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Effect of some edaphic conditions on physicochemical and physiological characteristics of ‘Horvin’ plum fruit

Efecto de algunas condiciones edáficas sobre las características fisicoquímicas y fisiológicas del fruto del ciruelo ‘Horvin’

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‘Horvin’ plum fruits grown in Nuevo Colón (Boyaca, Colombia).

Photo: M. Orjuela-Angulo

ABSTRACT

Edaphic conditions are determinant factors of fruit quality at harvest. The objective was to establish which edaphic variables influence fruit harvest and to determine the influence of these variables on some physicochemical and physiological characteristics of ‘Horvin’ Japanese plum fruits at harvest. In the municipality of Nuevo Colon (Boyaca, Colombia), records of two harvests were made in four locations during 2015 and 2016. Ten trees per row and twenty trees per location were marked, for a total of 80 trees for the four locations. For the chemical soil analyses, four samples were taken per location at a depth between 20 and 30 cm, for a total of 16 soil samples. For the physical analysis, 6 samples were taken per location at a depth between 20 and 30 cm, for a total of 24 soil samples. The results showed that the bulk density in the four locations was high, which is evidence of high levels of compaction in each location, resulting in low fruit development at harvest. A relationship was found with fruits at harvest in characteristics such as weight and diameter for some chemical variables, such as pH, phosphorus, cation exchange capacity, calcium, magnesium, potassium, zinc, copper, boron and sulfur.

Additional key words: fruit quality; harvest day; physicochemical soil analysis; bulk density; stone fruit.

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RESUMEN

Las condiciones edáficas son factores determinantes de la calidad del fruto en la cosecha. El objetivo fue establecer cuáles variables edáficas influyen en la cosecha de frutos, y determinar la influencia de estas variables en algunas características fisicoquímicas y fisiológicas de los frutos del ciruelo japonés 'Horvin' al momento de la cosecha. En el municipio de Nuevo Colón (Boyacá, Colombia) se realizaron registros de dos cosechas en cuatro localidades durante los años 2015 y 2016. Se marcaron diez árboles por surco y veinte árboles por localidad para un total de 80 árboles para las cuatro localidades. Para los análisis químicos de suelo se tomaron cuatro muestras por localidad a una profundidad entre 20 y 30 cm, para un total de 16 muestras de suelo. Para el análisis físico se tomaron 6 muestras por localidad, a una profundidad entre 20 y 30 cm, para un total de 24 muestras de suelo. Los resultados mostraron que la densidad aparente en las cuatro localidades es alta, lo que evidencia altos niveles de compactación en cada localidad, y por ende poco desarrollo de frutos al momento de la cosecha. En cuanto a algunas variables químicas como pH, fósforo, capacidad de intercambio catiónico, calcio, magnesio, potasio, zinc, cobre, boro y azufre, se encontró relación con el fruto a la cosecha en características como peso y diámetro.

Palabras clave adicionales: calidad de frutos; día de cosecha; análisis fisicoquímico de suelos; densidad aparente; frutas de hueso.

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INTRODUCTION

The 'Horvin' plum (*Prunus salicina* Lindl.) is a species whose origin includes different geographical areas. Within the *Prunus* genus, there are numerous fruit species known as 'stone fruits', including *Prunus domestica* L. (European plums) and *Prunus salicina* Lindl. (Japanese plums), each with diverse varieties (Milošević and Milošević, 2020; Afanador-Barajas *et al*., 2022). Plums originate from the Caucasus, Anatolia (Turkey) and Persia (Iran) regions. The main producing countries are Argentina, Chile, South Africa, the United States and Spain, whose cultivation stands out in Extremadura, in the Mediterranean area and in the provinces of Seville and Lerida (Sánchez, 2015).

China is the biggest plum producer in the world, with around 6.6 million tons in 2021 (FAO, 2023). The plum is also produced in Colombia, especially in "agro-ecological areas of the Cundiboyacense highlands" in the municipality of Nuevo Colon (Boyaca, Colombia) (Orduz-Ríos *et al.*, 2020). Additionally, the plum is reported to have beneficial impacts on human health, such as reducing metabolic syndromes (Ullah *et al.*, 2020), along with nutrition constituents with digestive benefits (Tabrizi *et al.*, 2020).

The soil-plant relationship is important because soil is a source of nutrients. As stated by García-Olalla (1996), one of the important soil characteristics is the amount of nutrients available for plants, determining production, water availability and accumulation of organic matter. Additionally, soil has life support functions (Schloter *et al.*, 2018), as well as vital chemical functions, such as carbon storage (Cotrufo *et al.*, 2019).

