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Macronutrient dynamics in avocado (*Persea americana* Mill.) 'Hass' under the central peruvian coast conditions

Dinámica de los macronutrientes en palto (*Persea americana* Mill.) ´Hass´ bajo condiciones de la costa central peruana

Luis Rodrigo Tomassini-Vidal[1]*; Nancy Marilu Pino-Huasacca[2]

*Corresponding author: ltomassini@lamolina.edu.pe

Abstract

The international growing demand of the avocado (*Persea americana* Mill.) market, together with the expansion of its agricultural area, requires the increasing of its technification, which makes necessary to have information aboutnutrient absorption in relation to its phenology. Therefore, an experiment was conducted in a commercial avocado production field of the farm "Don Ricardo" located on the central coast of Peru, in order to characterize the dynamics of macronutrients (N, P, K, Ca and Mg). The methodology followed and the results obtained will be the main guide to improve and implement more efficient fertilization strategies that will lead to higher yields and lower production costs in this crop. The experiment included 5 production cycles, from 2014-15 to 2018-19, in 7 phenological stages, collecting according to the crop development, leaves, panicles and fruits. 40 randomized plants were selected from a total of 50 plants marked as sampling area. The results were analyzed using a descriptive statistic, with box diagrams of the concentration of each nutrient by phenological stage. Two graphs per element were generated to represent the leaf dynamic and the fruit dynamic, respectively, including the data taken from the flower. It was concluded that the highest nutrient requirements of avocado were during the flowering, the fruit set and in fruits from 10 mm to 30 mm in diameter. The most abundant form of nitrogen was nitric, and it was accumulated mainly in the productive organs. The phosphorus, potassium, calcium and magnesium concentrations decreased as the fruit grew, and calcium and magnesium concentrations in leaves were higher than in fruits.

Keywords: *macronutrient dynamics, avocado, fertilization, mineral nutrition, nutrient concentration*

Resumen

La creciente demanda internacional del mercado del palto (*Persea americana* Mill.) unido a la expansión de su área agrícola, requiere incrementar su tecnificación, lo que hace necesario tener información acerca de la absorción de nutrientes en relación con su fenología. Por ello, se realizó un experimento en un campo de producción comercial de palto del fundo "Don Ricardo" ubicado en la costa peruana, para caracterizar las dinámicas de los macronutrientes (N, P, K, Ca y Mg). La metodología seguida y los resultados obtenidos serán la guía principal para mejorar e implementar estrategias de fertilización eficientes que conduzcan al incremento de rendimientos y menores costos de producciónen este cultivo.El experimento abarcó 5

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[1] Universidad Nacional Agraria La Molina, Departamento de Suelos, Facultad de Agronomía, Av. La Molina s/n, Lima, Perú.
[2] Universidad Nacional Agraria La Molina, Facultad de Agronomía, Av. La Molina s/n, Lima, Perú.

ciclos de producción, del 2014-15 al 2018-19, en 7 etapas fenológicas, colectando según desarrollo del cultivo, hojas, panículas y frutos. 40 plantas fueron tomadas al azar, de un total de 50 plantas marcadas como zona de muestreo. Los resultados se analizaron usando estadística descriptiva con diagramas de cajas de la concentración de cada nutriente por etapa fenológica. Se elaboraron dos gráficos por elemento, para representar la dinámica en hoja y la dinámica en fruto, respectivamente, incluyendo datos tomados en la flor. Se concluyó que los mayores requerimientos nutricionales del palto se dieron durante la floración, cuaja y en frutos de 10 mm a 30 mm de diámetro, y que la forma de nitrógeno más abundante fue el nítrico, el cual se acumuló principalmente en los órganos productivos. Las concentraciones de fósforo, potasio, calcio y magnesio disminuyeron al crecer el fruto y las concentraciones de calcio y magnesio en hojas fueron mayores que en frutos.

Key words: *dinámica de macronutrientes, palto, fertilización, nutrición mineral, concentración de nutrientes.*

Introduction

Avocado is an important crop in Peru, which exceeds 42 thousand hectares in the country and generates the second export product among fruits and vegetables. Its fruit positioned to Peru in 2017 in second place worldwide with 247.000 tons. In 2018 the avocado export increased to 397.248 tons (+60.8 %) but dropped significantly to 290.000 tons in 2019, although the total national production reached to 469.949 tons (Ministerio de Agricultura - Sistema Integrado de Estadísticas Agrarias [MIDAGRI-SIEA], 2022). Huett and Dirou (2000) found that the macronutrient removal by a 10 t/ha avocado crop was (kg/ha) 41 nitrogen (N), 61 potassium (K), 8 phosphorus (P), 4 sulfur (S), 7 calcium (Ca) and 8 magnesium (Mg). Knight (2007) argues that the increase in exports and cultivated area may be due to its culinary and medicinal qualities, as well as its fruit interests, for its stored oils, being the most abundants the oleic, palmitic and linoleic acids, and for its carbohydrate and protein contents (Joubert, 2016).

Nutritional imbalances in an avocado plant cause physiological disorders that affect the fruit, producing a serie of postharvest problems and therefore lower fruit quality. Valuable tools such as chemical analysis of leaves and fruits make possible to determine the behavior of nutrients, ensuring good yield and fruit quality (Guerrero et al., 2018; Joyce et al, 2022; Razzeto & Salgado, 2004). However, the information on those matters in Peru is limited. Therefore, the aim of this research was to evaluate the nutritional dynamics of macronutrients through chemical analysis of avocado leaves and fruits under the agroclimatic conditions of the village Santa Rosa in order to characterize the nutritional status of the avocado crop, as a base for proposing appropriate fertilization practices.

Methodology

Experimental area

The research was carried out in a six hectares field from the farm 'Don Ricardo' lot R2, located at 14° 00' 52" S, 75° 41' 37" W in the village Santa Rosa from Los Molinos district, province of Ica, department of Ica (central coast of Peru).

Plant material

The plant material under study consisted of avocado trees of the 'Hass' cultivar grafted on 'Zriffin' West Indian rootstock, 17 years old, planted at a density of 278 plants/ha, 5 % of which were pollinizers in a ridge (Abraham et al., 2018; Aleman et al., 2005).

Observational study

The observational study considered seven phenological stages from flowering to harvest, which are listed in Table 1. (Alcaraz, 2013).

Procedure

The characterization of the experimental soil

Table 1. Phenological stages of the avocado crop considered in the study

Phenology	Treatment
Flowering	1
Fruit setting	2
Fruit 1 (10 – 30 mm)	3
Fruit 2 (31 – 50 mm)	4
Fruit 3 (65 – 70 mm)	5
Fruit > 70 mm	6
Harvest	7

included the collection of two soil samples, the first from 0 cm to 30 cm and the second from 30 cm to 60 cm deep, following concepts of proisotropic pedoturbation proposed by Johnson et al. (1987) and Holle (1961). Samples were sent to the laboratory for analysis.

For leaf sampling, the area of the middle third of the tree was divided into four quadrants according to the cardinal axes and one leaf was extracted from each quadrant (four leaves per tree). Leaves were from 3- to 6-months-old, dark green, physiologically healthy, expanded spring shoots, packed in paper bags and sent to the laboratory for analysis, after being collected from 40 randomized plants, from a total of 50 plants marked as sampling area (AGQ Lab, 2018). For the phenological stage of flowering, samples were collected from the exposed panicle with up to 10 % of flowers open. Flowering peduncles were selected, four per randomly marked tree, until 400 g to 600 g were collected from the entire field. Finally, for the collection of fruit samples, fruits were selected from the same trees of leaf sampling. Fruit setting were chosen, while in development, fruits of various sizes were chosen and assigned a number: fruit 1 (10 mm to 30 mm), fruit 2 (31 mm to 50 mm), fruit 3 (65 mm to 70 mm), fruit 4 mm > 70 mm. A sample was taken at the beginning of harvest.

The dry mass concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) in the sampled organs were measured by leaf and flower/fruit analysis (AGQ Lab., 2018). Five periods of production were considered to the analysis, ranging from 2014-2015 to 2018-2019. The changes of the elements through the time of the five campaigns, according to the phenological stages were statistical analyzed using descriptive box diagrams.

Results and Discussion

Results of soil analysis, (sampled in 2016) are shown in Table 2. The results show a moderately coarse soil, with low organic matter, total N, and available K for plants, low carbonates and electrical conductivity, medium available P for plants, alkaline reaction, and cation exchange capacity (CEC), and high exchangeable magnesium and sodium.

Fertilizer applications from 2014-15 through 2018-19 production periods are presented in Table 3 to Table 7. In addition, Table 8 shows foliar fertilizers applications and Table 9 shows the doses of fertilizers applied per ha and period.

Nutritional dynamics of total nitrogen

Fig. 1 and Fig. 2 show the nutritional dynamics of total N in fruits and leaves, respectively. In stage 1 results showed a slight dispersion (Fig. 1) and 25 % of the results were lower than 2.17 %. Despite the dispersion, the mean concentration of total N reached higher values in stages 1, 2, 3, and then gradually decreased until harvest. On the other hand, a higher dispersion of results was observed in stage 3, where 50 % of the results were higher than 2.45 %. This is probably due to the fact that the sample was taken from mature leaves. The variation of total N remained stable throughout the phenology, like values reported by Figueroa et al. (2001).

