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Effect of the physicochemical characteristics of soil and irrigation water on the quality of the bulb onion (*Allium cepa* L.) crop in the Usochicamocha irrigation and drainage district in Boyaca, Colombia

Efecto de las características fisicoquímicas del suelo y agua para riego con la calidad del cultivo de cebolla de bulbo (*Allium cepa* L.) del distrito de riego y drenaje Usochicamocha en Boyacá, Colombia

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Usochicamocha bulb onion.

Photo: F.-E. Forero-Ulloa

ABSTRACT

The bulb onion crop is not only one of the main vegetable crops worldwide, but it is also considered one of the pillars of the regional agricultural economy in Boyaca. Despite being so important from the economic point of view, at the agricultural level this crop has several problems among which stand out the nutritional requirements and poor practices in terms of soil management and conservation. That is why it is important to understand what are the physicochemical variabilities of the soil associated with the crop and how these can be related to intrinsic processes at a local geographic scale. To determine the variability of soil physicochemical conditions in the bulb onion crop, a total of 15 zones of 50 × 50 m were analyzed within the Usochicamocha irrigation district. A total of 15 soil samples and 15 irrigation water samples were collected and subsequently analyzed in the laboratory. Information was obtained on pH, MO, EC, bulk density, soil

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texture, Ca, Mg, K, Na, P, ion load, cations, hardness and turbidity in the water samples. The results obtained allowed observing a significant relationship between crop attributes, physicochemical properties of soil and water in the different study zones. These results support the hypothesis of the existence of a synergy between the extrinsic and intrinsic properties of the crop and how they have a relationship between the quality attributes of the bulb onion crop.

Additional key words: organic matter; irrigation water; variation of physicochemical properties; attributes and crop quality.

RESUMEN

El cultivo de cebolla de bulbo aparte de ser uno de los principales cultivos de hortalizas a nivel mundial, para Boyacá es considerado uno de los pilares en la economía agrícola regional. Pese a ser tan importante desde el aspecto económico, a nivel agrícola este cultivo posee varios problemas entre los cuales resalta las exigencias nutricionales y las malas prácticas en cuanto al manejo y conservación de los suelos. Es por eso que se hace importante entender cuáles son las variabilidades fisicoquímicas del suelo asociadas al cultivo y estas como pueden estar relacionadas a procesos intrínsecos a escala geográfica local. Para determinar la variabilidad de las condiciones fisicoquímicas del suelo en el cultivo de cebolla de bulbo, se analizaron un total de 15 zonas de 50 × 50 m dentro distrito de riego Usochicamocha. Un total de 15 muestras de suelo y 15 muestras de agua de riego fueron colectadas y posteriormente analizadas en laboratorio. Se obtuvo información de parámetros pH, MO, CE, densidad aparente, textura del suelo, Ca, Mg, K, Na, P, en las muestras de agua, carga de iones, cationes, dureza y turbidez. Los resultados obtenidos permitieron observar una relación significativa entre los atributos del cultivo, propiedades fisicoquímicas del suelo y agua en las diferentes zonas de estudio. Estos resultados apoyan la hipótesis de la existencia de una sinergia entre las propiedades extrínsecas e intrínsecas del cultivo y como tienen una relación entre los atributos de calidad del cultivo de cebolla de bulbo.

Palabras clave adicionales: materia orgánica; agua de riego; variación de propiedades fisicoquímicas; atributos y calidad de cultivo.

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INTRODUCTION

The bulb onion crop ranks fourth in world vegetable production, with an average production of 84 million tons and Boyaca being one of the main producing departments in Colombia, contributing about 51% of the national production being the Asociación de Usuarios del Distrito de Riego y Drenaje del Alto Chicamocha y Firavitoba "USOCHICAMOCHA" the main producer in the department. This association has jurisdiction in the municipalities of Paipa, Duitama, Tibasosa, Nobsa, Sogamoso, Santa Rosa de Viterbo and Firavitoba (Girón, 2019).

One of the fundamental aspects in bulb onion cultivation is the physical and chemical conditions and properties of the soil and irrigation water. The importance of soil and irrigation water properties is due to the fact that, depending on their intrinsic and extrinsic characteristics, they can catalyze or mitigate processes of crop destruction and degradation, as well as modulate crop qualities at harvest time (Ferreras *et al*., 2015). These effects together with anthropogenic variables such as agricultural expansion, modifications of the tillage system and even the rotation of sown crops between post-harvest seasons, cause variations in physicochemical properties such as carbon, nitrogen, phosphorus, calcium, organic matter and others (Díaz-Zorita *et al*., 2004; Toledo *et al*., 2013; Vankeirsbilck *et al*., 2016). Likewise, irrigation water is of utmost importance in onion cultivation, not only because of its high level of water requirement throughout all phenological stages of the crop, but also because the use of a technician irrigation water system allows obtaining a highly significant irrigation quality, i.e., water free of the main fertilizer contaminants such as nitrates NO_3 and nitrites NO_2 or other chemical agents that can alter the physicochemical properties of the soil for proper crop growth (González *et al*., 2007; Flores-Gallardo *et al*., 2014; López *et al*., 2015).