Plum fruits present, at harvest, great differences in their physicochemical characteristics, even among fruits harvested in the same crop. The physicochemical characteristics are influenced by the conditions of the production zone, which vary according to altitude (Fischer *et al*., 2022), precipitation or available soil moisture (Mertoğlu *et al*., 2020). Additionally, photosynthesis influences the physicochemical processes of harvested fruits, and respiration influences fruit metabolism changes during the growing season (Schouten *et al*., 2002).

The chemical, mineralogical and biological characteristics are determinant in the agricultural productivity of the soil (Stanturf and Schoenholtz, 1998). Soil properties define its suitability, and management depends on the degree of the different factors that affected its genesis over time and the interaction between them; so, soil properties affect plant development (Mihajlovic *et al.*, 2019).

Soil is the intermediary that provides the nutrients and water necessary for plants, and, consequently, its correct management "will result in satisfactory productivity and sustainability" (IGAC, 2005). Nutrients used by crops must be fully restored to the soil since the physical and chemical properties of the soil must be maintained (Rosemarin *et al.*, 2020); therefore, organic matter levels must be improved or at least kept constant.

To achieve sustainable production, it is necessary to know the limitations of the soil and its nutrient availability in terms of crop requirements to implement appropriate management practices for crop development through the most appropriate application of fertilizers, chemicals and organic amendments to the specific soil and crop conditions (Ramesh *et al.*, 2019). Soil quality must always be maintained (IGAC, 2005).

In Colombia, the exploration of modeling and simulation techniques has been scarce despite the influence of climatic variables (Cepeda *et al.*, 2021). On the other hand, edaphic variables, such as iron, are essential to crops since an increase or decrease can produce low growth in leaf area and therefore affect the crop (Brasili *et al.*, 2020).

Because of the importance of soil in crop production, the objective of this study was to establish which edaphic climatic variables influence the physicochemical and physiological characteristics of 'Horvin' plum fruits in the municipality of Nuevo Colon (Boyaca, Colombia).

MATERIALS AND METHODS

Location and study zones

The present study was developed in the town of Nuevo Colon, in Boyaca, Colombia. According to Pulido-García (2012), the municipality zone of Nuevo Colon has a humid climate, with a maximum temperature of 15.2°C in March and a minimum temperature of 12.9°C in July. It is characterized by a relative humidity of 87% in high areas and 35% in low areas, a B2d B1 cold humid climate (Thornthwaite classification), and monomodal precipitation with annual precipitation values of 907.2 mm. The climatic variables of the studied localities were evaulated. The present study was carried out at four locations (Tab. 1) in the municipality of Nuevo Colon.

Diamond peach rootstocks, grafted with 'Horvin' plum scions (*Prunus salicina* Lindl.), are found in the localities; these cultivars are from different years. The treatment used for the four locations were similar: no irrigation or drainage systems in the plum production, fertilization done by applying manure with a 15% nitrogen, 15% phosphorus and 15% potassium composition. Finally, for crop management, pruning was done by the farmers at the same time based on their expertise.

Experiment design

10 trees were taken per row from two rows per location for two harvests, for a total of 80 trees per harvest. Observations were carried out in the center of each location to avoid the edge effect. Additionally, 10 fruits were taken from each tree to run the tests.

Sampling

Temperature and relative humidity were recorded every 10 min with a Major Tech thermo hygrometer (Johannesburg, South Africa). Precipitation data were calculated with 50 mm capacity Tildenet® rain gauges (Buckingham, UK) installed in each of the localities to maintain uniform meteorological conditions.

For the soil analysis, four samples of approximately 1 kg were taken for each locality from several

Table 1. Location of the studied zones for the years 2015 - 2016.