Campisi et al. (2017) mentioned that optimal ranges of N in cauliflower inflorescences of 'Hass' vary from 2.7 % to 3 %. In our case, the concentration of 2.7 % was obtained. Silber et al. (2018) mentioned thattotal N in 'Hass' fruits increase from the beginning of inflorescence until fruit set, and then decrease during fruit development (Salazar-García et al., 2015). After fruit set, in new fruit development, Lovatt (1995) and Salvo (2017) declared that the highest N demands occur due to the competition between fruit and new

Table 2. 2016-soil analysis, between 0 to 30 cm and 30 to 60cm

Characteristics	2016			
	0-30cm	30-60cm	Units	Method
Clay	15	10	%	Boyoucos hydrometer
Limo	20	20	%	Boyoucos hydrometer
Sand	65	70	%	Boyoucos hydrometer
Texture classification	Sandy Loam	Sandy Loam		
Available phosphorus	11.8	7.4	mg/kg	Olsen
Organic material	1.02	0.57	%	
Active Limestone	0.7	0.5	%$CaCO_3$	Ammonium Oxalate
Nitrogen	969	534	mg/kg	
Available calcium	13.5	9.3	cM(+)/kg	NH_4 acetate
Available magnesium	2.27	1.41	cM(+)/kg	NH_4 acetate
Available potasium	0.5	0.27	cM(+)/kg	NH_4 acetate
Available sodium	0.7	0.43	cM(+)/kg	NH_4 acetate
pH (Extract 1/1)	7.91	7.82		Aqueous extract
Sum of available bases	17	11.4	cM(+)/kg	
Iron	5	6.91	mg/kg	DTPA
Manganese	3.38	2.98	mg/kg	DTPA
Copper	2.77	1.89	mg/kg	DTPA
Zinc	3.15	1.3	mg/kg	DTPA
Effective CEC	13.7	8.4	cM(+)/kg	
Ca changeable	11.4	7.17	cM(+)/kg	NH_4 acetate
Magnesium exchangeable	1.82	1.05	cM(+)/kg	NH_4 acetate
Sodium exchangeable	0.09	0.05	cM(+)/kg	NH_4 acetate
Potasium exchangeable	0.37	0.18	cM(+)/kg	NH_4 acetate
Bases of exchange	13.7	8.4	cM(+)/kg	NH_4 acetate
C/N relation	6.09	6.22		
Available Ca/Mg	5.97	6.6		
Available Mg/K	4.5	5.28		
Boron	1.33	0.74	mg/L	Aqueous extract
E.C.	0.7	0.76	dS/m	

Source: AQP Labs: Agroalimentaria y Medio ambiente

Table 3. Doses of nutrient applied per phenological phase (kg/ha, period 2014– 2015)

Phenology	N	P	K	Ca	Mg	Zn	B	Fe
Pre-flowering	--	--	--	--	--	--	--	--
Flowering	4.5	--	--	--	--	--	--	--
Flower setting	10.9	1.0	10.1	--	--	--	--	--
Fruit 1 (10-30 mm)	58.5	4.1	40.5	22.4	2.7	2.3	--	--
Fruit 2 (31-50 mm)	73.4	3.1	66.5	5.9	--	--	--	--
Fruit 3 (65-70 mm)	68.0	--	125.2	--	--	--	--	--
Fruit > 70 mm	52.4	--	110.0	--	--	--	--	--
Harvest	--	--	--	--	--	--	--	--
TOTAL	**267.7**	**8.3**	**352.3**	**28.2**	**2.7**	**2.3**	**0.0**	**0.0**

Source: ADR, 2019

shoot formation; however, if there are reserves in the soil and small branches, fertilization is not required (Lahav et al, 1990; Rosecrance et al, 2003). Undoubtedly the mineralization of organic nitrogen, requires favorable conditions such as adequate moisture and soil temperature (Cassity et al., 2020; Cassity et al., 2018), neutral or alkaline pH and additions of dairy digestato (Wagoner et al., 2021), and amount of ammonium, season and management (Giguere

Table 4. Doses of nutrient applied per phenological phase (kg/ha, period 2015– 2016)

Phenology	N	P	K	Ca	Mg	Zn	B	Fe
Pre-flowering	--	--	--	--	--	--	--	--
Flowering	33.7	4.9	--	17.8	7.0	2.3	--	--
Flower setting	18.2	4.0	8.0	11.1	--	2.3	--	--
Fruit 1 (10-30 mm)	45.3	9.4	25.1	16.7	18.0	--	1.80	--
Fruit 2 (31-50 mm)	32.1	10.9	18.0	16.7	7.0	--	--	--
Fruit 3 (65-70 mm)	102.4	--	112.4	--	--	--	--	--
Fruit > 70 mm	57.4	--	72.2	--	--	--	--	--
Harvest	--	--	--	--	--	--	--	--
TOTAL	**289.2**	**29.2**	**235.7**	**62.3**	**32.0**	**4.5**	**1.8**	**0.0**

Source: ADR, 2019

Table 5. Doses of nutrient applied per phenological phase (kg/ha, period 2016– 2017)

Phenology	N	P	K	Ca	Mg	Zn	B	Fe
Pre-flowering	14.5	--	15.1	--	--	--	--	--
Flowering	58.7	--	42.1	--	18.0	--	--	0.1
Flower setting	10.3	--	7.6	--	7.0	2.0	--	--
Fruit 1 (10-30 mm)	25.0	4.0	8.0	8.9	--	3.0	--	--
Fruit 2 (31-50 mm)	76.4	8.0	61.1	8.9	12.0	4.0	--	0.1
Fruit 3 (65-70 mm)	68.1	19.7	48.8	26.7	30.9	--	--	0.1
Fruit > 70 mm	109.9	--	179.1	17.8	10.0	--	--	--
Harvest	--	--	--	--	--	--	--	--
TOTAL	**362.8**	**31.6**	**361.7**	**62.2**	**77.9**	**9.0**	**0.0**	**0.4**

Source: ADR, 2019

Table 6. Doses of nutrient applied per phenological phase (kg/ha, period 2017– 2018)

Phenology	N	P	K	Ca	Mg	Zn	B	Fe
Pre-flowering	6.0	--	20.0	--	--	--	--	--
Flowering	53.5	4.9	20.0	13.3	20.3	8.0	--	--
Flower setting	35.9	4.9	20.0	6.7	6.0	8.0	--	0.1
Fruit 1 (10-30 mm)	48.8	9.9	29.0	12.2	9.0	4.0	--	--
Fruit 2 (31-50 mm)	65.2	2.9	77.9	5.5	6.0	--	--	--
Fruit 3 (65-70 mm)	98.2	--	109.1	--	12.0	--	--	--
Fruit > 70 mm	89.6	--	264.8	--	--	--	--	--
Harvest	--	--	--	--	--	--	--	--
TOTAL	**397.2**	**22.6**	**540.7**	**37.8**	**53.3**	**20.1**	**0.0**	**0.1**

Source: ADR, 2019

et al. 2015). All these factors explain why N doses varied in the different campaigns for the early phenological stages. When N applications started late (stage 4) results were lower, as shown in Table 6 and reported by Atta et al. (2021).

N is related to vegetative processes and contributes to delaying fruit ripeninReducing N application would favor the contribution of K (Mengel & Kirkby, 2000). N doses decreased from stage 6 until they were no longer applied at harvest, which would explain why the lowest concentration occurred at the beginning of harvest. During fruit development, N levels varied from 2.3 % at fruit set to 0.74 % at harvest. Granados (2013), found similar levels in 'Lorena' avocado fruit pulp, ranging from 3.1 % to 1.1 % from the beginning of slow

Table 7. Doses of nutriente applied per phenological phase (kg/ha, period 2018– 2019)

Phenology	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**B**	**Fe**
Pre-flowering	--	--	--	--	--	--	--	--
Flowering	39.8	21.9	18.0	35.5	6.0	8.0	--	--
Flower setting	39.1	13.8	10.0	53.3	10.0	4.0	--	--
Fruit 1 (10-30 mm)	52.8	13.8	29.9	48.8	18.0	4.0	--	--
Fruit 2 (31-50 mm)	83.2	24.8	92.0	6.7	16.0	4.0	--	0.1
Fruit 3 (65-70 mm)	110.9	--	168.1	--	--	--	--	--
Fruit > 70 mm	60.2	--	178.1	--	--	--	--	--
Harvest	--	--	--	--	--	--	--	--
TOTAL	**386.1**	**74.3**	**496.0**	**144.3**	**50.0**	**20.1**	**0.0**	**0.1**

Source: ADR, 2019

Table 8. Foliar applications per productive season

Commercial product	**Composition**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**	**2018-2019**
Aminofer® K	Phosphorus (P_2O_5)/(P): 6 % w/v Potassium (K_2O)/(K):44 % w/v Total aminoacids:10 % w/v	56 l	--	36 l	72 l	30.5 l
Basfoliar® AKTIV	Phosphorus:40 % (P_2O_5) w/w Potassium: 15 % (K_2O) w/w Magnesium 5 % (MgO) w/w Boron:0,01 % (B) w/w Iron * 0,05 % (Fe) w/w *Fe completely chelated with EDDHA and EDTA	42 l	52.5 l	18 l	--	--
Carboxy® Zn	Zinc	--	--	--	61.1 l	--
Fertimar® (kg)	Carbohidrates: 55-65 % Proteins: 8-12 % Total nitrogen: 1-2 % Available prosphorus (P_2O_5): 0.5-1.5 % Soluble potassium (K_2O): 4-6 % Extract of seaweed: 100 %	9 kg	34.5 kg	18 kg	28.37 kg	30.66 kg
Fx Zinc®Flo-(Alt. Basfoliar Zn Flo)	Zinc (Zn): 750 g/l	50.44 l	42 l	12 l	--	--
Greenfol® Zinc	Zn	--	--	--	33 l	118.72 l
Packhard® (Carboxy)	Organic carbon oxidable 63 g/l Calcium (CaO) 141.1 g/l Boron (B_2O_3) 9.5 g/l	--	--	38.25 l	69.8 l	106.52 l
Sett-Fix®	Calcium: 8 % Boron: 1 %	77 l	99 l	27 l	--	--

Source: ADR, 2019

growth to the end of fruit ripening. Martínez et al. (2014) pointed out that the adequate N concentration varies according to the sampling season, indicating that in January (beginning of fruit growth in Chile) it should be less than 2.2 %, and then decrease up 0.8 % at harvest (Lovatt, 1995). Foliar N ranged between 1.93 % and 2.35 %, with a lower level at flowering and two peaks in stages 4 and 5, this range corresponds to optimum values obtained by Maldonado-Torres et al. (2007) for Hass crops (1.94 % to 2.32 %) with yields greater than 20 t/ha (Lovatt, 1995).

Granados (2013) measured foliar N in vegetative and reproductive shoots during two avocado

Tabla 9. Doses of fertilizers applied per period (kg/ha).

Fertilizer	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019
Ammonium nitrate	2604 kg	1585 kg	3128 kg	3153 kg	2192 kg
Potassium nitrate	4697 kg	3142 kg	4649 kg	7076 kg	6348 kg
Calcium nitrate	651 kg	1437 kg	1435 kg	872 kg	3331 kg
Magnesium nitrate	108 kg	1644 kg	2680 kg	2132 kg	2000 kg
Phosphoric acid	96 kg	338 kg	366 kg	262 kg	860 kg
Potassium sulphate	--	--	150 kg	--	230 kg
Magnesium sulphate	--	--	410 kg	--	--
Zinc sulphate	60 kg	120 kg	240 kg	535 kg	535 kg
Ultraferro® (Iron chelated)	24 kg	12 kg	24 kg	12 kg	--
Rexolín® (Iron chelated)	--	--	--	--	12 kg
*Sulfuric acid - 98%	1453.28	2165.26	907.97	1741.47	--
Boric acid	--	66 kg	--	--	--

Source: ADR, 2019

Table 10. Details of figures

DETAILS			
The horizontal line inside the box is the median of the nutrients The bars indicate the 25% and 75%. Dashes indicate the most extreme data points that are not considered outliers Outliers represented individually with circle signs			
PHENOLOGICAL PHASE	**SYMBOL**	**PHENOLOGICAL PHASE**	**SYMBOL**
		Fruit 2 (31 - 50 mm)	4
Flowering	1	Fruit 3 (65 - 70 mm)	5
Flower setting	2	Fruit 4 (>70 mm)	6
Fruit 1 (10 - 30 mm)	3	Start of harvest	7

campaigns. In the former, three peaks were found; in the latter, the nutrient decreased during slow fruit growth;andin the linear growth and ripening, it increased until reaching 2.1 %, and later decreased at harvest. This report coincides with the obtained results, since after harvest the flowering of the following campaign continues with the lowest N values. Rosecrance et al. (2003) found that N, P and K concentrations are highest in young leaves and decrease with time, this decrease rate accelerated at flowering, when the leaves were ten months old. Castillo et al. (2000), found no great changes in concentrations of N, P, K, Ca, Mg, in leaves and inflorescences, but it changed with the leaf age.