To understand the problem that leads to an unnatural variability of the physicochemical properties of soil and irrigation water along the agricultural system, it is necessary to emphasize that physical and chemical parameters form a harmonic set with the physical and chemical needs of the crop, i.e., non-rotation, use of untreated irrigation water or poor nutritional management will progressively affect the soil adjacent to the crop on a temporal scale (Monsalve *et al*., 2017). Variations in physical properties such as bulk density and texture are related to a decrease in crop productivity, as well as to an increase in soil nutrient loss by synergistic action of untreated irrigation water and agricultural managements to the soil (i.e., sowing density, crop age, crop rotation) (Calderón-Medina *et al*., 2018). In this sense, chemical and physical properties are strongly related to soil quality, irrigation water and crop productivity attributes, among which are: pH, organic matter, electrical conductivity, P, N, Ca, Mg, K and physical properties such as: texture, bulk density and depth. The turbidity, hardness, ion and cation load of the water, allow establishing not only the health of the soil, but also its capacity to offer a good level of crop productivity (i.e., productivity in tons per hectare, quality and size of the onion bulb) (Toledo *et al*., 2013; Quinteros-Carabalí *et al*., 2019). Therefore, obtaining information on the variability of soil and irrigation water physicochemical variables and how these could be related to intrinsic crop attributes becomes relevant to provide the farm-er and the agricultural industry with information on how to improve the quality of demanding crops such as bulb onion (Dinler and Aksoy, 2014).

The objective of this study is to analyze the relationships between the physicochemical properties of soil and irrigation water with the quality attributes of the bulb onion crop (*Allium cepa* L.) in the Usochicamocha district.

MATERIALS AND METHODS

Study area and inclusion criteria

The Usochicamocha irrigation district is located in the department of Boyaca (Colombia) (Fig. 1), which includes the municipalities of Paipa, Duitama, Nobsa,