Zone	Altitude (m)	Latitude	Longitude	RH (%)	Max. temperature (°C)	Min. temperature (°C)
Locality 1	2,449	5º 21' 25.61" N	-73º 27' 41.51" O	64.5	28.7	7.3
Locality 2	2,285	5º 20' 32.79" N	-73º 27' 47.41" O	68.3	29.1	8.2
Locality 3	2,215	5º 20' 21.33" N	-73º 27' 49.32" O	70.2	29.2	9.3
Locality 4	2,195	5º 20' 17.56" N	-73º 27' 53.85" O	73.8	30.7	9.5

Data were taken with a GPS and a thermo-hygrograph for each point.
RH, relative humidity.

subsamples. For the moisture retention curves, six unaltered samples were taken per location with a metal ring, 2 inches in diameter and 1 inch in height, using the pressure plate method with an Eijkelkamp (Royal Eijkelkamp, Giesbeek, The Netherlands). The real density was determined with a pycnometer, the bulk density was determined with the cykubder method, and the texture was done with Bouyoucos. For the soil chemical attributes, the following methods were applied: TruSpec CN determinator (LECO, St. Joseph, MI) for total carbon (%); potentiometer with a 1:1 relation between water and soil for pH; exchangeable aluminum and exchangeable acidity were measured by titration; phosphorus was determined using Bray II method; Ca, Mg, K and Na were determined through extraction ammonium acetate at 7.0 pH and reading in an equipment of atomic absorption; Cu, Fe, Mn and Zn contents were determined through extraction and readings using an atomic absorption device; the B content was determined with monobasic calcium phosphate – Azomethine H.

At harvest, weight variables were taken with a Mettler PC2000 electronic balance (Metter Toledo, Columbus, OH), 0.01 g precision. For the variation of equatorial diameter and fruit length (mm), a Kanon vernier hand caliper was used (Nakamura Mfg. Co., Nagano, Japan), with an accuracy of 0.01 mm. For the calculation of the variation of the firmness of the peel and pulp of the fruit, firmness samples were taken using a Broofield CT3-4500 texturometer (Broofield Engineering, Middleboro, MA) with a TA39 probe (2 mm diameter) with an accuracy of ±0.5%, taking one reading per fruit.

The color of the surface layer of the 'Horvin' plum fruit (hue angle; °h) was established using a Minolta CR-400 colorimeter (Konica Minolta, Ramsey, NJ); for the measurement of total soluble solids (TSS), an NTC 440 (Icontec, 2015) was applied, and an Eclipse refractometer (Bellingham Stanley, Tunbridge Well, UK) was used with a scale of 0 to 32 and a precision of 0.2 °Brix; the total titratable acidity (TTA) was determined following NTC 440 (Icontec, 2015). Finally, the maturity ratio (MR) was determined from the ratio of total soluble solids to total titratable acidity (TSS/TTA) (Parra-Coronado, 2014).

Processing and analysis of the data

For the behavioral analysis of each variable, the IBM-SPSS v. 22 (SPSS Inc., Chicago, IL, USA) statistical program was used for box plots and Tukey's test after the corresponding ANOVA test. The data were analyzed with descriptive statistics. Principal component factor analysis was performed using Varimax rotation to visualize the variables with the greatest incidence in the study, and Tukey tests were performed on the physical, chemical and fruit characteristics for each location and for each harvest.

A Pearson correlation was performed to identify the relationship between some climatic and soil attributes in the fruits. Additionally, a cluster analysis was performed with the aim of estimating the correlation between the fruit development and the soil and climatic attributes.

RESULTS AND DISCUSSION

Descriptive analysis of the physical properties of the soil

The soils of the four localities had loam, clay loam, sandy, and sandy loam textures (Tab. 1). Additionally, the soil of the four localities had typical characteristics (Tab. 2), such as coarse textures resulting from particle disaggregation (percentage of macropores between 2.0 and 12.5% - micropores 17.5 and 34.5%, calculated from the water retention curve), and low contents of available water (between 12.5 and 27.5%), as reported by Jaramillo (2002). The bulk density was between 1.56 and 1.8 g cm^{-3}, which indicated high resistance to soil penetration (Souza *et al.*, 2021).

Knowing the porosity is very important since this variable defines the water-air relationship (Fu *et al.*, 2019). According to IGAC (2005), most mountain soils have a high total porosity in the first horizon, greater than 50%, but the distribution between macropores and micropores is inadequate, since micropores predominate in most soils. The total porosity value does not always reflect all the changes that can occur in a cultivated soil, especially when found in the pore size distribution (Jensen *et al.*, 2020).

The percentage of sands was higher in locality 3 (56%) (Tab. 2), as opposed to locality 4, where it was lower (43%). The locality with the lowest percentage of clays was locality 3 (19%), in contrast to locality 4, which had a higher percentage (31%). For the percentage of silts, locality 1 (28%) had the highest percentage, and locality 2 had a percentage of 21%. These results agree with those recorded by the IGAC

(2005) in a study of some soils in MMX units for the localities, characterized by soils with colloidal clay resulting from mechanical migration because of a cold dry climate, with alternating dry and wet seasons.

