

Influence of soil properties on yield and fruit maturity at harvest of 'Williams' pear

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In the Upper Rio Negro Valley, northern Patagonia (Argentina), there is a large variability of soils and the success of a fruit plantation depends mostly on soil characteristics. The main objective of this work was to determine the relationships between yield and fruit internal maturity at harvest of pear trees (*Pyrus communis* L.) grown in soils with different properties. The soil around each of 30 trees was morphologically characterized by measuring physical, physico-chemical, and chemical variables. At harvest time, total and commercial yields were measured, and maturity was determined by measuring flesh firmness, soluble solids, and titratable acidity. According to edaphic variables, soils were classified into five groups. Yields presented significant differences among such groups and growing seasons. The distribution of commercial sizes was similar in soils with fine texture, and high K content (897 and 663 mg kg⁻¹) and cation-exchange capacity. Smaller fruits predominated in soil groups with high salinity (6.1 dS m⁻¹ in surface and 10.8 dS m⁻¹ in subsurface horizons) and shallow depth. The soil group with the highest salinity presented fruits with 11% more titratable acidity compared to all other groups. The soil group with the smallest depth presented fruits with high levels of flesh firmness (11.18 kg cm⁻²) and soluble solids (14.8%). The selected set of edaphic variables allowed us to differentiate groups of soils and analyze its influence in pear tree yield, commercial sizes, and fruit internal maturity.

Key words: Integrative multivariate analysis, internal maturity indices, *Pyrus communis*, soils, yield.

INTRODUCTION

Argentina has a wide variety of climate and soil conditions that allows cultivating species from temperate, subtropical, and tropical zones and producing important exports of apples (*Malus domestica* Borkh.), pears (*Pyrus communis* L.), and citrus. The country is segmented into eight fruit regions (Altube et al., 2007). The southern region is the most important in terms of pear and apple production, it corresponds to northern Patagonia and includes areas from the provinces of Neuquén and Río Negro. The Upper Río Negro Valley is a narrow area of 1-12 km width and 130 km long located in northern Patagonia that comprises alluvial valleys from lower Neuquén and Limay rivers, as well as from upper Negro river. The Upper Río Negro Valley presents a large variability of soils (Talledo Yovera and Pacheco, 1969). Generally, when deciding which fruit tree species to implant, the soil quality of the orchard is not taken into consideration; however, achieving a successful, or not, implantation mostly relies on soil physical, physico-

chemical, and chemical properties (Aruani and Behmer, 2004; Draghi et al., 2005). Important soil agronomic factors such as texture, clay mineral type, structure, soil moisture, soil acidity or alkalinity, effective soil depth, and salinity, directly influence the development of the root system and indirectly the crop productivity level (Bengough et al., 2011).

Flooding is the most popular irrigation system applied in Upper Rio Negro Valley. The low efficiency of such method (Aruani et al., 2007) raises groundwater levels and generates a gradual soil salinization. Salt toxicity is one of the most limiting edaphic factors for producing good quality fruit. Excessive amounts of salts have adverse effects on soil physical and chemical properties, microbial processes, and plant growth (Liang et al., 2005). High osmotic potential generated by salts creates disturbances in the water absorption mechanisms, photosynthesis, protein synthesis, as well as in nutritional balances that affect fruit growth (Khayyat et al., 2007; Ajeet and Ramasare, 2009). Aruani et al. (2011) found that a high exchangeable Na percentage (ESP 20%) was negatively associated with pear yield, and if ESP decreased in 30% there was a significant improvement in yield, commercial size and internal quality of fruits. Similar results were obtained by Tejada et al. (2006) that utilized organic amendment as a strategy to reduce the saline effect in soils. Various studies of soil profile indicate that adequate

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K nutrition during the rapid growth phase ensures balance between acid and sugar content. As a consequence, fruits have a pleasant sweet taste and storage is prolonged (Hudina and Štampar, 2005; Sánchez, 2007). Fallahi et al. (2010) and Stino et al. (2011) noted that a good K⁺ content in soils is crucial to ensure fruit size increments. Analogous results were obtained by Noë et al. (1997) when studying the effect of N and K on the quality of apple fruits. The authors reported an increment in fruit firmness and soluble solids, and better storage conditions.