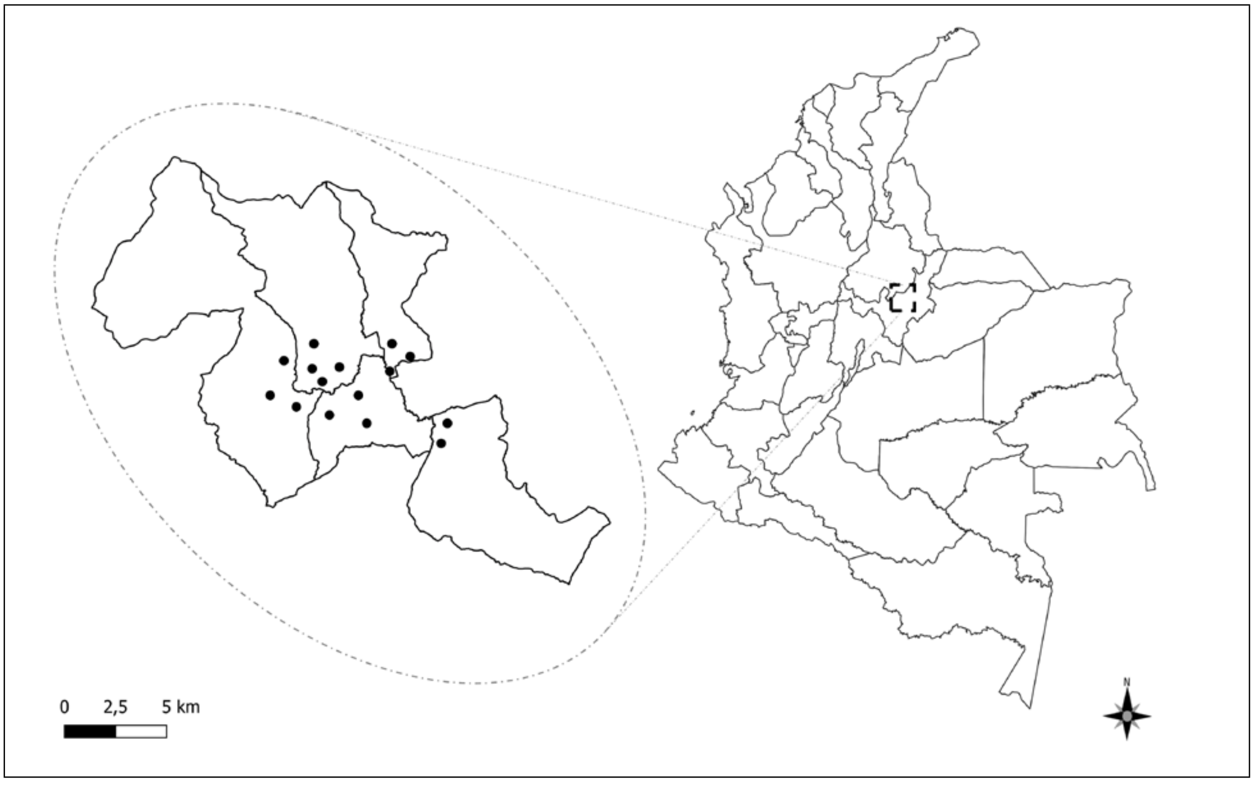

Figure 1. Location of the sampling zones in the study. Center of the Department of Boyaca, Colombia.

Pesca, Firavitoba, Santa Rosa de Viterbo and Tibasosa, in the provinces of Tundama and Sugamuxi. In the district, according to the latest user census, there are more than 260 bulb onion (*Allium cepa* L.) farmers with crops of more than 0.5 ha. This area belongs to the central zone of the Department of Boyaca, which has an average altitude of 2,500 m a.s.l. The study area belonging to Usochicamocha has soils with mainly acid sulfate characteristics, moderate to low structural stability in organic horizons; high clay content in mineral horizons (GISSAT, 2004; 2006). For the selection of the 15 sampling zones, a deterministic design was used, in which zones with a minimum of 5 years of cultivation history of bulb onion were selected. In addition, the sampling area had to have irrigation water supplied by the irrigation district for its crops, in order to avoid additional losses due to the use of untreated water for crop irrigation.

Field and laboratory phases

For each area sampled, a sample of soil and irrigation water associated with bulb onion cultivation was obtained. For the soil samples, a 50 × 50 m sampling quadrant was delimited. In each quadrant a zigzag path was made, choosing 20 sample collection points at random with a depth of 15 cm, in order to form a single sample composed of the 20 collection points for each sampling zone. Finally, a total of 200 g per sample was taken in each sampling zone, which was stored and sent to the laboratory for subsequent physicochemical analysis. On the other hand, the irrigation water samples were taken in sterile plastic bottles to avoid contamination by salts or other substances in the irrigation water. From each sampling zone, 3 L of water were collected to be stored and sent to the laboratory for the corresponding laboratory analyses. The analyses of the physicochemical properties of the soil and water samples were carried out in the laboratory of the Universidad Pedagógica y Tecnológica de Colombia, which used the methodologies proposed by the Instituto Geográfico Agustín Codazzi (Colombia IGAC, 2006), the physicochemical properties and the methods implemented are shown in table 1.

The attributes of the onion crop were analyzed by direct survey with each of the owners of the sampling areas. These surveys have the onion quality information obtained from post-harvest, which is categorized as (Q1 = "Cero" type onion; Q2 = "Gruesa" type onion; Q3 = "Pareja" type onion). Crop production size quantified in bulks as tons per hectare (t ha^{-1}). Crop age quantified in years. The geographical sowing altitude of each of the sampled zones and finally the sowing density as plants per hectare (plants/ha).

Statistical analysis

To evaluate the effect of the physicochemical properties of the soil and water of the bulb onion crop, descriptive statistical tests were performed for the results of the analyses obtained. Contingency tables were constructed for the analysis of quantitative and qualitative variables for the performance of non-parametric multidimensional scaling (NMDS) and Canonical Correlation Analysis (CCA) using the free software R version 4.1.1 (The R Foundation, 2015). Exploratory multivariate exploratory data analyses

Table 1. Chemical and physical properties of soil and irrigation water evaluated.

Parameters	Method
Soil physicochemical variables	
pH	Ratio 1:1
OM (%)	Walkley-Black
EC (dS m^{-1})	Electrical conductivity
Ca (cmol^{+} kg^{-1})	Exchangeable calcium. Atomic absorption spectrometry
Mg (cmol^{+} kg^{-1})	Exchangeable magnesium. Atomic absorption spectrometry
K (cmol^{+} kg^{-1})	Exchangeable potassium. Atomic absorption spectrometry
Na (cmol^{+} kg^{-1})	Exchangeable sodium. Atomic absorption spectrometry
P (mg kg^{-1})	Available phosphorus: Bray II - colorimetry
Texture	Bouyoucos hydrometer
Bulk density (ρ_b)	Graduated cylinder
Water physicochemical variables	
pH	Ratio 1:1
EC (dS m^{-1})	Electrical conductivity
Turbidity	Turbidity due to nephelometry (ntu)
Hardness	Titrating with a standard solution of ethylene diamine tetra acetic acid (EDTA)
Ca (meq L^{-1})	Direct spectrometer in water
Mg (meq L^{-1})	Direct spectrometer in water
K (meq L^{-1})	Direct spectrometer in water
Na (meq L^{-1})	Direct spectrometer in water
SO_4 (meq L^{-1})	Turbidimetric method
Cl (meq L^{-1})	Turbidimetric method
HCO_3 (meq L^{-1})	Turbidimetric method