The total pore space increases as texture becomes finer and is consistent with the low silt and clay content (Zhang *et al*., 2020).

Table 2. Distribution of sand, silt, and clay contents (%) in the four studied localities.

Locality	Sand	Silt	Clay
1	45.7 b	27.5 a	26.8 a
2	52.18 a	20.05 b	27.77 a
3	55.48 a	25.72 a	18.8 b
4	43.3 b	26.65 a	30.05 a

Locality with the same letter had no statistically significant difference, *locality* with different letters had a statistically significant difference according to the Tukey test with a value of $P \leq 0.05$.

The highest percentage of macropores (Tab. 3) was found in locality 2 (10%), and the lowest percentage was found in locality 1 (5%), presenting the same trend in the percentage of mesopores, where the highest percentage was found in locality 2 (10%), and locality 1 only had 6%. The lowest percentage of micropores was found in locality 2 (20%), and the highest percentage was in locality 4 (32%). A total porosity percentage of 36% was found in locality 1. According to IGAC (2005), this area has soils with the following: 46% total porosity, 11% macropores, and 35% micropores, which indicates that the amount of macropores in some localities is low, while the percentages of microporosity are high.

The bulk density in the four locations showed the following trend (Tab. 3): location 1 had a mean value of 1.77 g cm^{-3}, location 2 had 1.76 g cm^{-3}, location 3 had 1.63 g cm^{-3}, and location 4 had 1.73 g cm^{-3}. Location 3 had the lowest bulk density, which affected the penetration of water into the soil, root development and development of microorganisms in the soil (Cochavi *et al.*, 2019).

The highest percentage of available water was in locality 2 (25%), and the lowest value was in locality 3 (15%). Localities 1 and 4 had percentages of 23 and 16%, respectively, in contrast to Álvarez-Herrera *et al.* (2021), where the available water for the MMX soil class was between 20 and 40%, which showed that some localities were below this value, meaning the trees are not making an effective use of water at the root depth (Cochavi *et al.*, 2019).

Soil chemical properties

For the localities (Tab. 4), the following characteristics were observed, according to IGAC (2005): acid soils, with low cation exchange capacity (CEC), total carbon, high phosphorus content, probably because of the continuous application of fertilizers.

The pH in the four localities ranged between 5.73 and 6.25, which indicated a strongly acid and slightly acid soil, respectively (Tab. 4), according to Cremona and Enriquez (2020). The pH of a soil determines its acidity and basicity ratio and nutrient availability, among others (Neina, 2019). These values are most likely due to the application of fertilizers and correctives that affect pH, such as gypsum and agricultural lime.

A higher proportion of total carbon (3.75 and 3.65%) was observed in localities 2 and 4, respectively (Tab. 4). Locality 1 had a percentage of 1.68, while locality 3 had 2.28%. According to Yang *et al.* (2019) and Wiesmeier *et al*. (2019), these mean values are characteristic of mountains and high plateaus that have

Table 3. Physical properties of the soil in the four localities.

Locality	Macropores	Mesopores	Micropores	Total porosity	Bulk density	Available water
	(%)				(g cm^{-3})	(%)
1	5.2 a	6.4 a	23.8 ab	36.2 a	1.77 b	23.4 a
2	10.3 a	10.4 a	20.1 a	42.4 ab	1.76 ab	24.6 a
3	7.3 a	6.9 a	27.3 bc	42.7 ab	1.63 a	14.9 a
4	7.4 a	10.1 a	32.3 c	48.8 b	1.73 ab	15.9 a

Locality with the same letter had no statistically significant difference, *locality* with different letters had a statistically significant difference according to the Tukey test with a value of $P \leq 0.05$.

Table 4. Soil chemical attributes for the locations.