The principal sources of N in the "RP2" plot were ammonium nitrate, potassium, calcium and magnesium, being ammonium magnesium the most used. This nutrient was applied throughout the phenology (from pre-flowering to pre-harvest), being more concentrated in flowering until stage 6.

Nitrate nitrogen:

Fig. 3 and Fig. 4 show the dynamics of nitrate N in fruits and leaves, respectively. Fig. 3 shows high dispersion of results in stage 2, 25 % of them were higher than Q3 (654 mg/kg), while 75 % were lower. Likewise, there was high dispersion in stage 6, only 25 % were lower than Q1 (252 mg/kg). Meanwhile, Fig. 4 shows a very high dispersion of results in stages 1, 2, 3, 6 and 7. Stage 3 stands out because 50 % of the results were higher than 359.3 mg/kg.

Nitrate fertilizers produce rapid plant response (Mengel & Kirkby, 2000). Spann (2019) explained that nitrification is due to temperature and it can happen between 1 to 2 weeks in warm soils of 75 °F (23.89 °C), this explains that nitrate formation in the soil has been favored by high summer temperatures (23 °C to 33 °C) which coincides with stage 4. Furthermore, Mengel and Kirkby (2000), and Giguere et al. (2015), mentioned that pH between 7 and 8 favors bacterial conversion of ammonium to nitrate, in the soil conditions.

Nitogen

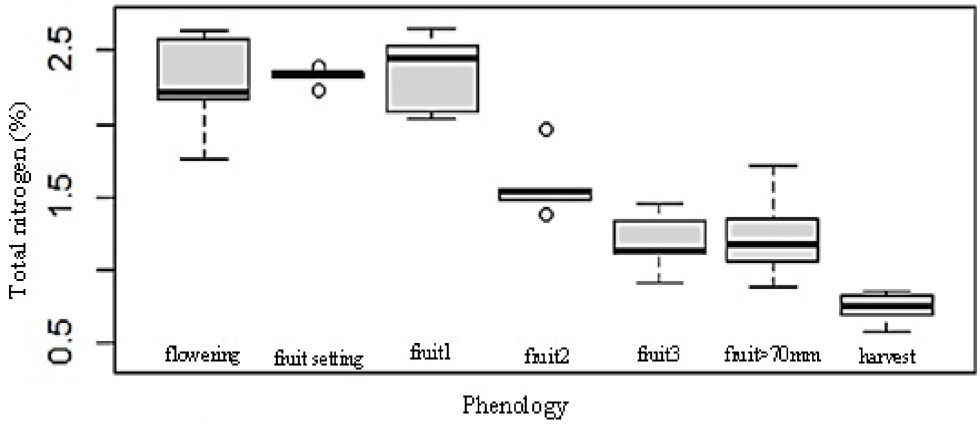

Figure 1. *Nutritional dynamics of total N in fruits*

```
> CV(x=N, na.rm=T)
[1] 0.388268

Mean Income
  1     2     3     4     5     6     7
2.272 2.322 2.352 1.588 1.192 1.236 0.742

stats
     [,1]  [,2]  [,3]  [,4]  [,5]  [,6]  [,7]
[1,] 1.76 2.32 2.04 1.49 0.92 0.89 0.58
[2,] 2.17 2.32 2.08 1.49 1.12 1.06 0.69
[3,] 2.21 2.34 2.45 1.54 1.13 1.17 0.76
[4,] 2.58 2.34 2.54 1.56 1.34 1.35 0.83
[5,] 2.64 2.34 2.65 1.56 1.45 1.71 0.85

$out
[1] 2.22 2.39 1.38 1.97
```

It was observed that N was more concentrated as nitrate than as ammonium, both in fruits and leaves. Lovatt (1995) reported the same behavior, mentioning that plants can accumulate nitrate without reduction in high quantities, which would explain the average concentration of 315 mg/kg at the beginning of harvest. This author also mentioned that from the beginning of summer until leaf fall, the activity of the nitrate reductase enzymes tends to be reduced, as well as that of glutamine synthetase tends to increase.

Nitrate N in leaves during flowering and fruit set are low although in fruit the total and ammoniacal N are high. Likewise, in the phenological stages 5, 6 and 7 that include fruit growth, the amounts of nitric nitrogen show low levels.According to Salvo (2017), this is beneficial for the fruit since an excessive N level in the pulp can generate deterioration and a reduction of Ca level, as well as it would cause a greater sensitivity to diseases due to a weakness in the cell walls.

Ammoniacal nitrogen

Fig. 5 and Fig. 6 show the dynamics of ammonia N in fruits and leaves, respectively. Fig. 5 shows highly dispersed results in stage 2, most of them (75 %), were higher than 208 mg/kg. However, a peak corresponding to the highest total N demand of the avocado at this stage, was observed. Fig. 6 shows a high dispersion of results in stage 6, since 25 % of the results

Nitogen

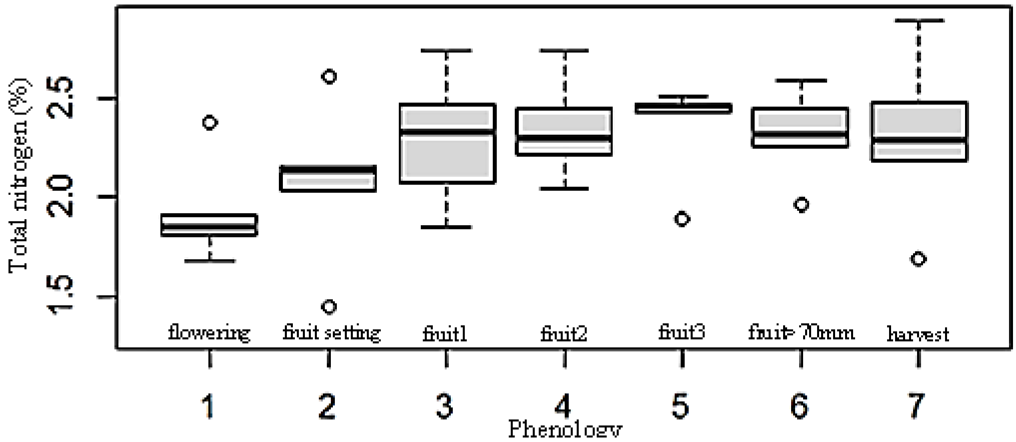

Figure 2. *Nutritional dynamics of total N in leaves*

```
CV(x=N, na.rm=T)
[1] 0.15048

Mean
  1      2      3      4      5      6      7
1.926  2.072  2.292  2.350  2.352  2.315  2.310

stats
     [,1] [,2] [,3] [,4] [,5]  [,6]  [,7]
[1,] 1.68 2.03 1.85 2.04 2.43 2.260 2.19
[2,] 1.81 2.03 2.07 2.22 2.43 2.260 2.19
[3,] 1.85 2.13 2.33 2.30 2.46 2.315 2.29
[4,] 1.91 2.15 2.47 2.45 2.47 2.450 2.48
[5,] 1.91 2.15 2.74 2.74 2.51 2.590 2.90

$out
[1] 2.38 2.61 1.44 1.89 1.96 1.69

$group
[1] 1 2 2 5 6 7
```

were higher than 238.3 mg/kg, which could be explained mainly by nitrogen fertilization and leaf litter decomposition. The highest and lowest peaks occurred in stage 3, with 238 mg/kg and 150 mg/kg, respectively. In the results of the leaf analysis, the values obtained for ammoniacal N (186 mg/kg to 359 mg/kg) were lower than those for nitric-N.

The dynamics of ammoniacal N is similar to that of total N, since it tends to decrease during fruit growth, even to levels less than those of nitric N. This may be due to the fact that the ammonium ion is rapidly assimilated and combined with sugars to form aminoacids, which encourages vegetative development, undesirable during fruit development (Montgomery, 2019). The plant can absorb N in the form of nitrate or ammonium, and in order to be assimilated, nitrate must be transformed into ammonia so that it combines with carbohydrates to form aminoacids, making this form more rapidly assimilated (Mengel & Kirkby, 2000).

Nutritional dynamics of phosphorus

Fig. 7 and Fig. 8 show the P dynamics in fruit and leaves, respectively. Fig. 7 shows that in the first three stages, the concentrations are high, butdecrease as the fruit grows. Fig. 8 shows a high dispersion between P results at flowering

Nitrate

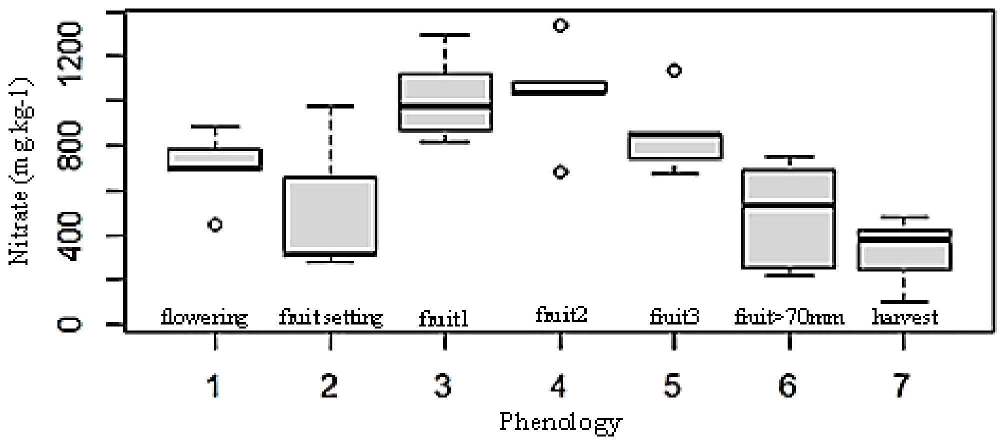

Figure 3. *Nutritional dynamics of nitrates in fruits*

CV(x=Nn, na.rm=T)
[1] 0.4612243

Mean

1	2	3	4	5	6	7
699.78	509.74	1016.00	1035.30	851.32	488.26 7	325.80

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	686.8	283.0	815	1035.3	677.0	220.3	100
[2,]	686.8	316.0	870	1035.3	744.0	252.0	244
[3,]	699.8	316.7	980	1035.3	851.3	528.0	383
[4,]	785.0	654.0	1117	1086.9	851.3	688.0	422
[5,]	884.0	979.0	1298	1086.9	851.3	753.0	480

$out
[1] 443.3 681.0 1338.0 1133.0

$group
[1] 1 4 4 5

(50 % of them less than 0.12 %) and fruit set (50 % of them less than 0.15 %), it may be due to the use of mature leaves for foliar analysis.