The influence of factors that affect the fruit size of pear 'Williams' as pollination, fruit thinning, and girdling has been evaluated under experimental conditions (Dussi et al., 2008; Dussi and Sugar, 2010; Gimenez et al., 2010); however, there is limited knowledge about the effect of soil properties on yield and fruit quality. In Upper Rio Negro Valley, Echenique et al. (2007) and Apcarian et al. (2006) described the relationship of yield of grapevine cultivars on soils with hardened layers, and Sánchez et al. (2007) found that cover crops did affect soil properties and apple yield. In such context, the objective of this paper was to determine relationships between soil physical, chemical, and physic-chemical properties, yields and fruit internal maturity at harvest of pear trees 'Williams' in the Upper Rio Negro Valley.

MATERIAL AND METHODS

Study area

The study was conducted during three growing seasons (2008-2009, 2009-2010, and 2010-2011) in three commercial orchards implanted with pear trees (*Pyrus communis* L.) 'Williams'. Orchards were owned by the

same grower. The experimental unit consisted in a tree and its surrounding soil. We selected 30 trees between 15 and 17 yr old, in three orchards located in the Upper Rio Negro Valley (38°54'-38°44' S, 68°02'-68°08' W). Trees were trained using a trellis system with a planting distance of 4 × 2 m and were irrigated by flooding. Crop management at all sites was performed according to standard cultural practices in the region of study and directed in the same way by the same technician. In every growing season, we added 150 U N applying half the dose in spring-summer and half the dose in autumn, and 8 kg tree⁻¹ chicken manure (3.0% N, 1.0% P, 2.2% K, 45% C and C/N ratio = 15) in winter. Herbicides were used to control weeds. Paraquat (276 g ai L⁻¹) was applied once in spring at a dose of 3 L ha⁻¹ and glyphosate (1.92 g ai L⁻¹) was applied five times in summer at a dose of 4 L ha⁻¹.

The parent material of soils is alluvial with aridic moisture regimen and termic temperature regime, which reflect conditions of water deficit throughout the year (CIL, 1991). The annual average temperature of the warmest month (January) is 21.9 °C and of the coldest month (July) is 5.7 °C. The annual average precipitation is 224 mm (data from weather station installed in the College of Agricultural Sciences, Universidad Nacional del Comahue, period 1972-2010).

Soil determinations

To study the soil profile, in late spring 2008, test pits were opened at 1 m from the trunk of each selected plant. Internal and external morphological features of each profile were described and soil taxonomy was classified according to Soil Survey Staff (2010) (Table 1). Samples were taken from surface (0-20 cm) and subsurface

Table 1. Morphological characteristics of soils.

Horizons	Depth cm	Color (Munsell)		Texture	Structure			Coarse fragments, %	Mottles	Consistence		
		Dry	Wetter		Type	Classes	Grade			Slightly dry and wetter	Slightly wetter and wet	Carbonates
Typic Aquicambids, fine-silty family												
Ap	0-20	10YR 6/2	10YR 3/3	Fa	B1	F	Mod	-	-	Fr	LA, LP	MLC
Bw	20-40	10YR 7/3	10YR 4/2	fal	B1	Med	Mod	-	-	Fir	A, P	FC
Ck1	40-55	10YR 6/3	10YR 4/1	fl		Structureless		-	-	Fr	LA, LP	FC
Ck2	55-100	10YR 6/3	10YR 4/2	f		Structureless		20	Commons	Fr	LA, LP	FC
2Ck3	100+	-	-	f	-	-	-	70-80	-	-	-	-
Oxyaquic Torrifluvents, coarse-loamy family												
Ap	0-20	10YR 4/3	10YR 3/2	f	Bl	F a Med	Mod	-	-	Fr	LA, LP	LC
AC	20-40	10YR 5/2	10YR 3/3	fl	Bl	F a Med	Mod	-	-	Fr	LA, LP	LC
C1	40-75	10YR 6/2	10YR 3/3	f		Structureless	-	-	Commons	Fr	LA, LP	MC
C2	75-100+	10YR 6/2	10YR 3/3	f		Structureless	-	-	Abundant	Fr	NA, NP	MLC
Typic Torriorthents, sandy-skeletal family												
Ap	0-16	10YR 5/2	10YR 3/3	f	B1	F	D	5	-	Fr	LA, NP	-
C1	16-32	10YR 5/2	10YR 3/3	fA		Structureless		30	-	Fr	NA, NP	-
2C2	32-50	10YR 6/2	10YR 4/3	A		Structureless		70	-	Fr	NA, NP	-
3C3	50+	-	-	A		Structureless		80-90	-	-	NA, NP	-
Typic Fluvaquents, coarse-silty family												
Ap	0-20	10YR 5/2	10YR 3/2	fl	Bl	F	Mod	-	-	Fr	LA, LP	LC
C1	20-40	10YR 6/2	10YR 4/2	fl		Structureless		-	-	Fir	LA, LP	FC
C2	40-50	10YR 6/2	10YR 4/2	fl		Structureless		-	Commons	Fr	LA, LP	FC
C3	50-78	10YR 6/2	10YR 3/2	fl		Structureless		-	Abundant	Fr	LA, LP	FC