Attribute	Units	Location			
		1	2	3	4
pH		5.93	6.25	5.73	5.93
Total carbon	%	1.68 b	3.75 a	2.28 b	3.65 a
CEC	cmol(+) kg^{-1}	12.2 c	16.5 b	12.05 c	18.1 a
Ca		6.13 c	12.00 a	6.75 c	9.98 b
Mg		2.81 b	1.53 c	1.40 c	3.38 a
K		0.94 b	1.53 a	0.50 b	1.45 a
Na		0.05 b	0.06 b	0.07 b	0.10 a
TB		8.00 b	15.13 a	8.75 b	14.93 a
BS	%	65.53 b	86.6 a	72.96 ab	82.2 a
Mn	mg kg^{-1}	4.93 c	15.50 a	9.28 b	15.45 a
Fe		122.30 ab	42.58 c	90.70 bc	182.50 a
Zn		18.50 ab	34.72 a	4.40 b	18.75 ab
Cu		11 b	46.6 a	0.95 d	6.93 c
B		1.35 ab	2.18 a	0.44 b	1.34 ab
S		7.38 b	13.45 a	1.07 c	5.22 b
P		213.8 b	744.0 a	146.0 c	298.3 b

Locality with the same letter had no statistically significant difference, *locality* with different letters had a statistically significant difference according to the Tukey test with a value of $P \leq 0.05$.

TB, total bases; BS, base saturation.

evolved with oxidation conditions that are favorable for biological activity, which contributes to the mixture of organic and inorganic material.

The amount of phosphorus (Tab. 4) in localities 2 and 4 (744.0 and 298.3 mg kg^{-1}, respectively) was higher than in localities 3 and 1 (146.0 and 213.8 mg kg^{-1}), which agrees with IGAC (2005), where large amounts of phosphorus are fixed by acidity and high Al-exchangeable, Al hydroxide, Fe oxides, silicate clays or crestalline minerals, characteristics that are found in the localities. Phosphorus is a very important element for plant nutrition because of the large quantities required for growth and for the transformation of energy by photosynthesis (Taliman *et al*., 2019).

The cation exchange capacity (Tab. 4) was greater in locality 4 and 2 (18.10 and 16.5 cmol kg^{-1}, respectively), while for locality 1 and 3, it was lower (12.20 and 12.05 cmol kg^{-1}, respectively). The total bases (Tab. 4), such as Ca, Mg, K, Na, were high according to that recorded for this soil class (Inceptisol) as reported by IGAC (2005). In addition, soil pH and fertility are inversely related, since the more acid a soil is, the lower the percentage of base saturation will be since an increasing number of exchange sites are occupied by Al and H because of the loss of Ca, Mg, K and Na from the soil system (Guerrero, 1993).

For the minor elements (Mn, Mg, Fe, Zn, Cu, B, and S) (Tab. 4), locality 2 had the highest percentage of Mg (15.50 mg kg^{-1}), in contrast to locality 1, which had a lower percentage (4.93 mg kg^{-1}). Locality 2 had a lower percentage of Fe (42.58 mg kg^{-1}) but higher values of Zn (34.72 mg kg^{-1}), Cu (46.6 mg kg^{-1}), B (2.18 mg kg^{-1}) and S (13.45 mg kg^{-1}). These values are in the optimal range according to Piper (2019). These results are probably due to the different practices carried out by each farmer regarding the use of fertilizers and coadjutants in their crops.

Physicochemical and physiological characterization of 'Horvin' plum fruit

For fruit size at harvest (Tab. 5), weight was the variable with the greatest incidence. The respiratory intensity was lower on this day. The variable fruit diameter equatorial line is directly proportional to weight at harvest. This phenomenon can be shown by the many attempts to describe the mechanisms that control fruit size and weight, usually with the hypothesis that development changes are directly related to environmental, climatological, or endogenous factors (Jiang *et al.*, 2019).

The physical, chemical, and physiological properties maintained a typical behavior of drupes or stone fruits. The altitudes where some fruit crops are established have different characteristics, such as relative humidity, temperature, and precipitation, which affect the time of harvest (Brasili *et al.*, 2020), as observed in the present study and shown in table 5.

The Hue angle showed that the four locations had higher value correlations. This may have been a consequence of climatic conditions not being equal since climate can influence ripening processes (Parra-Coronado *et al.*, 2007), as shown in table 5. For length, it was found that the altitude, average temperature and relative humidity were correlated, unlike the fruit diameter, which did not have a significant correlation. These differences were probably due to the amount of rain in the four locations after a long drought caused by the El Niño phenomenon and to the practices carried out in each location.

The weight and the respiratory intensity of the fruits had a negative correlation with the precipitation, water availability, minerals and photoassimilates, which determines the size and timing of the senescence (Jiang *et al*., 2018). No significant differences were found for TSS, TTA, peel firmness or pulp firmness.