In this experience, the most used P source was phosphoric acid (384.4 kg on average per season). P is an element that is easily mineralized and persists in the soil (Crowley, 2007). As it is not very mobile and does not leach easily, so it is not applied constantly. Ibacache and Sierra (1998) detected no differences between the absence and presence of P fertilization in 'Hass' orchards for 18 years in Spain. Recent study, reveled that urea applications stimulated P release and P mineralization after 5 days, and P bioavailability up to 40 days (Ning et al., 2021)

Phosphorus influences the development of flowers and fruit set, the plant formation stage and root growth. Therefore, the application of P in this experience was carried out mainly in the first three phenological stages, occasionally extending to stages 4 and 5, depending on whether there were active roots. It is associated with the transport of chemical energy during photosynthesis (Salvo, 2017) and its scarcity generates little vegetative growth, inhibiting the growth of shoots and buds (Ataucusi, 2015).

Salvo (2017) recommends applying phosphorus after fruit set in the spring and in proportion to the expected crop year. Silber et al. (2018), demonstrated with their P dynamics

Nitrate

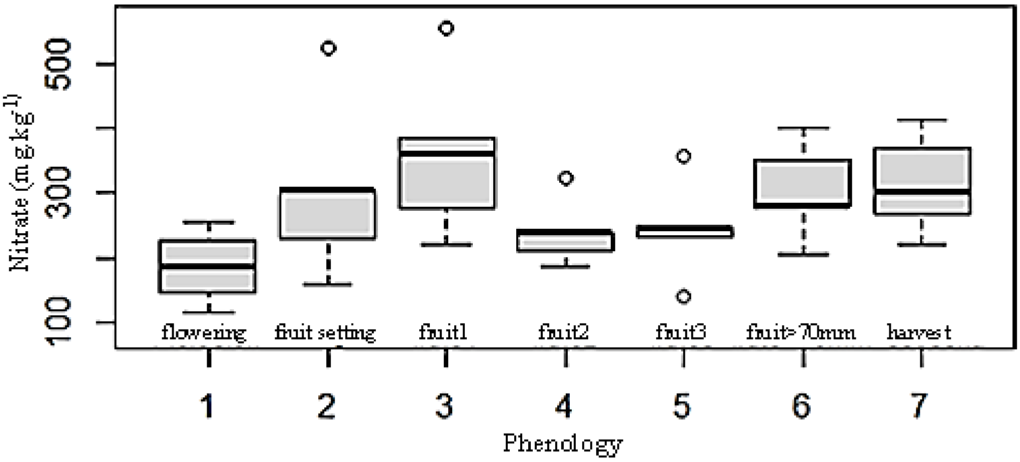

Figure 4. *Nutritional dynamics of nitrates in leaves*

CV(x=Nn, na.rm=T)
[1] 0.3564186

Mean

1	2	3	4	5	6	7
185.78	305.36	359.30	240.20	244.00	303.10	314.54

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	114.0	160.0	221.0	187.0	234	204.0	222.0
[2,]	146.0	231.0	275.2	212.0	234	279.0	268.7
[3,]	185.8	304.6	359.3	240.2	244	279.0	301.0
[4,]	227.3	305.4	386.0	240.2	244	352.0	369.0
[5,]	255.8	305.4	386.0	240.2	244	401.5	412.0

$out
[1] 525.8 555.0 321.6 357.0 141.0

$group
[1] 2 3 4 5 5

in fruits that the concentration of the nutrient increases from flowering to early fruit set, and then decreases in fruit growth. Campisi et al. (2017), found that P increased as inflorescence development progressed.Additionally, they mention that during the cauliflower phase were found valueshigher than those for full flowering, and the latter even exceeded those found in developing fruits (Campisi et al, 2017). Studies in cowpea obtained similar results regards to the P increase at flowering stage and at the beginning of pod formation (Suzuki et al.,2021).

The fertilization plan used in the orchard did not contemplate P during flowering in the 2014-15 and 2016-17 seasons. However, at this stage the P concentration was high probably due to the phosphorus reserves in the soil from the previous season because of the use of ammonium nitrate in early stages.Mengel and Kirby (2000) reported the same experience. Those authors expressed that plants fertilized with ammonium, absorb more anions than cations, in addition release H^+ ions to the soil, acidifying the rhizosphere. Bar et al. (1997), found that high nitrate reduced phoshorus levels in plants of avocado. It is possible that the relatively neutral soil pH (7 to 8) has improved P absorption, since this mineral is usually available in greater quantities at pH 6 to 7, but insoluble at very high pH (Mengel and Kirkby, 2000).

Ammoniacal nitrogen

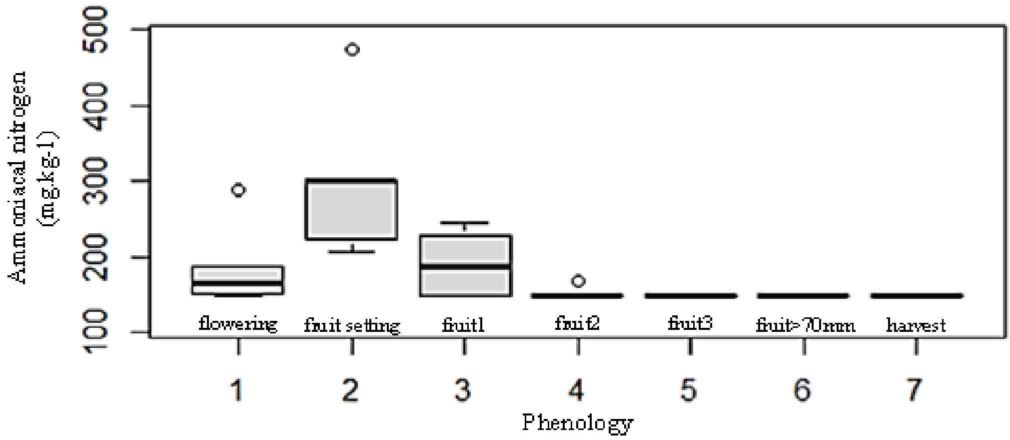

Figure 5. *Nutritional dynamics of ammoniacal N in fruits*

```
> CV(x=Na, na.rm=T)
[1] 0.3706084

Mean
     1        2        3        4        5        6        7
188.56   301.82   192.30   153.60   150.00   150.00   150.00

stats
      [,1]  [,2]  [,3]  [,4] [,5] [,6] [,7]
[1,] 150.0 208.0 150.0  150  150  150  150
[2,] 151.0 223.4 150.0  150  150  150  150
[3,] 165.2 301.8 188.5  150  150  150  150
[4,] 188.6 301.8 228.0  150  150  150  150
[5,] 188.6 301.8 245.0  150  150  150  150

$out
[1] 288.0 474.1 168.0

$group
[1] 1 2 4
```

P levels in young leaves are very high and decrease rapidly as they age. According to Lahav et al. (1990), P is translocated from old to young leaves. Therefore, it could explain the peak in its concentration during stage 3, which coincides with the time of application.

P concentrations in leaves ranged from 0.12 % to 0.19 %, being lower than those found in fruits (0.12 % to 0.36 %). Maldonado-Torres et al. (2007) consideredoptimal P values for 'Hass' between 0.15 % to 0.18 %. . The higher P concentration in fruits may be due to the fact that they are the main drains of avocado trees, so nutritional analysis is a key tool for knowing when to add nutrients (Silber et al, 2018). It is worth mention that values exceeding 0.3 % were obtained during flowering (0.33 %), fruit set (0.36 %) and fruit 1 (0.34 %). Novela et al. (2018), found that phosphorus content in fruit decreases almost half, from early to late harvest.

Nutritional dynamics of potassium

Fig. 9 and Fig. 10 show the K dynamics in fruits and leaves, respectively. Fig. 9 shows dispersed results during fruit set (25 % of values higher than Q3 (2.99 %)). It could be affirmed that this dispersion was affected by the fruit load of the trees or by foliar applications. Fig. 10 shows more dispersed results at flowering (50 % was

Ammoniacal nitrogen

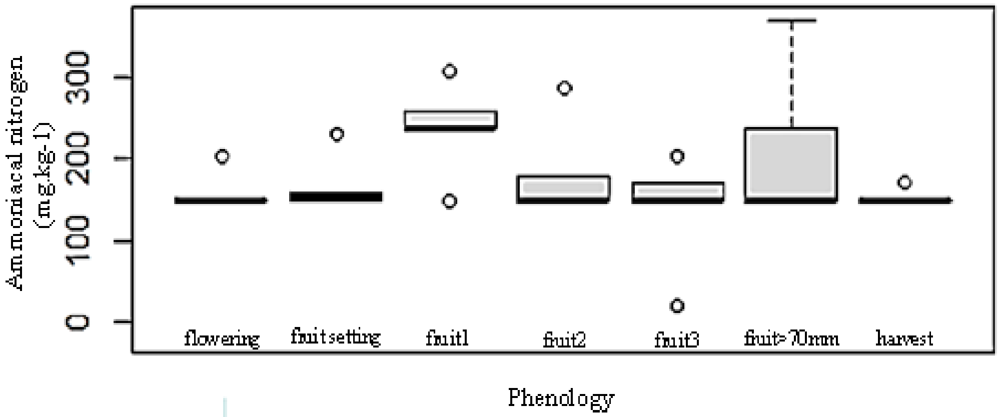

Figure 6. *Nutritional dynamics of ammoniacal N in leaves*

```
CV(x=Na, na.rm=T)
[1] 0.2956461

> Mean
     1      2      3      4      5      6      7
160.40 168.96 237.68 183.28 172.52 211.46 154.20

stats
       [,1]  [,2]   [,3]    [,4]   [,5]   [,6]    [,7]
[1,]  150 150.0 237.7 150.0 150.0 150.0  150
[2,]  150 150.0 237.7 150.0 150.0 150.0  150
[3,]  150 154.0 237.7 150.0 170.6 150.0  150
[4,]  150 159.8 257.0 178.4 190.0 238.3  150
[5,]  150 159.8 257.0 178.4 202.0 369.0  150

$out
[1] 202 231 306 150 288 171

$group
[1] 1 2 3 3 4 7
```

less than 1.12 %), which could be due to the sampling of old leaves. In stage 2 there was a high dispersion of results (25 % of these were lower than the media,1.36 %), probably due to the high demand for K by the fruits. At this stage, the concentration of K in fruits was 2.82 %, while in stage 3, its high concentration (1.73 %)could be explained by foliar applications.

