Article

Evaluation of the chemical components of the soil in the arracacha production system in Cajamarca, Colombia

José Luis Contreras-Santos[1]
Jorge Enrique Villamil-Carvajal[2]
Johanna Paola Garnica-Montaña[2§]
Liliana Margarita Atencio-Solano[1]

[1]Turipana Research Center-Colombian Corporation for Agricultural Research-Agrosavia. Vía Montería Cereté km 13, Montería, Colombia. CP. 230009. (jlcontreras@agrosavia.co; latencio@agrosavia.co).
[2]Nataima Research Center-Colombian Corporation for Agricultural Research Agrosavia. Via Espinal Ibagué, Espinal Tolima Km 9, Colombia. CP. 733529. (jvillamil@agrosavia.co).

[§]Corresponding author: jgarnicam@agrosavia.co.

Abstract

The crop of arracacha (*Arracacia xanthorrhiza* Bancr.) is part of the Andean culinary culture and economy of Colombia, its importance lies in being a primary source in the peasant diet and nutrition. The low technification of the crop, associated with inadequate soil management practices, has generated stagnation in regional yields, which has generated an increase in the technological knowledge gap among producers. For this reason, the objective of the present study was to evaluate the chemical properties of the soil, under the production system of arracacha (*Arracacia xanthorrhiza* Bancr.) and identify the main chemical limitations of the soil that affect the yield in the crop, in the municipality of Cajamarca, Tolima. Soil samples were taken during the dry-rainy transition period in 50 farms distributed in 17 villages of the municipality, on which the chemical parameters of soils were evaluated, likewise, the production of tuberous roots was estimated based on the average sowing density of the region, 16 666 plants ha^{-1}. It was observed that 81% of the farms evaluated presented an acid reaction (5.25 ±0.15 to 6.6 ±1.1), organic matter (OM) content in the medium range (>3%) and cation exchange capacity (CEC) with low values (3.31 ±0.64 to 15.35 ±10.25 cmol kg^{-1}). The yield of fresh tuberous roots was conditioned to the presence of the contents of OM, interchangeable calcium (Ca) and potassium (K) in the soil. The results obtained showed processes of chemical degradation of the soil associated with fertilization implemented by producers in the region.

Keywords: agricultural production, Apiacea, organic matter, pH, soil.

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Introduction

Arracacha (*Arracacia xanthorrhiza* Bancr.) is a rustic herbaceous plant, typical of the Andean zone, adapted to different agroecological areas with altitude between 1 500 and 3 000 masl. Arracacha is of great agrifood importance (Morillo *et al*., 2020), is a source of fiber and minerals, such as iron, phosphorus, calcium and magnesium, which is generally marketed fresh and also stands out for its agro-industrial potential (Garnica *et al*., 2021). The productive system is developed by small producers, who transmit their knowledge among members of the communities by oral tradition (Muñoz *et al*., 2015).

In Colombia, 9 277 ha of arracacha are sown in 14 departments, with an average yield of 8.55 t ha^{-1} and a total production of 101 604 t, of which Tolima contributes 62.2%. This department established 5 504 ha with a production of 63 233 t and an average yield of 9.98 t ha^{-1} (MinTIC, 2019), with the municipality of Cajamarca standing out, with an average yield of 12 t ha^{-1} and 4 521 ha sown in 483 farms, distributed in 33 villages of the 42 it has (Garnica *et al*., 2021).

In Colombia, studies carried out on the crop of arracacha, mainly on the nutrition component and chemical characteristics of the soils, are scarce. More than 90% of producers fertilize without knowing the chemical properties of their soils, and they do so empirically with inadequate doses and nutrient sources, focused mainly on nitrogen (N), phosphorus (P) and potassium (K) (Muñoz *et al*., 2015). This inadequate implementation of chemical fertilization of the soil in order to improve the productive development indicators of the crop has led to an increase in production costs, which generates a reduction in the income of the producer, in addition to contributing to soil degradation.

Considering the above, the present study sought to evaluate the chemical properties of the soil, under the production system of arracacha (*Arracacia xanthorrhiza* Bancr.) and identify the main chemical limitations of soil that affect the yield in the crop, in the municipality of Cajamarca, Tolima.