Correlation analysis between harvest parameters and soil properties

The physical properties of the soil had a significant correlation with weight, diameter, respiratory intensity and firmness of the fruits, leading to the conclusion that the soil was directly related to the fruit quality (Tab. 6). It was observed that silt percentage (0.369), bulk density (-0.341), micropore percentage (0.500) and water availability (0.329) had an impact on fruit weight at harvest. In addition, the percentages of silts, macropores, mesopores, micropores and water availability affected the respiratory intensity, which had a relationship with the ripening and development of the fruits (Liu and Zhang, 2021); these correlation values resulted from the fact that fruit weight is higher if the soil bulk density decreases.

The variables that were more correlated with weight were total carbon (0.58), cation exchange capacity (0.59), calcium (0.51), magnesium (0.50) and manganese (0.58). These correlations showed the importance of the physical and chemical characteristics of the soil to fruits at harvest (Tab. 7).

The correlations between Fe and fruit diameter (0.46), between respiratory intensity and total carbon (0.46), calcium (0.42) and manganese (0.56) were significant (Tab. 7). As the TSS increased because of the influence of some properties of the soil, fruit and climate, the fruits reached maximum respiratory intensity (Pešaković *et al*., 2020). All these correlations were probably due to the soil characteristics of each locality, contrary to the characterization of the fruits at harvest.

Table 5. Correlation of physical-chemical and physiological properties of plum fruits 'Horvin' and climatic characteristics of four locations.

	Altitude	Medium temperature	Relative humidity	Precipitation
Hue angle	-0.77*	0.69*	0.72*	-0.50*
Length	0.50*	-0.58*	-0.58*	-0.07
Diameter equatorial	0.38	-0.39	-0.44*	0.07
Weight	0.26	-0.14	-0.17	0.44*
Respiratory intensity	-0.24	0.03	0.13	-0.69*
Total soluble solids	-0.01	0.08	0.05	0.22
Total titratable acidity	0.25	-0.30	-0.27	-0.03
Peel firmness	0.11	-0.08	-0.23	0.01
Pulp firmness	0.15	-0.07	-0.18	0.24

* Significant correlations ($P \leq 0.05$).

Table 6. Correlation of physical-chemical and physiological properties of plum fruits 'Horvin' and physical properties soil of four locations.

	Hue color angle	Length	Fruit diameter	Weight	Respiratory intensity	Total soluble solids	Total titratable acidity	Peel firmness	Pulp firmness
Sand	0.030	0.002	0.259	-0.048	0.163	-0.254	0.089	0.513*	0.331
Silt	-0.074	0.051	0.221	0.369	-0.696*	-0.027	0.074	-0.336	-0.101
Clay	0.016	-0.038	-0.454*	-0.198	0.289	0.314	-0.154	-0.366	-0.316
Macropores	0.101	-0.003	-0.119	-0.091	0.404	0.150	0.116	-0.014	-0.167
Mesopores	0.114	-0.051	-0.421	0.055	0.459*	0.043	-0.156	0.085	-0.087
Micropores	0.104	0.051	-0.018	0.500*	-0.437	0.119	0.019	-0.237	0.005
Total porosity	0.188	0.022	-0.241	0.386	0.039	0.203	0.025	-0.176	-0.125
Bulk density	-0.079	-0.032	-0.193	-0.341	0.251	0.330	-0.053	-0.298	-0.235
Usable water film	-0.105	-0.090	-0.010	-0.329	0.428*	-0.043	-0.002	0.273	-0.026

* Significant correlations ($P \leq 0.05$).

Table 7. Correlation of physical-chemical and physiological variables of plum fruit 'Horvin' and chemical properties of soil of four locations.

	Hue color angle	Length	Fruit diameter	Weight	Respiratory intensity	Total soluble solids	Total titratable acidity	Peel firmness	Pulp firmness
pH	0.075	0.055	0.005	0.161	-0.045	-0.121	0.318	0.037	0.210
Total carbon	0.070	0.057	0.107	0.577*	-0.461*	-0.042	-0.068	-0.026	0.087
P	0.087	0.065	0.240	0.355	-0.263	-0.212	0.062	0.231	0.251
CEC	0.151	0.036	-0.102	0.593*	-0.280	-0.029	-0.051	-0.047	0.082
Ca	0.083	0.067	0.128	0.507	-0.416*	-0.185	0.041	0.069	0.210
Mg	0.064	0.015	-0.265	0.502	-0.269	0.085	-0.111	-0.269	-0.089
K	0.199	0.052	-0.158	0.368	-0.083	-0.043	-0.046	-0.069	0.097
Na	0.044	-0.020	-0.247	0.175	-0.165	-0.126	-0.078	-0.266	0.133
Mn	0.048	0.040	0.117	0.576	-0.556*	-0.121	0.044	0.041	0.226
Fe	0.064	-0.047	-0.463*	0.072	0.231	0.172	-0.232	-0.196	-0.181
Zn	0.096	0.008	0.060	0.327	-0.020	-0.167	0.041	0.406	0.392
Cu	0.050	0.038	-0.057	0.164	-0.075	-0.215	0.162	-0.010	0.266
B	0.132	-0.007	0.052	0.157	0.103	-0.250	0.112	0.369	0.317
S	0.134	0.050	0.051	0.058	0.022	0.105	-0.159	0.013	-0.030