The potassium sources used sometimes were sulfate and nitrate, both contribute to fruit size increase, but not to yield (Lao, 2013). K in fruits was higher at flowering and fruit set, but an opposite behavior occurred at stages 4, 5 and 7. The concentration of K in the cauliflower stage ranged from 1.4 % to 1.7 % (Campisi et al., 2017). However, samples for fruit analysis were taken from peduncles of completely differentiated, unopened flowers, in which a concentration of 2.22 % was found. It could have been favored by K fertilization via the irrigation system.

In the soil analysis, exchangeable K had a value of 3.2 meq/L to 5.1 meq/L. Montgomery (2019) mentioned that nitrate and sulfate K fertilization should be applied from the beginning of flowering until harvest, increasing the concentration of the mineral in the solution from 1.25 meq/L to 2.2 meq/L. Fortunately, the amounts obtained exceeded those mentioned, so a high application was not

Phosphorus

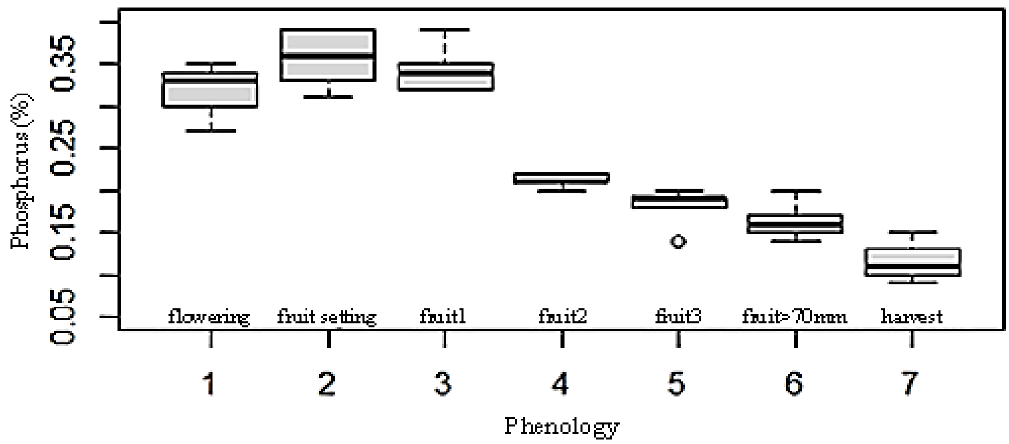

Figure 7. *Nutritional dynamics of phosphorus in fruits*

> CV(x=P, na.rm=T)
[1] 0.3884438

Mean Income

1	2	3	4	5	6	7
0.318	0.356	0.344	0.212	0.180	0.164	0.116

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	0.27	0.31	0.32	0.20	0.18	0.14	0.09
[2,]	0.30	0.33	0.32	0.21	0.18	0.15	0.10
[3,]	0.33	0.36	0.34	0.21	0.19	0.16	0.11
[4,]	0.34	0.39	0.35	0.22	0.19	0.17	0.13
[5,]	0.35	0.39	0.39	0.22	0.20	0.20	0.15

$out
[1] 0.14

$group
[1] 5

necessary. Despite a good nutritional reserve, the fertilization program required a constant supply of K, but the amounts varied according to the phenological stage. During flowering and fruit set, the units contributed were low since soil reserves were sufficient. However, during fruit growth, especially in stages 4, 5 and 6, the doses were higher.

The fertilization generated a similar curve to that found by Campisi et al. (2017), where K in flowering stage was higher than that measured in pedicels during their growth. Potassium is essential for an adequate accumulation of dry matter, facilitating the transport of carbohydrates to the fruits (Salvo, 2017), as well as favoring sap circulation.Moreover, owing to its high mobility, this nutrient maintain the pH of the cells by neutralizing organic acids, favoring photosynthesis (Mengel and Kirkby, 2000).

K levels decreased during fruit growth maintaining a range of 1.64 % to 2.82 %. Joubert (2016) pointed out that potassium amounts should not be less than 1.5 %, however, excess of this mineral is leached or can be consumed by the plant without being really useful for it (Mengel and Kirkby, 2000). Montgomery (2019), mentioned that as long as the curve does not descend to a deficiency level, this decrease can be favorable.Fernández et al. (2017) found that leaf K increased from fruit set having its

Phosphorus

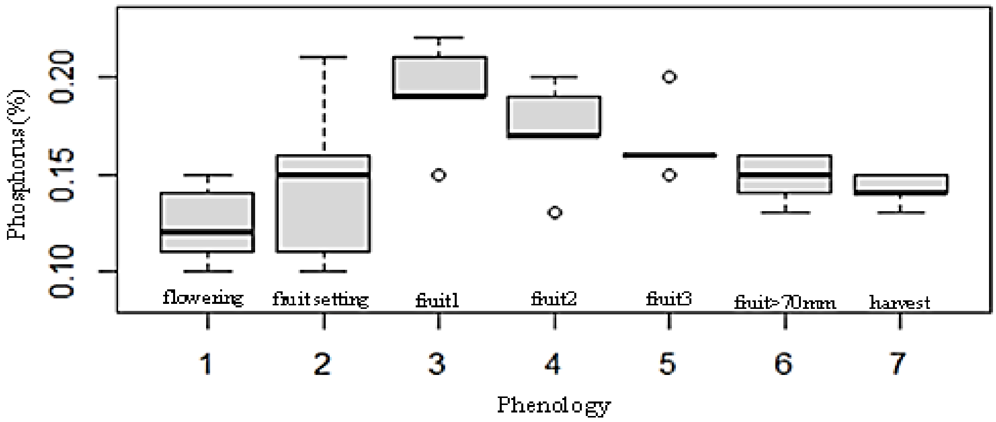

Figure 8. *Nutritional dynamics of phosphorus in leaves*

CV(x=P, na.rm=T)
[1] 0.1996397

Mean

1	2	3	4	5	6	7
0.124	0.146	0.192	0.172	0.166	0.148	0.142

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	0.10	0.10	0.19	0.17	0.16	0.13	0.13
[2,]	0.11	0.11	0.19	0.17	0.16	0.14	0.14
[3,]	0.12	0.15	0.19	0.17	0.16	0.15	0.14
[4,]	0.14	0.16	0.21	0.19	0.16	0.16	0.15
[5,]	0.15	0.21	0.22	0.20	0.16	0.16	0.15

$out
[1] 0.15 0.13 0.20 0.15

$group
[1] 3 4 5 5

maximum peak in the olive fruit dropping to the minimum value at mid-harvest. The optimal range of K in the leaf proposed by Maldonado-Torres et al. (2007) was 0.8 % to 1.1 %. Similar values were obtained from the five campaigns in this work.

Potassium influences the concentration increase of solutes in shoots and leaves (Salvo, 2017), contributing to the water balance by promoting the opening and closing of stomata (Knight, 2007). In addition, it ensures a good generative ratio. Montgomery (2019), reported that in the rapid fruit growth phase a N/K ratio lower than 1.8 favors fruit development, while once get over 2.4, favors vegetative growth. In this experience, the ratio in leaf was lower than 1.8 in the fruit set (0.95) and fruit 1 (1.47) phases.

Calcium nutritional dynamics

Fig. 11 and Fig. 12 show the nutritional dynamics of Ca in fruits and leaves, respectively. Fig. 11 shows that the Ca peak occurred at fruit set (0.54 %), being higher than the subsequent phenological stages (3 to 7). Moreover, the lowest amounts were obtained in the last three phenological stages. Fig. 12 shows that the two stages with the highest Ca concentrations were flowering (2.65 %) and fruit set (2.2 %).

Phosphorus

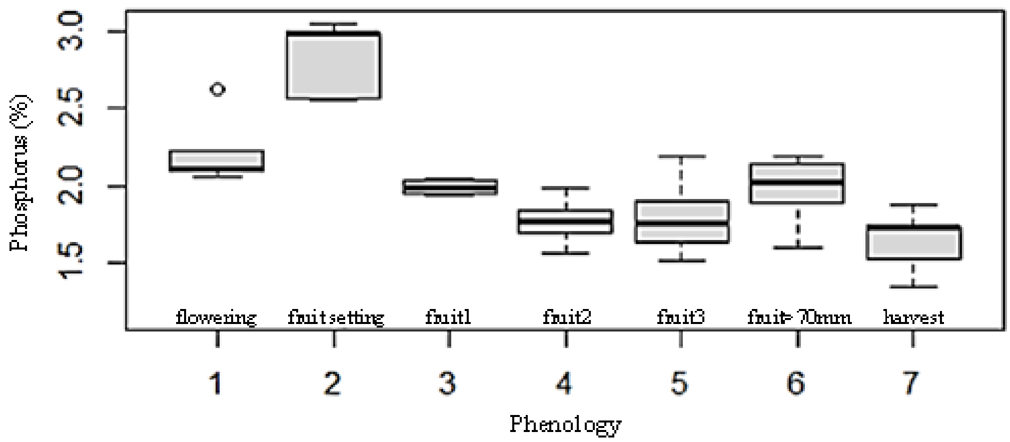

Figure 9. *Nutritional dynamics of potassium in fruits*

CV(x=K, na.rm=T)
[1] 0.2060815

Mean Income

1	2	3	4	5	6	7
2.220	2.824	1.990	1.770	1.800	1.968	1.642

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	2.06	2.55	1.94	1.56	1.52	1.60	1.34
[2,]	2.09	2.56	1.95	1.69	1.64	1.89	1.53
[3,]	2.11	2.98	1.98	1.77	1.75	2.02	1.73
[4,]	2.22	2.99	2.03	1.84	1.90	2.14	1.73
[5,]	2.22	3.04	2.05	1.99	2.19	2.19	1.88

$out
[1] 2.62

$group
[1] 1

Ca tends to decrease after fruit set, this may be due to the fact that applications are concentrated on flowering, fruit set and fruit (Ataucusi, 2015), since at these times the fruit has a greater absorption capacity (Penter & Stessen, 2000), and therefore applying it in the early stages of fruit development results more effective (Rosecrance et al., 2003). The Ca contained in the fruit is accumulated during the first five months of development, because it moves towards the actively growing cells (Salvo, 2017), it may explain why Ca concentrations were lower from fruit measuring 65 to 70 mm until the beginning of harvest. Escobar et al. (2021) found high content of calcium in fruits associated to reduced avocado flesh disorders and improved the internal fruit quality.