Materials and methods

Localization

The study was carried out in the main growing area of arracacha (*Arracacia xanthorrhiza* Bancr.), located in the municipality of Cajamarca, Tolima, in Colombia, which is characterized by a predominant mountain and high mountain relief, long slopes greater than 50%. The predominant environmental conditions are: rainfall of 2 500 to 2 800 mm year^{-1}, average annual temperature of 12 to 18 °C and relative humidity of 83%. According to the agroecological zones identified, the study was carried out in a premontane moist forest (PM-mF) for the villages located between 1 000 and 2 000 masl and a premontane wet forest (PM-wF) for those located between 2 000 and 4 000 masl (Table 1) (Holdridge, 1982).

Table 1. Villages selected in the study in the municipality of Cajamarca, Tolima 2016.

Villages	Altitudinal range (m)	Area (ha)	Production (t ha^{-1})
El Águila	2 151 to 2 603	468	18.56
Potosí	2 253 to 2 534	432	21.34
Las Lajas	2 255 to 2 649	377	13
La Leona	2 340 to 2 485	356	20.31
Plata Montebello	2 427 to 2 556	241	33.37
La Tigrera	2 097 to 2 633	190	23.88
La Judea	2 163 to 2 559	171	14.83
Cedral	2 325 to 2 345	162	15
Las Hormas	2 022 to 2 196	129	17.08
La Bolívar	2 644 to 2 834	115	15.43
La Paloma	2 266 to 2 680	109	16.31
La Despunta	2 131 to 2 218	90	15
Rincón Placer	2 350 to 2 367	80	7.81
Pan de Azúcar	2 367 to 2 370	62	18.37
Altamira	2 352 to 2 576	54	15.83
Puente Hierro	1 958 to 2 006	34	23.37
La Alsacia	1 850 to 1 872	25	14.41

UMATA (2018).

The characteristic soils of the study area correspond to the Andisol order, with distribution of horizons: A-AB-Bw-C, predominance of loam-sandy texture, granular structure, moderately developed and good natural drainage. The landscape delineates narrow valleys, developed on igneous rocks as metamorphic, covered with volcanic ash of different thickness, from which derive the most abundant soils in the area: Hapludands and Melanudands. The soils of the municipality of Cajamarca have a medium to high fertility (IGAC, 2004; Chaali *et al*., 2020).

Sample frame

Seventeen villages were selected in Cajamarca based on the area of sowing and production of arracacha (Table 1) according to the Municipal Unit for Agricultural Technical Assistance in 2018 (UMATA, 2018). The calculation of the sample size was performed by applying equation 1 described by (Aguilar, 2005). $n=\frac{Z^2Npq}{pqZ^2+(N-1)e^2}$ 1). Where: n: sample size; N= population size; Z= coefficient for a confidence level of 95%; p= proportion of individuals who have the characteristic of interest, it was assumed at 0.5; q= proportion of individuals who do not have the characteristic of interest, it was assumed at 0.5; e= maximum permissible error, it was assumed at 6.36%. Because the variance of the study population is not known, the greatest possible variance was assumed, that is, considering the values of p= q= 0.5

The application of the equation allowed determining a sample size of 50 farms for the diagnosis of soils, which corresponded to 10.4% of the total population of the farms registered for the production of arracacha, which is 483 farms. The database on soil chemical parameters was fed with secondary information provided by the soil and water laboratory of AGROSAVIA from the last 10 years.

In order to generate reliability in the information, the data was cleaned based on three criteria: arracacha crop, dry to rainy transition period and sample depth of 0-30 cm. Obtaining 51 farms that met the minimum data required for the analysis of the information (secondary information). In general, we worked with 101 analyses of chemical soil fertility, distributed in the 17 villages (Table 1).