and Pearson correlations between physicochemical properties and crop attributes were performed using the *FactoMineR* and *Hmisc* package (Husson *et al*., 2012; Harrell and Dupont, 2018). Non-parametric multidimensional scaling (NMDS), was performed to observe which soil and water properties could present possible groupings or relationships in each of the sampled areas, using the *vegan* package (Oksanen *et al*., 2017). Canonical correlation analysis (CCA) was performed to find the relationship between the sets of physicochemical properties and crop attributes for each of the sampled zones, using the *CCA* package (González and Déjean, 2021). The graphical visualization of each of the procedures was performed using the package *ggvegan* (Simpson, 2019).

RESULTS AND DISCUSSION

The lowest pH value (4.57) was given by sample C13 and the highest (7.81) by sample C9. The lowest OM% value was (1.2) corresponding to sample C14, while the highest was (17.14) from sample C15. The EC values remained in a range of 0.31-2.0 (dS m^{-1}), with sample C5 being the lowest and sample C11 the highest. On the nutritional side, Ca and Na ($cmol^+$ kg^{-1}) values share the sample with the lowest and highest values, being (1.77-15.97) for Ca and (0.16-1.17) for Na in samples C14 and C15, respectively. On the other hand, Mg values ($cmol^+$ kg^{-1}) have a low range oscillating from (0.22-1.3) in samples C14 and C2, respectively. For K values ($cmol^+$ kg^{-1}), sample C5 presents the lowest value (0.45) and sample C11 the highest value (1.54). Finally, the values of P (mg kg^{-1}) presented the lowest value in sample C2 (28.86) while samples C5 and C7 presented the highest value (233.6), while the real density presented the highest value in sample C12 (20.56) and the lowest in sample C3 (1.29). In general, for all samples, the dominant soil texture was the clay type (Ar), followed by the clay loam soil type (Fr-Ar) (Tab. 2).

Sample C7 presents the lowest values in the physicochemical properties of irrigation water, such as

Table 2. Physicochemical properties of the soil found in each of the sampling sites related to the bulb onion crop.

Sample	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
BD[3] (ρ_b)	0.88	0.97	1.29	0.83	1.14	1.11	1.11	0.97	1.17	0.76	0.9	1.16	0.57	1.08	0.66
Texture (%)	Ar	Ar	Ar	F-Ar-A	F-Ar	F-Ar	F	Ar	Ar	Ar	Ar	Ar	Ar-A	F-Ar-A	F-Ar
	A(24) - L(34) - Ar(42)	A(29) - L(18) - Ar(53)	A(19) - L(36) - Ar(45)	A(51) - L(25) - Ar(24)	A(43) - L(35) - Ar(22)	A(29) - L(39) - Ar(32)	A(35) - L(38) - Ar(27)	A(15) - L(19) - Ar(66)	A(7) - L(27) - Ar(66)	A(26) - L(14) - Ar(60)	A(16) - L(19) - Ar(65)	A(33) - L(18) - Ar(44)	A(46) - L(17) - Ar(37)	A(58) - L(15) - Ar(27)	A(45) - L(23) - Ar(32)
P (mg kg^{-1})	44.87	28.86	60.88	125.3	233.6	161	233.6	36.49	150.6	36.49	121.8	150.6	33.84	211	31.33
Na ($cmol^+$ kg^{-1})	0.26	0.27	0.19	0.24	0.26	0.53	0.22	0.52	0.39	0.19	0.47	0.05	0.36	0.16	1.17
K ($cmol^+$ kg^{-1})	0.71	0.79	0.92	0.52	0.45	0.89	0.8	1.15	0.62	0.52	1.54	0.79	0.47	0.47	0.75
Mg ($cmol^+$ kg^{-1})	1.1	1.3	0.57	0.67	0.97	0.78	0.66	0.95	1.22	0.44	0.53	1.06	0.22	0.38	0.47
Ca ($cmol^+$ kg^{-1})	2.98	8.27	4.28	6.35	4.03	5.67	6.0	7.02	7.55	7.29	11.05	3.8	14.51	1.77	15.97
EC[2] (dS m^{-1})	0.56	0.83	0.54	0.66	0.31	0.92	0.54	1.23	0.71	1.01	2.0	0.49	0.78	0.39	0.99
OM[1] (%)	3.25	3.41	1.35	3.18	4.82	3.41	3.48	5.95	1.93	8.38	7.7	1.9	12.24	1.2	17.14
pH	5.47	7.48	7.79	6.89	6.64	7.62	6.93	7.15	7.81	5.54	5.74	7.26	4.57	5.55	5.72