Both foliar and irrigation applications of Ca are included in the first three phenological stages. The amount of available Ca (12.2 meq to 13.5 meq per 100 g), water content and the basic pH of soil favored the calcium absorption. Hofman et al. (2002) explained that low CEC results in rapid leaching. It makes difficult to increase Ca concentration in fruit, considering that soil CEC was relatively low (12.6 meq and 13.7 meq per 100 g). This fact could be influenced by soil texture and soil moisture, according to concepts of Bonomelli et al. (2019).

Potassium

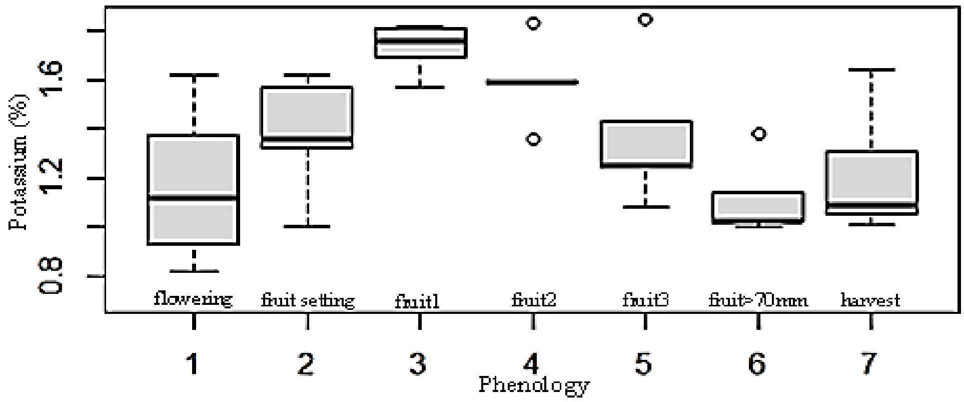

Figure 10. *Nutritional dynamics of potassium in leavess*

```
> CV(x=K, na.rm=T)
[1] 0.2202058

Mean
  1     2      3      4      5      6      7
1.172 1.374 1.730 1.592 1.370 1.112 1.220

stats
      [,1]  [,2]  [,3]  [,4]  [,5]  [,6]  [,7]
[1,] 0.82 1.00 1.57 1.59 1.08 1.00 1.01
[2,] 0.93 1.32 1.69 1.59 1.24 1.02 1.05
[3,] 1.12 1.36 1.76 1.59 1.25 1.02 1.09
[4,] 1.37 1.57 1.81 1.59 1.43 1.14 1.31
[5,] 1.62 1.62 1.82 1.59 1.43 1.14 1.64

$out
[1] 1.83 1.36 1.85 1.38

$group
[1] 4 4 5 6
```

Once Ca is absorbed and integrated into the plant, it can become immobile, therefore, a direct foliar application is made to fruits and foliage (Spann, 2019). One of the main functions of Ca is to form part of the middle lamella and cell wall, which helps organic compounds and mineral salts to be conveniently retained, and to favor the fruit firmness (Mengel & Kirkby, 2000;Barrientos, 2016).

The N/Ca ratio at flowering was 5.27 and 14.8 at harvest. High N and low Ca levels in the exocarp of avocado could be associated with anthracnose and lower postharvest quality. Salazar-García et al. (2015) mentioned that variations in Ca concentrations in leaves of vegetative shoots are very similar, and these also increase with age. Lahav et al. (1990) found that Ca in leaves of the previous years was higher than those of summer leaves. Nevertheless, the Ca levels in the latter did not exceed 1.6 %, while in spring it was higher than 1.8 %, therefore, it is possible to distinguish between spring and summer leaves, because of the leaves Ca oncentration. Regards to Ca content at flowering (~2.7 %), it is possible to think that mature leaves were taken. In the 2014-15 season, edaphic Ca fertilization started at fruit 1, while foliar ones started from 10 % of flowering. The increase in Ca content after

Calcium

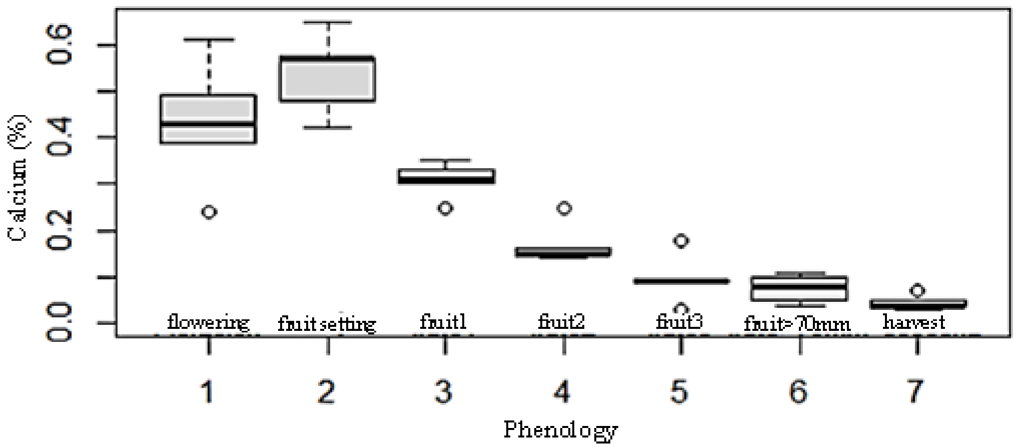

Figure 11. *Nutritional dynamics of calcium in fruits*

CV(x=Ca, na.rm=T)
[1] 0.8016814

Media

1	2	3	4	5	6	7
0.432	0.538	0.308	0.170	0.096	0.076	0.046

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	0.39	0.42	0.30	0.14	0.09	0.04	0.03
[2,]	0.39	0.48	0.30	0.15	0.09	0.05	0.04
[3,]	0.43	0.57	0.31	0.15	0.09	0.08	0.04
[4,]	0.49	0.57	0.33	0.16	0.09	0.10	0.05
[5,]	0.61	0.65	0.35	0.16	0.09	0.11	0.05

$out
[1] 0.24 0.25 0.25 0.03 0.18 0.07

$group
[1] 1 3 4 5 5 7

stage 3 was probably favored by temperatures and evapotranspiration rise in the summer months.

The shape of the dynamic curve in leaves differs greatly from that observed in fruit. The first peak is attributed to applications at flowering, the subsequent decrease may be due to the greater demand for fruit during these stages. Witney et al. (1990), found that Ca concentration in avocados was high in leaves, bark and small branches, but low in immature reproductive organs and very low in the fruit and wood.

The Ca in fruit (0.05 % to 0.54 %) was lower than that observed in leaves (1.5 % to 2.65 %), due to the fact that transpiration is an important factor in the absorption and movement of this mineral, which is transferred to areas with a high transpiration rate, such as leaves (Mengel & Kirkby, 2000; Montgomery, 2019). Similar values of Ca in leaves to those mentioned by Martínez et al. (2014) as optimal (1 % - 3 %),were found in this research.

Nutritional dynamics of magnesium

Fig. 13 and Fig. 14 show the nutritional dynamics of Mg in fruits and leaves, respectively. Fig. 13 shows that Mg had its maximum value at fruit

Calcium

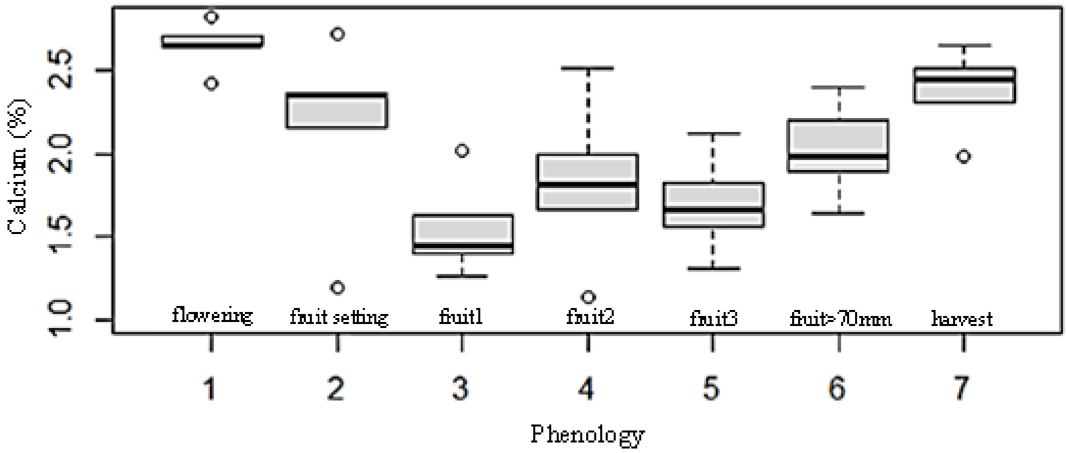

Figure 12. *Nutritional dynamics of calcium in leaves*

CV(x=Ca, na.rm=T)
[1] 0.240754

Mean

1	2	3	4	5	6	7
2.648	2.158	1.552	1.824	1.696	2.020	2.376

stats

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
[1,]	2.65	2.16	1.26	1.66	1.31	1.64	2.30
[2,]	2.65	2.16	1.40	1.66	1.56	1.89	2.30
[3,]	2.65	2.35	1.45	1.81	1.66	1.98	2.44
[4,]	2.70	2.36	1.63	2.00	1.83	2.20	2.51
[5,]	2.70	2.36	1.63	2.51	2.12	2.39	2.65

$out
[1] 2.42 2.82 1.20 2.72 2.02 1.14 1.98

$group
[1] 1 1 2 2 3 4 7

set (0.2 %) and the minimum at the beginning of harvest (0.07 %). In the stages 1, 2 and 3 Mg levels were relatively high. In Fig. 14, stages 5 and 6, the results were very scattered, in the first one 25 % of results were lower than Q1 (0.4 %), while for the second one 50 % were higher than 0.49 %. The peak is probably due to the fact that fertilization was concentrated in the first three stages, since 50 % of the total requirements of the developing fruit are accumulated in these stages (Salvo, 2017). Mg decreased the number of natural abortions, improved fruit size, provided a greater number of new shoots and allowed early flowering (Ataucusi, 2015). Joubert (2016) recommended apply Mg during early spring bud break, flowering and fruit growth. However, Rosecrance et al. (2003), recommended that Mg should be supplied annually after flowering.

The highest concentration of Mg and also Ca, occurs during fruit set. Martínez et al. (2014), mentioned in a study accomplished in Chile that Mg and Ca have a directly proportional relationship in fruit.. Furthermore, increasing both nutrients improve the fruit quality. Witney et al. (1990), found that Mg concentration tends to decrease with the fruit ripening, as also does Ca. It could be seen in the dynamics of this experiment, where the lowest values were found close to harvest.