* Significant correlations ($P \leq 0.05$).

Principal components analysis

The first component represented 22.43% of the variance, and the properties that expressed this behavior for CP1 were weight, respiratory intensity, percentage of silts, mesopores, micropores, bulk density and available water (Tab. 8). According to Carrasco *et al*. (2010), changes in the soil structure, porosity and apparent density are determinants of crop development.

The second principal component (CP2) explained 18.60% of the variance, finding characteristics such as diameter, TSS, firmness in peel and pulp, sand and clay contents, and bulk density for the soil. Sandy soils, known as light, retain less water, affecting the water supply for plants. Additionally, soils with this characteristic are generally poor in mineral elements, requiring a constant application of nutrients and organic matter at considerable quantities (Ji *et al*., 2020).

The third component (CP3) explained 13.65% of the variance of variables such as Hue angle, length and diameter, which indicated that, at harvest, the quality selection was determined by the parameters length, diameter and Hue Angle, as observed in the linear correlation analysis. This agrees with Parra-Coronado *et al*. (2007), who confirmed that the classification fruit parameters during harvest is done when they reach their maximum weight, a variable that is directly proportional to the length and diameter.

The fourth and fifth principal components (PC4 and PC5) explained 12.41 and 7.98% of the variance. The coefficients indicated that the macropores, the total porosity and the firmness of the pulp influenced the fruits at harvest.

The results of the analysis indicated that the variables with greater incidence (CP1) included some physicochemical properties of the fruits, such as weight and respiratory intensity in relation to some soil chemical variables, such as pH, amount of OC, P, CEC, Ca, Mg, K, Zn, Cu, and B (Tab. 9). The first principal component (CP1) explained 31.08% of the variance and indicated that, when the fruit is at its maturity stage, the weight and respiration are at their maximum. In these processes, some soil variables intervene in the total development. According to Carrasco *et al*. (2010), this behavior can be related to the soil structure and management method.

The second main component (PC2) explained 14.44% of the variance, where the diameter of the fruit and the firmness of the peel are related to the contents of P, Mg and Fe. According to Medeiros *et al*. (2020), plum trees do not require large amounts of phosphorus, but the necessary dose may vary depending on the planting density, which was not analyzed in the present study.

Table 8. Coefficients of the first five principal components considering physiological, fruit physicochemical and soil physical variables for the four locations.

	CP1	CP2	CP3	CP4	CP5	Communalities
Hue color angle	0.338	-0.066	-0.891*	0.111	0.153	0.951
Length	-0.390	0.199	0.769*	0.084	-0.315	0.915
Fruit diameter	-0.190	-0.492	-0.540*	-0.337	-0.277	0.806
Weight	-0.650*	0.164	0.234	0.367	-0.075	0.798
Respiratory intensity	0.864*	-0.120	-0.305	0.195	0.018	0.896
Total soluble solids	0.205	0.455	0.075	0.124	0.229	0.802
Total titratable acidity	-0.171	-0.249	0.044	0.042	-0.341	0.825
Peel firmness	0.060	-0.718*	0.342	0.125	0.449	0.896
Pulp firmness	-0.147	-0.548*	0.296	0.100	0.598*	0.906
Sand	0.004	-0.848	0.040	0.330	-0.203	0.971
Silt	-0.732*	0.358	-0.247	-0.366	0.078	0.896
Clay	0.499	0.742	0.123	-0.133	0.183	0.938
Macro pores	0.408	-0.062	0.006	0.632*	-0.504	0.889
Mesopores	0.554	0.258	0.206	0.403	0.262	0.944
Micro pores	-0.673*	0.367	-0.340	0.398	0.187	0.924
Total porosity	-0.120	0.367	-0.205	0.853*	-0.040	0.949
Bulk density	0.482	0.426	0.134	-0.360	-0.216	0.795*
Available water	0.717*	-0.131	0.353	-0.208	-0.117	0.794*
Eigenvalue	4.038	3.348	2.457	2.235	1.438	
Variance (%)	22.434	18.601	13.651	12.415	7.987	
Cumulative variance (%)	22.434	41.035	54.686	67.101	75.088	

CP1, CP2, CP3, CP4, and CP5: principal components 1, 2, 3, 4, and 5, respectively, values > 0.7 (absolute value).