[1] Organic matter; [2] Electrical conductivity; [3] Bulk density.

pH, electrical conductivity, hardness, and ion and cation load, unlike all other samples, with a significant comparison value $P<0.05$. On the other hand, the highest values for irrigation water properties were found mainly in sampling zones C8 and C4 with a significant comparison value $P<0.05$ (Tab. 3). Showing little variability between study zones compared to soil samples. This low variability can be attributed mainly to the origin of the irrigation water, where it mainly comes from the irrigation canals coming from the irrigation association of the zone.

The Pearson coefficient was used to analyze the relationship between the different soil physicochemical variables. Among the most relevant results was the inverse relationship between pH values and crop altitude (r=-0.25; $P<0.05$), Ca and plant density (r=-0.22; $P<0.05$) and bulk density with crop altitude (r=-0.35; $P<0.05$). While the significant positive relationships were between OM% and crop altitude (r=0.74; $P<0.05$), Mg and productivity t/ha (r=0.49; $P<0.05$), Na and crop altitude (r=0.85; $P<0.05$) and P and plant density (r=0.71; $P<0.05$) (Tab. 4).

In turn, for irrigation water properties, Pearson's coefficient evidenced the relationship between the different physicochemical variables of irrigation water with crop attributes, where the main results are the inverse relationship between hardness values and

Table 3. Physicochemical properties of the irrigation water found in each of the sampling sites related to the bulb onion crop.

Sample	pH	EC[1] (dS m^{-1})	NTU[2]	Hardness	Ca (meq L^{-1})	Mg (meq L^{-1})	K (meq L^{-1})	Na (meq L^{-1})	SO_4 (meq L^{-1})	Cl (meq L^{-1})	HCO_3 (meq L^{-1})
C1	6.81	502.6	12.59	8.31	1.18	0.48	0.62	3.2	0.17	1.73	3.74
C2	6.95	410	13.45	6.72	1.02	0.32	0.51	2.3	0.07	1.32	2.71
C3	7.05	343.6	6.82	5.52	0.83	0.27	0.49	2.1	0.04	1.56	2.14
C4	6.82	960.9	50.9	12.91	2.12	0.46	0.56	1.96	0.24	3.2	2.24
C5	6.73	562	16.27	7.87	1.12	0.45	0.69	3.46	0.2	2.14	3.21
C6	7.08	337.96	12.42	5.8	0.88	0.24	0.51	2.28	0.14	1.4	2.63
C7	7.29	84.66	2.34	4.19	0.73	0.11	0.12	0.26	0	0.18	1.29
C8	6.08	859.1	2.16	20.97	3.46	0.73	0.81	3.24	0.39	2.88	4.81
C9	6.89	480.7	8.96	7.68	1.17	0.37	0.56	2.56	0.15	1.81	2.85
C10	6.7	491.7	2.55	6.94	1.05	0.34	0.6	2.81	0.13	1.73	3.21
C11	6.94	414	9.32	6.02	0.91	0.29	0.49	2.24	0.06	1.48	2.67
C12	6.91	391	4.13	5.72	0.87	0.28	0.54	2.22	0.06	1.64	1.96
C13	7	482.7	23.1	8.02	1.26	0.34	0.51	2.45	0.22	1.64	2.55
C14	7.05	559.8	26.2	7.24	1.1	0.35	0.57	2.87	0.2	1.89	2.85
C15	6.93	486.9	5.85	8.54	1.23	0.55	0.53	2.57	0.21	1.8	2.65

[1] Electrical conductivity; [2]Turbidity.

Table 4. Pearson's correlation coefficient of the physicochemical properties of the soil with the bulb onion crop with the attributes of the growing area. Values with a significant *P*-value are presented in bold.