Sampling and chemical properties of soil

Sampling was carried out in 2019 in the dry-rainy transition period (February-March) in each of the selected villages (Table 1). Soil samples from 0 to 30 cm deep were taken in triplicate at random points within the farm. The soil samples of each farm were mixed and homogenized to obtain a representative composite sample of approximately one kilogram of weight, which was packed and identified with the name of the farm, owner, village, corregimiento, municipality and later sent to the soil and water laboratory of AGROSAVIA, where a complete chemical analysis was carried out.

The chemical parameters of the soil were analyzed using the following methods: The reaction of the soil or pH was determined by the potentiometric method, with a 1:1 W/V ratio (Hendershot *et al*., 2007), method of organic matter-OM (%) Walkley-Black oxidation (Nelson and Sommers, 2018); phosphorus-P (mg kg^{-1}) modified Bray II extraction and quantification by reduction with ascorbic acid (Bray and Kurtz, 1945); sulfur-S (mg kg^{-1}) extraction with calcium monophosphate 0.008 M and turbidimetric quantification; potassium-K, calcium-Ca, magnesium-Mg and sodium-Na (cmol(+) kg^{-1}) by means of atomic absorption and emission spectrophotometry (Hendershot *et al*., 2007; Chapman 2016), Colombian Technical Standard-NTC 5349 (ICONTEC, 2016); iron-Fe, manganese-Mn, zinc-Zn and copper-Cu (mg kg^{-1}) were determined by the modified Olsen method, spectrophotometry and quantification by atomic absorption, NTC 5526:2007 (ICONTEC, 2007) and boron-B (mg kg^{-1}) by extraction with monobasic phosphate of calcium-azomethine H, NTC 5404:2011 (ICONTEC, 2011).

Arracacha crop yield (t ha^{-1})

The yield was obtained from the information provided by the farmers of the selected farms, for which an average population density of 16 666 plants ha^{-1} was considered with a loss margin of 7% due to non-commercial roots and purple pigmentation (Atencio *et al*., 2021).

Statistical analysis

A descriptive statistical analysis was performed, using analysis of frequency and concentrations of nutrients (Castro and Gómez, 2010). Subsequently, the information of soil chemical parameters was processed using static methods described by Gómez and Gómez (1984). Normality was performed with the Shapiro-Wilk statistic (p> 0.05), no data transformation was required for this study. The selection of the minimum dataset was performed with a principal component analysis (PCA); through the Pro-factor procedure. The linear correlations were verified using Pearson's correlation analysis (PROC CORR), the software used for the analysis of the information is the Statistical Analysis System-SAS v.9.3.

Results and discussion

The pH showed an overall average of 5.94 ±0.4 with a variation range from 5.25 ±0.15 to 6.22 ±0.15 (Table 2), values indicating that the soil varied from a strongly acidic (La Bolívar) to slightly acidic condition (Plata Montebello) (Castro and Gómez, 2010). The frequency analysis showed that 81% of the farms had a range of variation of pH 5.6 to 6.5 (modern to slightly acidic), 16% values below 5.5 (strongly acidic) and the remaining 3% values greater than 6.6 (neutral) (Figure 1A).

Table 2. Macronutrient contents of the soil in the study area.

