aguilera, C., Videla, X., Rojas, X., & Fernandez, V., 2021, Absorption and mobility of radio-labelled calcium in chili pepper plants and sweet cherry trees. *Soils and Plant Nutrition*, 78, e20200092.
- Elshamly, A.M.S., & Nassar, S.M.A., 2023, The Impacts of Applying Cobalt and Chitosan with Various Water Irrigation Schemes at Different Growth Stages of Corn on Macronutrient Uptake, Yield, and Water Use Efficiency. *Journal Soil Science Plant Nutr.*, 23, 2770–2785.
- Galvão, S., Moraes, S., da Silva, S.P., da Costa, P., de Freitas, V., & Magno, P.L., 2022, Growth and macronutrient content of Habanero pepper (*Capsicum chinense* Jacq.) subjected to organic fertilization. *Colloq. Agr*, 18, 11-23.
- Guevara, A., Villanueva, E., Nolzaco, D., Llontop, G., & Cancino, K., 2023, Effects of applying saturated steam as an Organic Sterilization System (OSS) in mirasol chili pepper (*Capsicum baccatum* var. *pendulum*) and panca chili pepper (*Capsicum chinense* Jacq.). *Enfoque UTE*, 12, 1-10.
- Houba, G., Novozamsky, I., & Temminghoff, E., 1994. Soil and plant analysis. Part 5A. Soil analysis procedures. Extraction with 0.01 M CaCl₂. 66 p. Wageningen Agricultural University, Department of Soil Science and Plant Nutrition, Wageningen, The Netherlands.
- Huang, C.H., Singh, G.P., Park, S.H., Chua, N.H., Ram, R.J., & Park, B.S., 2020, Early diagnosis and management of nitrogen deficiency in plants utilizing Raman spectroscopy. *Front Plant Sci.*, 11, 663.
- Janket, A., Vorasoot, N., Toomsan, B., Kaewpradit, W., Theerakulpisut, P., Holbrook, C.C., Kvien, C.K., Jogloy, S., & Banterng, P., 2021, Quantitative Evaluation of Macro-Nutrient Uptake by Cassava in a Tropical Savanna Climate. *Agriculture.*, 11, 1199.
- Jiang, W., Zhang, J., Jia, Z., Zhang, T., Zhang, W., & Wei, M., 2023, Physiological and Nutrient Responses to Nitrogen, Phosphorus, or Potassium Deficiency of Hydroponically Grown Strawberry. *HortScience*, 58, 628-634.
- Jiaying, M., Tingting, C., Lin, J., Fu, W., Feng, B., Li, G., Zhihai, W., Longxing, T., & Guanfu, F., 2022, Functions of Nitrogen, Phosphorus and Potassium in Energy Status and Their Influences on Rice Growth and Development. *Rice Sci.*, 29(2), 166-178.
- Malik, A.A., Narayan, S., Magray, M., Shameem, S.A., Hussain, K., & Bangroo, S., 2020, Effect of foliar application of micronutrients on growth, yield, quality and seed yield of chilli (*Capsicum annum* L.) under temperate conditions of Kashmir Valley. *Int. J. of Chem. Stud.*, 8, 2781-278. <https://www.researchgate.net/publication/343684011>
- Neugschwandtner, R.W., Száková, J., Pachtrog, V., Tlustoš, P., Kulhánek, M., Černý, J., Kaul, H., Wagentristl, H., Moitzi, G., & Euteneuer, P., 2022, Exchangeable and Plant-Available Macronutrients in a Long-Term Tillage and Crop Rotation Experiment after 15 Years. *Plants*, 11, 565.
- Olsen, S.R., & Sommers, L.E., 1982. Phosphorus. pp 403-430. In: A. L. Page (ed.). *Methods of soil analysis. Part 2. Chemical and microbiological properties.* American Society of Agronomy, Soil Science Society of America. Madison, WI, USA.
- Pereira, D., Puiatti, M., Pereira, P. R., Cecon, P., Sedyama, M. A., & Ribeiro, F., 2023, Crop growth and macronutrient extraction and export curves for two arrowroot cultivars. *Acta Scient.*, 45, e58132.
- Subedi, P., Bhattarai, P., Lamichhane, P., Khanal, A., & Shrestha, J., 2023, Effect of different levels of nitrogen and charcoal on growth and yield traits of chili (*Capsicum annum* L.). *Heliyon*, 9(2), e13353.
- Veazie, P., Pandey, P., Young, S., Balance, M.S., Hicks, K., & Whipker, B., 2022, Impact of Macronutrient Fertility on Mineral Uptake and Growth of *Lactuca sativa* ‘Salanova Green’ in a Hydroponic System. *Horticulturae*, 8, 1075.
- Yu, Y., Qian, C., Gu, W., & Li, C., 2021, Responses of Root Characteristic Parameters and Plant Dry Matter Accumulation, Distribution and Transportation to Nitrogen Levels for Spring Maize in Northeast China. *Agriculture*, 11, 308.
- Zydlik, Z., Zydlik, P., Kafkas, N. E., Yesil, B., & Cieśliński, S., 2022, Foliar Application of Some Macronutrients and Micronutrients Improves Yield and Fruit Quality of Highbush Blueberry (*Vaccinium corymbosum* L.). *Horticulturae*, 8, 664.
- Žurawik, A., Jadcak, D., Panayotov, N., & Žurawik, P., 2020, Macro- and micronutrient content in selected cultivars of *Capsicum annum* L. depending on fruit coloration. *Plant, Soil and Env.*, 66, 155–161.