Soil samples	pH	OM[1] (%)	EC[2] (dS m^{-1})	Ca ($cmol^+ kg^{-1}$)	Mg ($cmol^+ kg^{-1}$)	K ($cmol^+ kg^{-1}$)	Na ($cmol^+ kg^{-1}$)	P (mg kg^{-1})	B.D[3]
Cultivation age	-0.22	0.02	0.16	0.22	-0.36	-0.09	-0.01	0.15	-0.08
Planting density	0.11	-0.32	-0.15	-0.22	0.14	-0.07	-0.28	0.71	0.17
Altitude	-0.25	0.74	0.12	0.6	-0.25	-0.04	0.85	-0.28	-0.35
Productivity	0.03	-0.04	-0.04	0.05	0.49	-0.12	-0.11	-0.21	-0.26

[1] Organic matter; [2]Electrical conductivity; [3]Bulk density.

Table 5. Pearson's correlation coefficient of physicochemical properties of irrigation water with bulb onion crop with the attributes of the growing area. Values with a significant p-value are presented in bold.

Water samples	pH	EC[1] (dS m^{-1})	NTU[2]	Hardness	Ca (meq L^{-1})	Mg (meq L^{-1})	K (meq L^{-1})	Na (meq L^{-1})	SO_4 (meq L^{-1})	Cl (meq L^{-1})	HCO_3 (meq L^{-1})
Cultivation age	0.46	-0.01	0.58	-0.27	-0.25	-0.37	-0.19	-0.13	-0.04	-0.03	-0.3
Planting density	0.15	0.1	0.45	-0.01	0.02	-0.17	-0.18	-0.22	-0.01	0.03	-0.24
Altitude	0.06	0	-0.14	0.02	-0.02	0.33	-0.02	0.06	0.17	0.02	-0.04
Productivity (t ha^{-1})	0.03	-0.07	0.11	-0.13	-0.14	-0.08	0.09	0.15	-0.07	-0.1	0.08

[1] Electrical conductivity; [2]Turbidity.

crop age (r=-0.27; P<0.05), Ca, Mg, K and Cl with crop age (r=-0.25; r=-0.37; r=-0.19; r=-0.03; P<0.05) and Na, HCO_3 with plant density (r=-0.22; r=-0.24; P<0.05). While significant positive relationships were pH, turbidity with crop age (r=0.46; r=0.48; P<0.05) and SO_4 with altitude (r=0.17; P<0.05) (Tab. 5).

Fertilization management plans, soil restoration plans and soil use between crops have been shown to have an impact on soil physicochemical characteristics, mainly in crops with high nutritional requirements and that generate a high impact on soil health, such as onion bulb crops (Allan *et al*., 2015; Toledo, 2016). In fruit crops, it has been shown how management plans and irrigation water quality have an impact not only on the quality of crop productivity, but also on the local variation of physicochemical and biological soil conditions (Hillel, 1982; Gough *et al*., 2000; Suding *et al*., 2005; Monsalve *et al*., 2017). This type of variation in the physicochemical properties of soil and irrigation water is mainly observed in chemical properties such as pH, OM, P and the ion and cation load in water (Gough *et al*., 2000; Suding *et al*., 2005). Likewise, other studies in mixed crops have found that agricultural practices and other intrinsic factors related to the crop are related to the changes found in soil chemical characteristics such as the type, quality and concentrations of ionic loads in the water used to irrigate the crop, mainly in crops with a high demand for water resources such as bulb onion (Hyvönen *et al*., 2003; Quinteros-Carabalí *et al*., 2019; Chaveli *et al*., 2019; Loera-Alvarado *et al*., 2019). This favors the hypothesis that the physicochemical properties within the crop may be linked not only to the intrinsic conditions of the crop, such as the crop attributes, but could also respond to external factors such as the ion and cation loads present in the water used to irrigate the crop (Hillel, 1982; van Elsen, 2000; Bengtsson *et al*., 2005).

Therefore, the possible associations and relationships between the physicochemical properties of soil figure 1A and irrigation water figure 1B. They present completely different distribution patterns, i.e., the