Village	S	P	Ca	Mg	K	Na
El Águila	4.36 ±1.98 B	34.97 ±20.25 M	7.54 ±3.97 A	1.69 ±0.75 M	0.59 ±0.19 M	0.13 ±0.06 M
Potosí	5.27 ±1.58 B	21.28 ±10.29 M	7.78 ±1.65 A	1.36 ±0.81 M	0.48 ±0.23 M	0.05 ±0.01 B
Las Lajas	4.67 ±0.68 B	37.29 ±14.69 M	7.55 ±1.84 A	1.69 ±0.47 M	0.55 ±0.18 M	0.06 ±0 B
La Leona	7.97 ±5.48 B	111.21 ±90.7 A	7.45 ±1.74 A	1.62 ±0.42 M	0.87 ±0.58 A	0.08 ±0.05 B
Plata Monte	2.97 ±1.35 B	15.85 ±9.28 B	7.38 ±1.48 A	1.56 ±0.31 M	0.58 ±0.19 M	0.13 ±0.02 M
La Tigrera	3.83 ±0.73 B	34.74 ±18.88 M	6.97±0.83 A	1.04 ±0.45 B	0.35 ±0.13 B	0.05 ±0.02 B
La Judea	2.58 ±0.45 B	99.11 ±100.33 A	6.51 ±1.76 A	1.08 ±0.41 B	0.43 ±0.19 M	0.08 ±0 B
Cedral	3.45 ±0.67 B	18.57 ±8.78 B	6.9 ±0.67 A	2.47 ±0.52 A	0.25 ±0.12 B	0.1 ±0.4 B
Las Hormas	8.66 ±4.46 M	11.16 ±3.49 B	4.87 ±2.85 M	1.21 ±0.46 M	0.69 ±0.63 A	0.11 ±0.04 M
La Bolívar	6.23 ±1.15 B	16.49 ±2.9 B	1.79 ±0.44 B	0.45 ±0.16 B	0.22 ±0.08 B	0.06 ±0.01 B
La Paloma	5.79 ±3.84 B	22.42 ±5.43 M	4.87 ±2.43 M	0.97 ±0.51 B	0.28 ±0.08 B	0.07 ±0.02 B
La Despunta	5.06 ±0.74 B	56.56 ±34.79 A	9.3 ±1.98 A	1.35 ±0.23 M	0.82 ±0.47 A	0.12 ±0.03 M
Rincón Placer	5.96 ±2.93 B	94 ±132.24 A	6.72 ±1.63 A	1.91 ±0.82 M	0.25 ±0.04 B	0.11 ±0.06 M
Pan Azúcar	6.16 ±2.04 B	33.38 ±34.20 M	12.96 ±.39 A	1.86 ±0.99 A	0.31 ±0.08 B	0.12 ±0.03 M
Altamira	4.77 ±1.06 B	33.06 ±15.98 M	3.88 ±1.19 M	0.97 ±0.22 B	0.32 ±0.02 B	0.07 ±0.02 B
Puente Hierro	2.97 ±0.73 B	30.19 ±2.9 M	4.94 ±0.89 M	0.84±0.45 B	0.26 ±0.09 B	0.07 ±0.01 B
La Alsacia	2.6 ±0.1 B	12.95 ±4.15 B	6.24 ±0.27 A	1.48 ±0.36 M	0.33 ±0.09 B	0.09 ±0.03 B
R^2	0.57	0.45	0.45	0.56	0.48	0.65
CV	44.66	113.73	44.85	36.62	60.38	34.77
Media	5.06 ±2.76	39.43 ±48.7	7.2 ±3.49	1.4 ±0.62	0.51 ±0.34	0.09 ±0.04

S, P= mg kg^{-1}; Ca, Mg, K and Na= cmol kg^{-1}; H= high; M= medium; L= low; R^2= coefficient of determination; CV= coefficient of variation (%); ±= standard deviation.

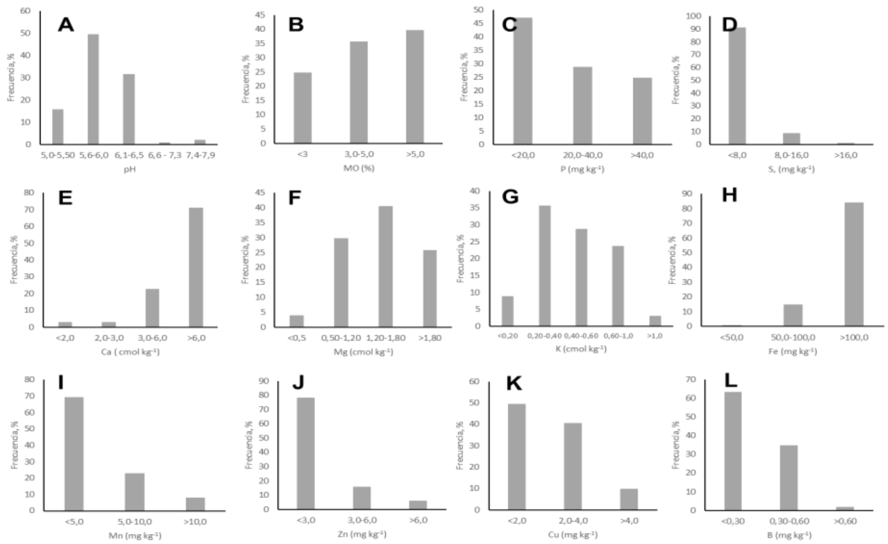

Figure 1. Frequency distribution of soil chemical properties.