Magnesium

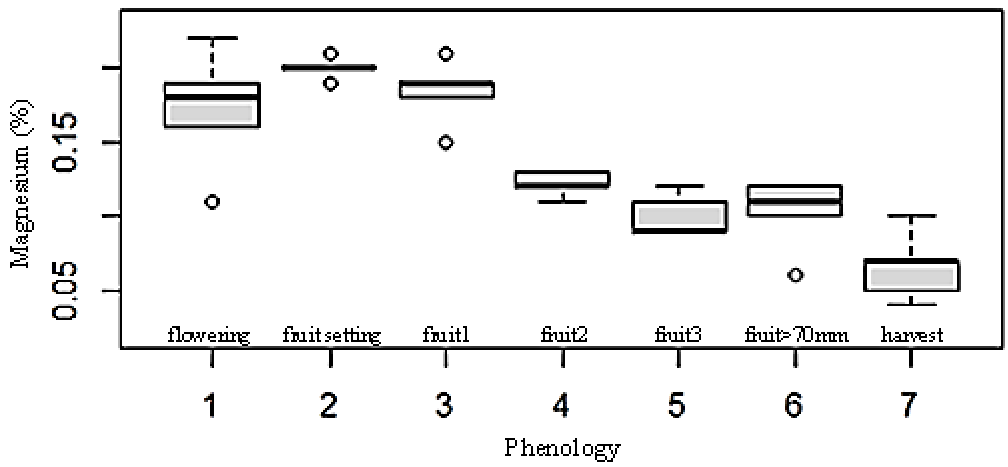

Figure 13. *Nutritional dynamics of magnesium in fruits*

```
> CV(x=Mg, na.rm=T)
[1] 0.1395861

Mean
    1     2     3     4     5     6     7
0.524 0.460 0.410 0.472 0.448 0.522 0.482

stats
     [,1] [,2] [,3] [,4] [,5] [,6] [,7]
[1,] 0.51 0.45 0.36 0.47 0.35 0.48 0.43
[2,] 0.51 0.45 0.38 0.47 0.40 0.48 0.45
[3,] 0.54 0.46 0.40 0.48 0.47 0.49 0.49
[4,] 0.54 0.47 0.42 0.49 0.48 0.58 0.50
[5,] 0.54 0.47 0.42 0.52 0.54 0.58 0.54

$out
[1] 0.59 0.44 0.34 0.58 0.49 0.40

$group
[1] 1 1 2 2 3 4
```

The concentration of Mg in leaves was higher than in fruits. Campisi et al. (2017), reported the same relationship when comparing the concentrations in leaves and peduncle tissues, becoming three times higher in the former stage in respect to the latter. Rosecrance et al. (2003), mentioned that the first magnesium reserves are the branches and leaves, recalling that this mineral plays a vital role in photosynthesis as it is the structural component in chlorophyll.

The Mg sources used were mainly in the form of magnesium nitrate and in a less extent magnesium sulfate. Montgomery (2019) recommended applying sulfate in alkaline and deficient soils. On the other hand, Martínez et al. (2014), indicated that Mg nitrate is the ideal source since Mg has a better uptake with nitrate ion.

Mg concentration at flowering was 0.52 %, which drops during fruit set, then rises again.

The dynamic of Mg in leaves was similar to that found in Ca. However, at the early harvest stage the trends of both elements become opposite, possibly as a result of antagonism. Montgomery (2019), showed that Mg and Ca concentrations had an increasing dynamic in relation to the advancing of the aging of the leaf, so it could be concluded that the sample taken could have been from mature leaves. Navarro

Magnesium

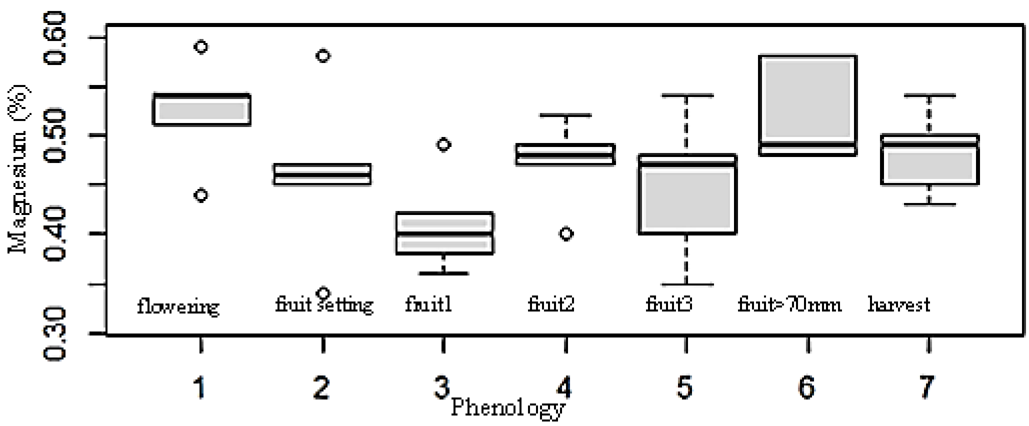

Figure 14. *Nutritional dynamics of magnesium in leaves*

```
> CV(x=Mg, na.rm=T)
[1] 0.1395861

Media
  1     2     3     4     5     6     7
0.524 0.460 0.410 0.472 0.448 0.522 0.482

stats
     [,1]  [,2]  [,3]  [,4]  [,5]  [,6]  [,7]
[1,] 0.51 0.45 0.36 0.47 0.35 0.48 0.43
[2,] 0.51 0.45 0.38 0.47 0.40 0.48 0.45
[3,] 0.54 0.46 0.40 0.48 0.47 0.49 0.49
[4,] 0.54 0.47 0.42 0.49 0.48 0.58 0.50
[5,] 0.54 0.47 0.42 0.52 0.54 0.58 0.54

$out
[1] 0.59 0.44 0.34 0.58 0.49 0.40

$group
[1] 1 1 2 2 3 4
```

(2003) explains that when the Ca/Mg ratio is higher than 10, Mg deficiency may already be visible. A high ratio is due to Ca displacing the Mg adsorbed in the colloidal complex, in this case the Ca/Mg ratio varied from 5.91 to 6.34, making a deficiency caused by soil imbalance unlikely.

Mg values varied between 0.4 % and 0.52 %, some authors pointed out that problems can be found with these concentrations. Bingham (1960), found that in deficient trees Mg could drop rapidly from a concentration of 0.3 % or 0.4 % to 0.1 % in the leaf, but other authors reported optimum Mg margin between 0.25 % to 0.8 %. For Maldonado-Torres et al. (2007), the optimum Mg concentration for yields above 20 t/ha ranges from 0.62 % to 0.77 %, while Gardiazabal (2004) mentioned that the normal Mg level is in the range of 0.4 to 0.8 %. Those authors pointed out that trees grafted on West Indian rootstocks have high foliar levels of Mg and K.. Finally, in all the cases the ranges obtained in this experiment would be within the acceptable range.

The levels of Mg is also influenced by potassium, comparing the curves of Mg and K in leaves, the minimum level of Mg was found in stage 3, in which K had its highest uptake (1.73 %). Mengel and Kirkby (2000), indicated that the possibility of antagonism between K and Mg is high, a K/Mg ratio should not exceed unity, since plants growing in these soils will prefer to take up K over Mg, leading to deficiencies. In this experiment, the obtained ratio was between 0.2 and 0.3, indicating an adequate balance in the soil.

Inside the plant, magnesium levels were much lower than those of potassium (1.11 % to 1.73 %), this is due to high potassium fertilization. Mengel and Kirkby (2000), reported that the amounts of Mg and Ca decrease with increasing K concentration in the medium, it is possible that K increases yield by generating a greater need for Mg. Hofman et al. (2002), found that Mg and Ca had a positive relationship with yield and number of fruits, in addition, the ratio (Ca+Mg)/K correlates positively with Mg and Ca in fruit pulp, and these three, correlate negatively with anthracnose.

Conclusions

- The nutritional concentrations of the studied elements are highest during the flowering, fruit set and fruit 1 (10 mm to 30 mm in diameter) stages.
- Nitrogen, phosphorus, potassium, calcium and magnesium, varied over phenological stages from higher to lower concentrations.
- Total N in fruit reaches its maximum absorption at fruit set in the form of nitrate, which tends to accumulate in flowers and growing fruit, while in leaves it is found in smaller proportions.
- The absorption of P, Ca and Mg destined to fruits is higher in the flowering and fruit setting stages.
- The concentration of Ca is higher than Mg in leaves, and during flowering and fruit set, the results of both elements show high dispersion. Nevertheless, the mean concentrations remained optimal according to some ranges cited in previous researches.
- P and K nutritional dynamics follow decreasing patterns as leaves age. Contrary, Ca and Mg follow opposite dynamics.

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Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

Author contributions

Elaboration and execution, Development of methodology, Conception and design; Editing of articles and supervision of the study have involved all authors.

ORCID and e-mail

N. PINO-HUASACCA 20090209@lamolina.edu.pe
https://orcid.org/0000-0002-8035-601X
L. TOMASSINI-VIDAL ltomassini@lamolina.edu.pe
https://orcid.org/0000-0003-2442-1558

References

Abraham, J. D., Abraham, J., & Takrama, J. F. (2018). Morphological characteristics of avocado (*Persea americana* Mill.). *African Journal of Plant Science, 12*(4), 88–97.

AGQ Labs. (Sept. 12, 2018). *Procedimiento para la toma de muestra de suelo agrícola. AQG agroalimentaria y medio ambiente*: http://www.agq.com.es/article-es/toma-muestras-hojas-paniculas-paltos

Alcaraz, M., Thorp, T., & Hormaza, J. (2013). Phenological growth stages of avocado (*Persea americana*) according to the BBCH scale. *Scientia Horticulturae*, *164,* 434–439.

Aleman, G., Ledesma, N., Campbell, R., & Herrera, J. (2005). The introduction of West Indian avocados to South Florida. *Proc. Fla. State Horticulture Society, 118*, 244–246

Ataucusi, S. (2015). *Manejo técnico del cultivo del palto* [Technical management of avocado cultivation]. Perú: Cáritas del Perú.

Atta, A., Morgan, K., & Mahmoud, K. (2021). Split application of nutrients improves growth and yield of Huanglongbind-affected citrus trees. Soil Science Society of America Journal, 85(6), 2040–2053. https://doi.org/10.1002/saj2.20310

Bar, Y., Applebaum, A., Kafkafi, U., & Goren, R. (1997). Relationship between chloride and nitrate and its effect on growth and mineral composition of avocadoand citrus plants. Journal of Plant Nutrition, 20(6), 715–731. https://doi.org/10.1080/01904169709365288

Barrientos, A., Martínez, M., Vargas, H., & Lázaro, M. (2016). Effect of preharvest calcium spraying on ripening and chilling injury in ‘Hass’ (*Persea americana* Mill.) avocado. *Revista Chapingo Serie Horticultura, 22*(3), 145–159

Bingham, F. T. (1960). Magnesium deficiency of the ‘Hass’ avocado tree. *California Avocado Society, 44,* 101–105.