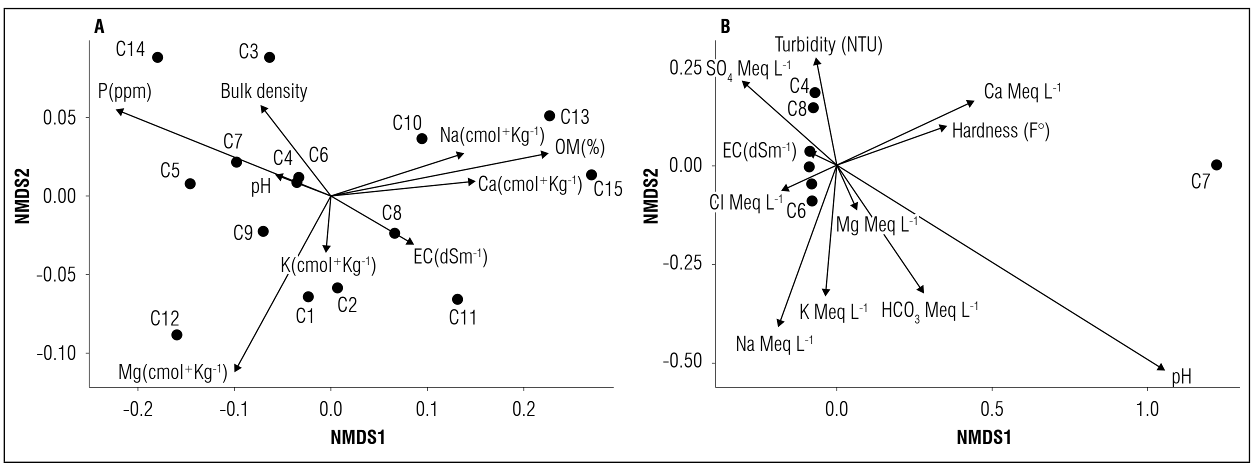

Figure 1. The non-metric multidimensional scale (NMDS) relates the sampling zones to the physicochemical properties of soil (A) and irrigation water (B) associated with the bulb onion crop.

variations that can be found within the soil samples of the onion crop could be linked to the attributes of crop productivity, such as sowing density. On the other hand, the little variation in the properties of the irrigation water samples can be explained by the unification of the irrigation system within the association. This reinforces the idea that the soil physicochemical values linked to the crop belong largely to the synergy that exists between the crop attributes and the original microclimatic conditions of each of the sampling zones (Fig. 1).

The availability of nutrients and their use are the main factors to be taken into account when determining the variation of soil physicochemical conditions. Some studies carried out on crops of low agricultural impact have shown how the short rest time between harvesting seasons generates a great limitation in the soil nutrient bank, resulting in a nutritional imbalance and complications in nutrient uptake at the time of starting a new planting season (Soane *et al*., 1980; Thomas *et al*., 2004; Troeh and Thompson, 2005; Berner *et al*., 2008; Sweeney *et al*., 2008). Likewise, it has been found that some physical and chemical characteristics are related to each other, such as bulk density and pH, or even positive effects on the concentrations of available Mg in the soil, or between chemical characteristics such as OM%, Na and Ca, which play very important roles in the growth, development and maturation of the crop (Davis, 2007; Sweeney *et al*., 2008; Cheimona *et al*., 2016). But all of these are regulated by anthropic factors, i.e., it has been demonstrated that in large crops such as fields or meadows that receive similar physical treatment or management have had not only a significant positive effect on the nutrient bank and the ability of plants to uptake nutrients, but also that the values and physicochemical variability is very similar between (Bilalis *et al*., 2010; Bilalis *et al*., 2012; Novillo *et al*., 2018).

Finally, to evaluate the geographic association of the sampling zones with the physicochemical variability of soil and irrigation water with crop productivity attributes, a canonical correspondence analysis was performed (Fig. 2). In general, it was observed that for the physicochemical properties of the soil, there was a not very high variation that was significant ($P<0.05$) in relation to onion bulb quality and plant density within the crop (Fig. 2A); at the same time, the variability found in each of the sampling zones for the soil samples shows a high dispersion of the data (Fig. 2A), which confirms that the high variation found in the soil properties is due to the synergy between the crop attributes and the conditions of the soil origin in each of the study zones. On the other hand, the low variability in the properties of the irrigation water samples compared to the variability of the soil samples ($P<0.05$) is mainly due to the origin, treatment and adequacy of the water network used by the association and the crop owners (Fig. 2B), i.e., the mechanical conditions, the origin of the irrigation water source and the local adaptations, allow maintaining the water in homogeneous physicochemical terms, thus, being a great resource to obtain good productivity levels, such as onion bulb quality linked to the planting densities within the crop (Fig. 2B). These results suggest that the variability of the physicochemical conditions of soil and irrigation water cannot be due only to the interaction of a single factor, either the crop attribute or the ion and cation load of the irrigation water, suggesting that the synergy between the different factors play a very important role in the homogeneity of the conditions or not, taking into account that the study areas have similar characteristics in terms of fertilization plans and irrigation water use (Fig. 2).