Significant correlation ($p< 0.05$) was observed between the yield of the crop and the pH of the soil, indicating that as it increases, the production of tuberous roots is substantially improved. It has been reported that fertile soils, well drained and with pH of 5.6 to 6 are optimal for the development of arracacha crop (Amaya and Julca, 2006; Alvarado and Ochoa, 2010), which agrees with the pH values recorded in the study area. Seventy-five percent of the farms had OM values >3%, according to the regional environmental conditions, it has a medium content of OM (Castro and Gómez, 2010), of this percentage, 39.6% of the farms had OM greater than 5%, which corresponds to high contents (Figure 1B).

The OM content showed an average value of 5.15 ±2.74%, with a range of variation between 3.27±1.56 (medium) and 8.88 ±5.47% (high), with the village Las Hormas being where there was the highest content of OM in the soil, followed by Potosí (7.25 ±2.55%), Las Lajas (7.19 ±1.59%) and La Bolívar (7.12 ±2.52%). It has been reported that high contents of OM in the soil under the arracacha production system are related to high yields of the tuberous root per hectare (Alvarado and Ochoa, 2010); likewise, other authors report that high values of OM in the soil favor the activity of microorganisms, favoring the availability of nutrients (Nunes *et al*., 2016; Heid *et al*., 2019). These results are similar to those reported in this research, finding a positive correlation (r= 0.55) between OM content and root yield per hectare (Table 3).

Table 3. Chemical properties of soils in the study area.

Village	pH		OM		EC		CEC	
El Águila	6.14 ±0.36	LA	3.38 ±1.36	M	0.24 ±0.13	VL	9.72 ±04.37	L
Potosí	5.98 ±0.24	MA	7.25 ±2.55	H	0.24 ±0.16	VL	9.69 ±2.45	L
Las Lajas	5.97 ±0.43	MA	7.19 ±1.59	H	0.15 ±0.05	VL	9.86 ±2.43	L
La Leona	6.04 ±0.19	LA	4.9 ±1.6	M	0.41 ±0.21	VL	10.01 ±1.85	L
Plata Monte	6.22 ±0.15	LA	3.39 ±1.05	M	0.19 ±0.07	VL	9.66 ±1.82	L
La Tigrera	5.85 ±0.11	MA	6.56 ±2.72	H	0.09 ±0.05	VL	8.42 ±1.04	L

Village	pH		OM		EC		CEC	
La Judea	5.57 ±0.02	MA	3.69 ±0.68	M	0.13 ±0.03	VL	8.1 ±2.11	L
Cedral	5.82 ±0.48	MA	3.27 ±1.56	M	0.18 ±0.04	VL	9.72 ±0.03	L
Las Hormas	5.72 ±0.48	MA	8.88 ±5.47	H	0.44 ±0.33	VL	6.86 ±3.7	L
La Bolívar	5.25 ±0.15	SA	7.12 ±2.52	H	0.21 ±0.04	VL	3.31 ±0.64	L
La Paloma	5.59 ±0.25	MA	5.41 ±0.72	H	0.23 ±0.13	VL	6.29 ±2.86	L
La Despunta	6.04 ±0.13	LA	4.74 ±0.52	M	0.45 ±0.26	VL	11.58 ±2.21	M
Rincón Placer	5.98 ±0.63	MA	4.4 ±2.41	M	0.28 ±0.19	VL	9 ±2	L
Pan Azúcar	6.6 ±1.1	LA	4.24 ±3	M	0.32 ±0.11	VL	15.35 ±10.25	M
Altamira	5.37 ±0.22	SA	3.8 ±0.05	M	0.21 ±0.12	VL	5.76 ±0.76	L
Puente Hierro	5.76 ±0.02	MA	0.97 ±1.23	L	0.08 ±0.03	VL	6.11 ±0.02	L
La Alsacia	5.82 ±0.08	MA	1.73 ±0.52	L	0.15 ±0.04	VL	8.14 ±0.54	L
R^2	0.42		0.46		0.36		0.45	
CV	6.52		43.8		64.7		39.51	
Mean	5.94 ±0.45		5.15 ±2.74		0.26 ±0.18		9.26 ±3.95	