Texture: fa: clay loam; fal: silty clay loam; fl: silty loam; f: loam; fA: sandy loam; A: sandy; Structure: Type: B1 blocky; Classes: F: fine; Med: medium; Grade: Mod: moderate; D: slight; Consistence: Fr: friable; Fir: firm; LA: slightly sticky; LP: slightly plastic; P: plastic; Carbonate: MLC: very lightly carbonated; FC: strongly carbonated; LC: lightly carbonated; MC: moderately carbonated.

horizons (20-40 cm) to determine: percentage of sand, silt and clay (hydrometer Bouyoucos method), pH measured in the saturation extract (potentiometric method, portable pH/mV/°C Meter HI 8424, Hanna Instruments, Woonsocket, Rhode Island, USA), electrical conductivity (EC dS m⁻¹, Metrohm AG, Herisau, Switzerland), cations and anions measured in saturation extract, Na adsorption ratio (SAR), organic matter (OM) of the surface horizon (Walkley and Black, 1934), cation-exchange capacity (CEC), and exchangeable cations (K and Na) (NH₄ acetate method, Flame Photometer 315, Metrolab, Buenos Aires, Argentina). In late spring 2009 and late spring 2010, soil samples were collected at the same sites and horizons to register the evolution of the following variables: pH, EC, soluble cations and anions, SAR, K and Na exchangeable cations, and OM from the surface horizon.

Yield and internal maturity indices

All the fruits from each tree were harvested (7 and 9 January 2009, 18 and 19 January 2010, and 10 and 11 January 2011) according to the official harvest authorization date for 'Williams' published by the National Secretary of Agriculture. Each fruit was individually weighed, and total yield was obtained by adding weights of all fruits for each tree, while commercial yield included only the sum of fruits ≥ 121 g. Commercial yield to total yield ratio was calculated. We determined the trunk cross-sectional area (TCSA) of each tree and expressed total and commercial yield in kg cm⁻² TCSA. Fruits were classified according to standard commercial sizes: 60, 70, 80, 90, 100, 110, 120, 135, 150, 165, and 180. These values indicate number of fruits per 18.2 kg box (Bramardi et al., 2006). In 2008-2009 and 2009-2010 seasons, 20 fruits from each tree were sampled to determine the following internal maturity indices: flesh firmness using an Effe-Gi-type manual penetrometer with an 8 mm plunger (FT 327, Facchini Srl, Alfonsine, Italy) and expressed in kg cm⁻²; soluble solids (SS), measured with a refractometer (N1 Brix 0-32%, Atago, Tokio, Japan) and expressed as % SS; and total titratable acidity measured with a digital pH-meter Atago-type neutralizing with KOH up to pH = 8.1 and expressed in g % malic acid.

Statistical analysis

Variables were grouped in three sets according to each of the three aspects that they described (soil, yield, or maturity) and each set was submitted to the following analysis procedure. First, we analyzed linear relationships among all the variables using a scatterplot matrix and calculating Pearson correlation coefficients with Infostat program (Di Rienzo et al., 2011). To diminished co-linearity among variables, we eliminated those variables that had a linear correlation coefficient greater than 0.85. Secondly, with the remaining variables we ran a multiple factor analysis (MFA) as defined in Escofier and Pagés (1994), with three ways of multivariate analysis being:

sites, variables, and growing seasons. This type of analysis allowed us to obtain consensus configuration of sites, to establish relationships among variables, and to analyze the evolution in time.