However, it has been shown that the variability of physical properties is lower compared to chemical properties, mainly because they respond to macrogeographic conditions such as climate, topography and geological parent material (Novillo *et al*., 2018; Awal *et al*., 2019). Recently, it has been evidenced that physicochemical variation responds mainly to intrinsic and anthropogenic factors of the crop, even to a greater extent than in relation to environmental conditions (Huang *et al*., 2013; Little *et al*., 2015). Being an effect of the physicochemical variations of the soil, the affectations in the concentrations of essential macronutrients which are going to be affecting the different stages of crop development and resulting in the implementation of poor soil management practices and the disproportionate addition of fertilizers which will help in increasing the variation of soil conditions (Ugen *et al*., 2002; Travlos, 2013; Cheimona *et al*., 2016; Travlos *et al*., 2018; Pakeman *et al*., 2020). Despite this, it has always been maintained that the use of agricultural practices will always positively affect the physicochemical quality of the soil, several studies have shown that the misuse of tillage, or addition of handmade fertilizers have a negative effect on soil health and crop productivity (Nichols *et al*., 2015; Mbong *et al*., 2020). That is why pilot studies on the variability of physicochemical conditions within a productive agricultural system

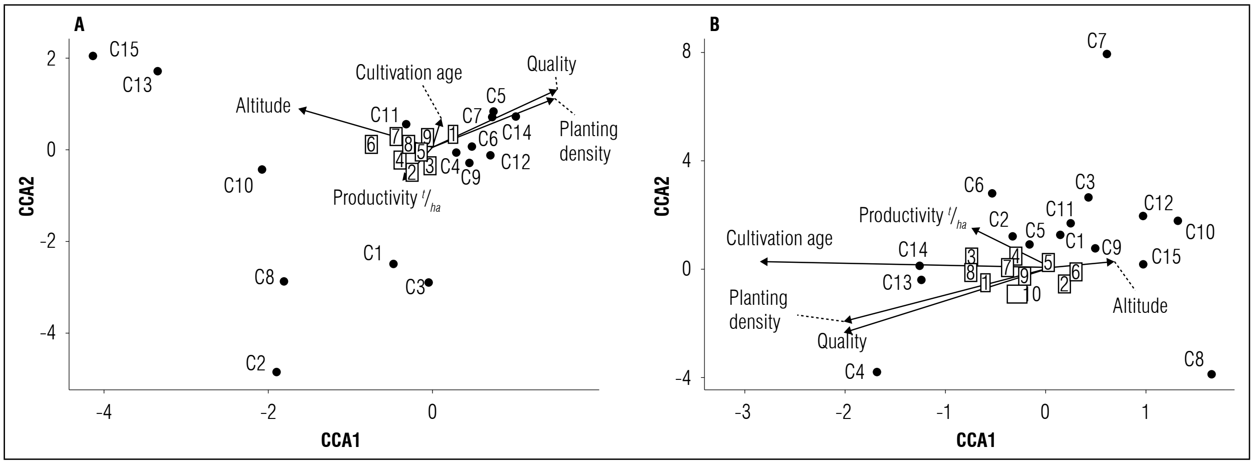

Figure 2. **Tri-plot of the Canonical Correspondence Analysis (CCA) between sampling zones, soil physicochemical properties (A) and irrigation water (B) with bulb onion crop productivity attributes. In figure 2A, the squares listed correspond to the following properties: 1=P (mg kg^{-1}); 2=Mg ($cmol^+$ kg^{-1}); 3=Bulk density; 4=K ($cmol^+$ kg^{-1}); 5=EC (dS m^{-1}); 6=Na ($cmol^+$ kg^{-1}); 7=Ca ($cmol^+$ kg^{-1}); 8=OM (%) y 9=pH. In figure 2B, the squares listed correspond to the following properties: 1=Hardness (°F); 2=Turbidity (NTU); 3=EC (dS m^{-1}); 4=Ca (meq L^{-1}); 5=Mg (meq L^{-1}); 6=SO_4 (meq L^{-1}); 7=Cl (meq L^{-1}); 8=K (meq L^{-1}); 9= Na (meq L^{-1}); 10=pH.**

are becoming more and more necessary, in order to provide the farmer with the necessary tools to be able to correctly and accurately provide the necessary implements for a correct agricultural functioning of the soil, without having problems of high economic costs or ecological risks to the surrounding systems (Thomas *et al*., 2004; Sheley *et al*., 2011; Grey *et al*., 2015).

CONCLUSION

The variation of soil physicochemical properties in bulb onion crops in the Usochicamocha District is mainly influenced by the intrinsic characteristics of the zone, such as: crop attributes, plant density at planting time, crop age, nutritional management plans of the crop. While the extrinsic characteristics, the ion and cation load of the irrigation water, may influence the zone in a more discrete way, mainly the quality attributes of the onion bulb, and sensitive nutritional loads in the soil such as phosphorus, electrical conductivity and pH values. Our results demonstrate and support that the internal conditions of the crop are as important as the conditions and care that should be taken with the soil care mechanisms; on the other hand, it is recommended to farmers to use irrigation water with controlled conditions, because although the load of ions and cations in the water affects less than other variables, it is still important for long-term control within the crops as a good practice of resource management.

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