OM= %; EC= dS cm^{-1}; CEC= cmol(+) kg^{-1}; LA= slightly acidic; MA= moderately acidic; SA= strongly acidic; H= high; M= medium; L= low; VL= very low; R^2= coefficient of determination; CV= coefficient of variation (%); ±= standard deviation.

The cation exchange capacity (CEC) had an average value of less than 10 cmol kg^{-1}, considered low, with a variation from 3.31 ±0.64 (very low) to 15.35 ±10.25 (medium) cmol kg^{-1} (Castro and Gómez, 2010). In general, the CEC was below 20 cmol kg^{-1} (medium), with the lowest values in La Bolívar and Altamira (Table 2).

The content of phosphorus (P) in the soil presented values higher than 20 mg kg^{-1} in 53% of the farms, which indicated a medium to high content, the rest of the farms evaluated (47%) had low P contents, with the villages Las Hormas (11.16 ±3.49 mg kg^{-1}) and La Alsacia (12.95 ±4.15 mg kg^{-1}) being the ones that had the lowest contents (Figure 1C). The sulfur content (S) in the soil was less than 8 mg kg^{-1} (low) in more than 90% of the farms (Figure 1D), reporting the lowest values in the villages of La Judea and La Alsacia (2.58 ±0.45 mg kg^{-1} and 2.6 ±0.61 mg kg^{-1}, respectively) (Table 3).

The content of exchangeable calcium (Ca) reported in more than 70% of the farms showed values lower than 6 cmol kg^{-1} (Figure 1E); that is, they presented a very low to medium condition (Castro and Gómez, 2010), being very low in the village La Bolívar (1.79 ±0.44 cmol kg^{-1}) (Table 3). Likewise, a significant positive correlation ($p< 0.007$; r= 0.41) was found between the Ca content and the yield of the arracacha crop, which indicates that high Ca values in the soil favor the development of the crop and the formation of tuberous roots.

These results are reaffirmed by those obtained by Souza *et al*. (2017); Taiz and Zeige (2006), who obtained the highest dry matter values of crown and tuberous roots, after the application of a source of fertilizer with calcium (Ca). The deficiency of this nutrient (Ca) in the soil leads to the reduction of the growth of the plant and its roots, in addition to producing chlorosis and death of meristems in plants (Souza and Madeira, 2008).

The magnesium contents in the soil (Mg) were higher than 1.2 cmol kg^{-1}, indicating high contents of this exchange base, highlighting that this condition corresponded to 66% of the farms analyzed, Figure 1F, the villages that showed the lowest contents of Mg were La Bolívar, Puente Hierro, Altamira, La Paloma and La Tigrera (Table 3). The potassium (K) content in the soil had values below 0.4 cmol kg^{-1}, in 53% of the farms, Figure 1G, which indicates low contents of this nutrient. While high K values (>0.6 cmol kg^{-1}) were recorded in the villages Las Hormas, La Despunta and La Leona (Table 3).

In nutrition studies carried out on the crop of *Arracacia xanthorrhiza*, a high dependence of the yield of fresh roots per hectare with respect to the contents of potassium (K) and Mg in the soil was found, highlighting that as these elements increased in the soil, production was improved (Souza and Madeira, 2008; Chen and Fan, 2018; Mazetti *et al*., 2018). These results are corroborated in this study, where a high dependence (r= 0.4383) of the root yield of the tuberous roots of arracacha with respect to potassium (K) in the soil is shown.