Bonomelli, C., Gil, P., & Schaffer, B. (2019). Effect of soil type on calcium absorption and partitioning in young avocado (*Persea americana* Mill.) trees. *Agronomy, 9,* 1–11.

Boñuelos, J., Sangabriel, W., Gavito, M., Trejo, D., Camara, S., Mendel, R., & Carreon, Y. (2017). Efecto de diferentes niveles de fósforo en aguacate inoculado con hongos micorrízicos arbusculares. *Revista Mexicana de Ciencias Agrícolas, 8*(7), 1509–1520.

Campisi, S., Zheng, Y., Rolshausen, P., Crowley, D., Faber, B., Bender, G., & Lovatt, C. (2017). Optimal nutrient concentration ranges of ‘Hass’ avocado cauliflower stage inflorescences-potential diagnostic tool to optimize tree nutrient status and increase yield. *HortScience, 52*(12), 1707–1715. https://doi.org/10.21273/HORTSCI12437-17

Cassity-Duffey, K., Cabrera, M., Gaskin, J., Franklin, D., Kissel, D., & Saha, U. (2020). Nitrogen mineralization from organic materials and fertilizers: Predicting N release. *Soil Science Society of America Journal, 84*(2), 522–533. https://doi.org/10.1002/saj2.20037

Cassity-Duffey, K., Moore, A., Satterwhite, M., & Leytem, A. (2018). Nitrogen Mineralization as affected by temperature in calcareous soils receiving repeated applications of dairy manure. *Soil Science Society of America Journal, 84*(1), 235–242. https://doi.org/10.2136/sssaj2017.02.0044

Castillo, A. M., Tirado, J. L., Rubi, M, & Avitia, E. (2000). Seasonal variation in nutrient concentration in leaves and inflorescens of avocado. *Journal of plant nutrition, 23*(5) 663–671. https://doi.org/10.1080/01904160009382048

Crowley, D. (2007). Managing soils for avocado production and root health. *California Avocado Society, 90*, 107–130.

Escobar, V., Cortes, M., Correa, G., Rondón T., & Rodríguez, P. (2021). ‘Hass’ avocado internal disorders under simulated export conditions and its relationship with flesh mineral content and preharvest variables. *Horticulturae, 7*(4), 77. https://doi.org/10.3390/horticulturae7040077

Fernández, C., Villavicencio, Y., & Salazar, S. (2017). Seguimiento y manejo nutrimental de la palta ‘Hass’ en el desierto del Perú. *Memorias del V congreso latinoamericano,* 255–265. Jalisco

Figueroa, M., Castillo, A., Avitia, E., & Tirado, J. (2001). Concentración nutrimental en hojas e inflorescencias de tres cultivares de aguacatero. *Terra, 19*(2), 127–132.

Gardiazabal, F. (2004). Riego y Nutrición en palto [Irrigation and Nutrition in avocado]. *2° Seminario Internacional de palto,* 21. Quillota-Chile.

Giguere, A., Taylor, A., Myrold, D., & Bottomley P. (2015). Nitrification responses of soil ammonia-oxidizing Archaea and bacteria to ammonium concentrations. *Soil Science Society of America Journal, 79*(5), 1366–1374. https://doi.org/10.2136/sssaj2015.03.0107

Granados, A. (2013). *Nutritional factors that determine the productive performance of avocado trees (Persea americana Mill.) Cv. ‘Lorena’ in San Sebastián de Mariquita in the departament of Tolima, Colombia. Medellín* [Thesis for a Master’s Degree, Universidad Nacional de Colombia].

Guerrero, F., Alejo, G., Sánchez, R., Bugarín, R., Aburto, C., & Isiordia, N. (2018) Respuesta del cultivo de aguacate (*Persea americana* Mill.) variedad Hass a la aplicación de nitrato de potasio. *Acta Agronómica, 67*(3), 425–430. https://doi.org/10.15446/acag.v67n3.68858

Hofman, P., Vuthapanich, S., Whiley, A., Klieber, A., & Simons, D. (2002). Tree yield and fruit minerals concentrations influence 'Hass' avocado fruit quality. *Scientia horticulturae*, *92*(2), 113–123. https://www.sciencedirect.com/science/article/abs/pii/S0304423801002862

Holle F. D. (1961). A classification of pedoturbations and some other processes and factors of soil formation in relation to isotropism and anisotropism. *Soil Science*, *91*(6), 375–377

Huett, D. O., & Dirou, J. F. (2000). An evaluation of the rationale for fertilizer management of tropical fruit crops. *Australian Journal of experimental agriculture, 40*(8), 1137–1143. https://doi.org/10.1071/EA00047

Ibacache, A., & Sierra, C. (1998). *Fertilización del palto [Fertilization of avocado].* Ovalle, Chile: Instituto de Investigaciones Agropecuarias.

Johnson, D. L., Watson-Stegner, D., Johnson, D. N., & Schaetzl., R. J. (1987) Proisotropic and proanisotropic processes of pedoturbation. *Soil Science, 143*, 278–292.

Joubert, E. (2016). *Avocado fertilizing principles*. http://redsunhort.co.za/wp-content/uploads/DOWNLOADS/Avo-general-norms-and-fertigation-guidelines.pdf

Joyce, D., Perkins, M., Newett, S., Coates, L, & Irvine-Brown, S. (2022). Mineral nutrition for avocado fruit quality – a brief review and recommendations. *Acta Horticulturae 1333*, 285-290. https://doi.org/10.17660/ActaHortic.2022.1333.37

Knight, R. (2007). Historia, Distribución y Usos [Distribution and Use]. In A. Whiley, B. Schaffer, & B. Wolstenholme (Eds.), *El palto botánica, producción y usos [Avocado botany, production and uses].* Valparaíso: Ediciones Universitarias de Valparaíso.

Lahav, E., Bar. Y., & Kalmar, D. (1990). Effect of nitrogenous fertilization on the anual variations in nutrients in avocado leaves. *Community in soil sciencie plant analysis, 21*, 1353–1365. BetDagan, Israel.

Lao, C. (2013). *Fertilización en el cultivo de palto*. Ancash, Perú.

Lovatt, C. (1995). *Nutrición nitrogenada del palto 'Hass'* [Nitrogen nutrition of 'Hass' avocado tres]. *Proceedings of the World Avocado Congress III*. 152–159. California: Universidad de California.

Maldonado-Torres, R., Álvarez-Sánchez, M., Almaguer-Vargas, G., Barrientos-Priego, A. F., & García-Mateos, R. (2007). Estándares nutrimentales para aguacatero 'Hass' [Nutritional standards for 'Hass' avocado tres]. *Revista Chapingo Serie Horticultura, 13*(1), 103–108.

Martínez, J., Muena, V., & Ruiz, R. (2014). *Nutrición y fertilidad en los paltos [Nutrition and fertility in avocado tres].* La Cruz, Chile: Centro Regional de Investigación La Cruz. INIA.

Mengel, K., & Kirby, E. (2000). *Principios de nutrición vegetal [Principles of plant nutrition]* (first Ed.). Basilea, Suiza: Instituto internacional de potasio.

Ministerio de Agricultura - Sistema Integrado de Estadísticas Agrarias (consulted on may 08, 2022) https://app.powerbi.com/view?r=eyJrIjoiMWZmNDY2NTEtODg4NC00ZmQxLTk1NjItNWRiYmE4OGY2MDA4IiwidCI6IjdmMDg0NjI3LTdmNDAtNDg3OS04OTE3LTk0Yjg2ZmQzNWYzZiJ9

Montgomery, L. (2019). *Consideraciones básicas del manejo nutrimental del aguacate 'Hass' para una óptima poscosecha en zonas tropicales [Basic considerations of nutritional management of 'Hass' avocado for optimal postharvest in tropical áreas].* World Avocado Congress 23-27 de Setiembre de 2019.

Navarro, G. (2003). *Química agrícola: el suelo y los elementos químicos esenciales para la vida vegetal* (Second Ed.). Madrid, España: Ediciones Mundiprensa.

Ning, J., Arenberg, M., & Arai, Y. (2021). Phosphorus mineralization affected by urea in an intensively managed agricultural soil. *Soil Science Society of America Journal, 85*(6), 2067–2076. https://doi.org/10.1002/saj2.20324

Novela, P., Maffeo, T. P., & Mathaba, N. (2018). Delayed harvest, fruit nutritional content and tree productivity of 'Reed' avocado (*Persea americana*). *Acta Horticulturae, 1225*, 239–246. https://doi.org/10.17660/ActaHortic.2018.1225.33

Penter, M., & Stessen, P. (2000). The effect of pre- and postharvest calcium applications on the postharvest quality of 'Pinkerton' avocados. *South African Avocados Growers´ Association, 23*, 1–7.

Razzeto, B., & Salgado J. (2004) The inflorescense and fruit peduncle as indicators of nitrogen status of the avocado tree. *HortScience, 39*(6), 1173–1174. https://doi.org/10.21273/HORTSCI.39.6.1173

Rosecrance, R., Lovatt, C., Faber, B., Redeer, D., & Savard, S. (2003). *Seasonal patterns of nutrient uptake and partitioning a function of crop load of the 'Hass' avocado.* California department of food and agriculture fertilizer research and education program (FREP).

Salazar-García, S., González-Durán, I. J. L., & Ibarra-Estrada, M. E. (2015). Identification of the apppropiate leaf sampling period for nutrient analysis in 'Hass' avocado. *HortScience, 50*(1), 130–136.

Salvo, J. (2017). Fertilización en huertos de paltos [Fertilization in avocado orchards]. In A. Torres (Ed.), *Manual de cultivo del palto [Avocado cultivation manual]* (pp. 11–23). Santiago, Chile.

Silber, A., Naor, A., Cohen, H., Bar-Noy, Y., Yechieli, N., Levi, M., & Assouline, S. (2018). Avocado fertilization: Matching the periodic demand for nutrients. *Scientia Horticulturae, 241*, 231–240.

Spann, T. (2019). *Avocado fertilization*: *The macronutrients.* In From the Grove (pp. 32–35).

Suzuki, K., Fatokun, C., & Boukar, O. (2021). Effects of phosphorus applications on the performance of some cowpea lines. *Agronomy Journal, 114*(1), 727–738. https://doi.org/10.1002/agj2.20878

Wagoner, A., Bottomley, P., Taylor, A., & Myrold, D. (2021) Soil nitrification response to dairy digestate and inorganic ammonium sources depends on soil pH and nitrifier abundances. *Soil Sience Society of America Journal, 85*(6), 1990–2006. https://doi.org/10.1002/saj2.20325

Witney, G., Hofman, P., & Wolstenholm, B. (1990). Mineral distribution in avocado trees with reference to calcium cycling and fruit quality. *Scientia Horticulturae, 44*, 279–291.