* Significant correlations ($P \leq 0.05$).

The third principal component (CP3) explained 11.62% of the variance. The coefficients indicated that length is an incident factor at harvest in Horvin plum fruits; this variety had lower values in weight and size at harvest, in contrast to Gulfruby, Beauty, Shiro and Rubyred cultivars, which explained why it has higher values of mean firmness (in pulp) and respiratory intensity, as reported by Parra-Coronado *et al.* (2007).

The fourth and fifth principal components (PC4 and PC5) explained 7.84 and 7.66% of the variance, respectively. The coefficients indicated that the amount of sulfur in the soil had an impact on the diameter and firmness of the fruit at harvest. According to Andina (s.f.), an adequate amount of sulfur should be considered for plant nutrition since sulfur is an important nutrient for production, after nitrogen, and producers should be prevented from removing it. On the other

Table 9. Coefficients of the first five principal components considering physiological and physicochemical variables of the fruit and soil chemical variables for the four locations.

	CP1	CP2	CP3	CP4	CP5	Communalities
Hue color angle	0.031	0.257	0.917*	-0.177	0.080	0.948
Length	0.126	-0.327	-0.787*	0.130	-0.292	0.918
Fruit diameter	0.047	0.517*	0.119	-0.644*	-0.045	0.951
Weight	0.605*	-0.395	-0.362	-0.128	0.020	0.763
Respiratory intensity	-0.406	0.324	0.654*	0.272	0.134	0.949
Total soluble solids	-0.198	-0.293	0.14	0.454	-0.312	0.791
Total titratable acidity	0.076	0.293	-0.308	-0.319	0.317	0.721
Peel firmness	0.116	0.535*	-0.281	0.509*	0.355	0.953
Pulp firmness	0.280	0.384	-0.291	0.464	0.540*	0.895
pH	0.518*	0.292	-0.081	-0.193	0.168	0.93
CO	0.903	-0.204	0.108	-0.076	-0.116	0.944
P	0.861*	0.409	-0.02	0.006	-0.267	0.981
CEC	0.872*	-0.345	0.242	0.085	0.047	0.972
Ca	0.941*	0.047	0.017	-0.140	-0.036	0.956
Mg	0.496	-0.744*	0.251	-0.013	0.242	0.94
K	0.836*	-0.061	0.269	0.165	-0.162	0.893
Na	0.281	-0.33	0.062	-0.180	0.452	0.886
Mn	0.84*	-0.261	0.028	-0.133	0.153	0.896
Fe	-0.214	-0.709*	0.324	0.310	0.270	0.944
Zn	0.767*	0.333	0.059	0.272	0.006	0.779
Cu	0.489	0.257	-0.032	0.010	0.043	0.777
B	0.495	0.347	0.074	0.280	0.184	0.653
S	0.364	0.257	0.169	0.267	-0.707*	0.851
Eigenvalue	7.139	3.321	2.674	1.804	1.763	
Variance (%)	31.038	14.441	11.625	7.845	7.667	
Accumulated variance (%),	31.038	45.479	57.103	64.948	72.615	

CP1, CP2, CP3, CP4, and CP5: principal components 1, 2, 3, 4, and 5.

* Significant correlations ($P \leq 0.05$).

hand, compost and crop residues can help restore the sulfur removed at each harvest.

CONCLUSION

According to the values obtained in the correlations, the variable with the highest correlation was fruit weight at harvest, in relation to the chemical variables (pH, phosphorus, cation exchange capacity, calcium, magnesium, potassium, zinc, copper, boron and sulfur) and the soil physical variables (bulk density and total carbon).

The behavior of the different physical and chemical variables of the soil in relation to the physiological and physicochemical variables of the fruit were identified. It was also found that the physical and chemical properties of the soil with a higher incidence included bulk density and total carbon in some locations. Additionally, the bulk density correlated with the fruit weight and length at harvest since good fruit development requires good oxygenation and good root development.

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