The microelements, iron (Fe) showed high values (>100 mg kg^{-1}) in 84% of the farms (Figure 1H), the average value per village was 200.22 ±108.46 mg kg^{-1}, with variation from 108.93 ±33.5 mg kg^{-1} (Pan de Azúcar) to 390.66 ±93.45 mg kg^{-1} (La Judea). In 50% of the farms, the microelements Mn, Zn, Cu and B showed values (mg kg^{-1}) lower than the range necessary for the development of the crop: Mn (<5), Zn (<3), Cu (<2) and B (<0.3), (Figure 1I, Figure 1J, Figure 1K and Figure 1L) (Table 4).

Table 4. Soil micronutrient contents in the study area.

Village	Fe		Cu		Zn		Mn		B	
El Águila	178.65 ±57.61	H	2.02 ±0.65	M	2.21 ±1.13	L	4.32 ±1.86	L	0.28 ±0.09	L
Potosí	171.82 ±45.91	H	2.52 ±0.76	M	2 ±1.05	L	6.04 ±4.92	M	0.33 ±0.09	M
Las Lajas	250.25 ±177.51	H	2.25 ±0.26	M	2.4 ±1.77	L	2.72 ±1.12	L	0.31 ±0.04	M
La Leona	252.38 ±147.44	H	2.28 ±0.78	M	5.03 ±3.4	M	7.05 ±5.93	M	0.39 ±0.12	M
Plata Monte.	163.61 ±45.72	H	1.73 ±1.5	L	1.4 ±0.31	L	3.47 ±0.94	L	0.2 ±0.05	L
La Tigrera	175 ±55.63	H	4.86 ±3.9	H	2.53 ±2.62	L	3.73 ±2.42	L	0.23 ±0.06	L
La Judea	390.66 ±93.45	H	5.33 ±2	H	3.26 ±0.81	M	7.63 ±3.36	M	0.19 ±0.03	L
Cedral	152.44 ±102.61	H	1.95 ±1.34	L	1.1 ±0.14	L	6.69 ±5.95	M	0.22 ±0.07	L
Las Hormas	358.88 ±213.71	H	2.16 ±1.05	M	3.08 ±2.18	M	4.37 ±3.07	L	0.24 ±0.09	L
La Bolívar	175 ±85.71	H	3.76 ±2.4	M	1.1 ±0.87	L	6.53 ±1.46	M	0.25 ±0.03	L
La Paloma	228 ±25.41	H	2 ±0.86	M	1.42 ±0.45	L	7.4 ±3.69	M	0.22 ±0.08	L
La Despunta	140.4 ±41.92	H	2.23 ±0.67	M	2.95 ±1.75	L	4.1 ±2.42	L	0.31 ±0.1	M
Rincón Placer	181.7 ±132.75	H	2.08 ±0.65	M	3.47 ±4.62	M	4.08 ±2.19	L	0.26 ±0.17	L
Pan Azúcar	108.93 ±33.5	H	1.57 ±0.47	L	2.14 ±0.71	L	3.56 ±2.56	L	0.25 ±0.05	L
Altamira	239.66 ±48.52	H	4.53 ±3.1	H	1.63 ±1.27	L	7.46 ±2.55	M	0.26 ±0.09	L
Puente Hierro	154 ±20.34	H	1.2 ±0.89	L	1 ±0.35	L	2.9 ±1.23	L	0.12 ±0.05	L

Village	Fe		Cu		Zn		Mn		B	
La Alsacia	191.54 ±35.53	H	2.86 ±0.75	M	1.5 ±0.35	L	5.8 ±1.46	M	0.2 ±0.09	L
R^2	0.46		0.38		0.38		0.44		0.49	
CV	49.72		66.59		79.01		63.23		32.35	
Mean	200.22 ±108.46		2.6 ±1.77		2.37 ±1.92		5.02 ±3.33		0.26 ±0.09	

Fe, Cu, Zn, Mn and B= mg kg^{-1}; H= high; M= medium; L= low; R^2= coefficient of determination; CV= coefficient of variation (%); ±= standard deviation.

The principal component analysis (PCA) of the 19 chemical indicators in the farms of the agricultural production system (arracacha) showed that five (5) principal components (PC) were able to explain 80.4% of the accumulated variance (Table 5). Component one (1) explains the 28.14%, with the CEC (0.95) and Ca (0.93) being the eigenvectors with the highest weight. Component two (2) explained 21. 3%, with the cationic relations Ca/K (0.93), Mg/K (0.85) and (Mg+Ca)/K (0.95) being the ones that best explained this behavior. Component three (3) denoted 14.3%, being dominated by the minor elements Fe, Zn and Mn, which best explained the behavior of the soil (Table 5). Component four (4) observed 8.88%, the variables related to S and pH were the most relevant. In the case of component five (5), it explained 7.8% of the total variance, with the cationic ratio Ca/Mg being the one that best explains (0.92) (Table 5).

Table 5. Principal components of soil chemical parameters.

Indicator	Eigenvectors					Communalities
	PC1	PC2	PC3	PC4	PC5	
pH	-0.02	-0.14	0.43	<u>0.77</u>	-0.32	0.91
EC	0.8	0.02	-0.2	-0.09	-0.04	0.7
OM	0.44	-0.48	-0.09	0.07	0.12	0.46
P	0.14	-0.31	0.68	0.24	-0.04	0.65
S	-0.15	-0.18	0.15	<u>0.83</u>	0.04	0.78
Ca	<u>0.93</u>	0.18	0.03	0.02	0.14	0.92
Mg	0.67	0.15	0.24	0.07	-0.63	0.94
K	0.42	-0.63	0.4	0.36	-0.18	0.9
Na	-0.04	0.13	0.17	-0.71	-0.06	0.56
CEC	<u>0.95</u>	0.11	0.13	0.07	-0.04	0.94
Fe	-0.14	0.05	<u>0.79</u>	-0.09	0.04	0.67
Mn	-0.21	0.13	<u>0.68</u>	0.47	-0.27	0.84
Zn	0.37	-0.18	<u>0.72</u>	0.3	-0.14	0.81
Cu	-0.04	0.1	0.45	-0.23	0.54	0.58
B	0.38	-0.06	0.3	0.7	-0.08	0.74
Ca/Mg	0.11	-0.06	-0.17	0.03	<u>0.92</u>	0.9
Mg/K	0.13	<u>0.85</u>	0	-0.14	-0.41	0.95
Ca/K	0.21	<u>0.93</u>	-0.07	-0.11	0.14	0.96
(Ca+Mg)/K	0.2	<u>0.95</u>	-0.06	-012	0.04	0.97

The underlined data were selected to obtain the minimum data set (MDS).

After identifying the minimum data set (MDS) (Table 5), supported by Pearson's correlation analysis, the indicator of greatest weight within each principal component (in cases where the PC showed more than one indicator) was selected, the significant correlation between them was considered. From PC1, CEC was selected for its weight within the component and its high correlation with Ca (r= 0.96). In PC2, the cationic ratio (Ca+Mg)/K (eigenvector= 0.95) and high correlation with Mg/K and Ca/K (r= 0.85 and 0.99, respectively) were selected. PC3, iron (Fe) was selected, which presented significant correlations with Mn and Zn (r= 0.45 and 0.44, respectively). In the case of PC4 and PC5, the chemical properties S (significant inverse correlation with pH r= -0.41) and the cationic ratio Ca/Mg, respectively, were selected.

Conclusions

The results obtained indicate that the municipality of Cajamarca has soils with adequate conditions for the establishment of the productive system of arracacha, highlighting that 19% of the villages have some chemical soil limitations, related to very acidic pH (La Bolívar and Altamira), deficient content of OM (Puente Hierro and La Alsacia), low content of exchange bases such as calcium (Ca) in the villages of La Bolívar, Altamira, Las Hormas and Las Palomas and magnesium (Mg) in La Bolívar.

The yield of tuberous roots of arracacha showed high dependence on pH and OM contents, likewise, it was found that the Ca content has a significant positive correlation with the yield of the crop, as well as the K and Mg contents. The microelements, Mn, Zn, Cu and B, did not significantly affect the development of the crop of arracacha. The balance between the cationic ratios (Ca/Mg, Ca/K and (Ca+Mg)/K) is relevant to ensure high yields of the arracacha crop.

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