The above procedure was firstly applied to the set of soil variables and a classification of sites into groups according to their distance in the main plane was obtained. Subsequently, such groups were used as a classification variable to analyze differences in yield and maturity variables among the groups. In all analyses, 95% confidence ellipses for each group mean were constructed. Multiple factor analysis (MFA) was executed with FactoMineR v.1.14 package (Husson et al., 2010) in R 2.14.0 (R Development Core Team, 2012). Groups were compared using ANOVA and multiple mean comparisons adjusted by Tukey test ($P < 0.05$) for unbalanced data.

RESULTS

Soil properties

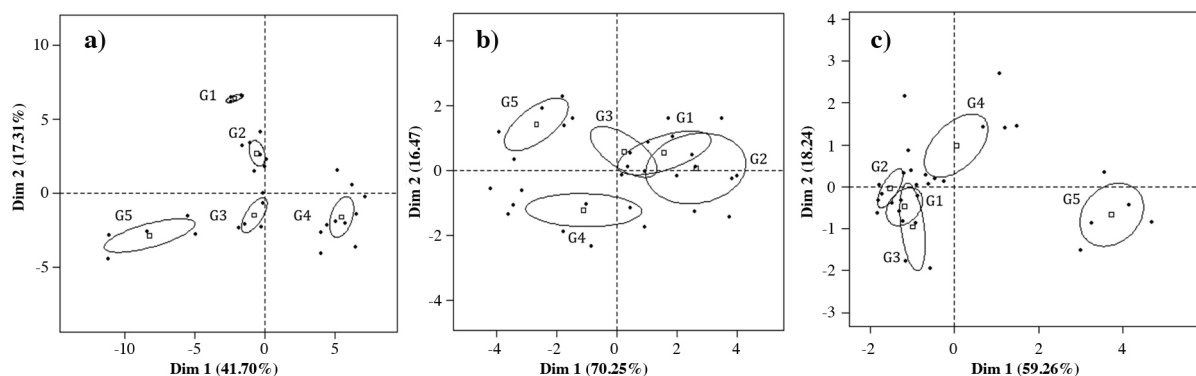
The first two dimensions of MFA accounts for 60% of the total variability (inertia). The complete description of the first two dimensions is presented in Table 2. Variables that consistently participated in the construction of dimension 1 over the 3 yr, included sand, silt, EC, % calcium carbonate, and CEC all from the surface horizon; and pH, EC, SAR, and % calcium carbonate, all from the subsurface horizon. Dimension 2 is highly correlated with K and CEC of the subsurface horizon in all 3 yr.

The configuration of sites in the principal plane of the MFA is presented in Figure 1a. Sites were divided into five soil groups according to Euclidean distances.

Table 2. Correlation coefficients between principal dimensions and edaphic variables for each growing season.

Edaphic variables	2008-2009		2009-2010		2010-2011	
	Dim1	Dim2	Dim1	Dim2	Dim1	Dim2
Surface horizon						
OM	0.47	-0.15	0.48	-0.35	0.34	-0.16
Sand	-0.90	-0.21	-0.80	-0.44	-0.87	-0.30
Silt	0.85	-0.04	0.81	0.19	0.84	0.10
Clay	0.72	0.54	0.55	0.70	0.68	0.49
pH	0.57	-0.12	0.81	-0.08	0.47	0.02
EC	0.78	-0.40	0.85	-0.28	0.73	-0.47
K ⁺	0.70	0.56	0.58	-0.22	0.34	0.73
CO ₃ Ca	0.76	-0.26	0.85	-0.21	0.81	-0.19
Bulk density	-0.15	0.53	-0.61	0.43	-0.51	0.63
CEC	0.70	0.30	0.63	0.45	0.71	0.23
Subsurface horizon						
Silt	0.70	-0.03	0.68	0.15	0.68	0.05
Clay	0.55	0.45	0.44	0.59	0.55	0.41
pH	0.69	-0.05	0.87	-0.12	0.71	0.08
EC	0.77	-0.55	0.90	-0.21	0.81	-0.47
K ⁺	0.41	0.65	0.06	0.84	-0.01	0.76
SAR	0.70	-0.55	0.86	-0.26	0.75	-0.53
CO ₃ Ca	0.67	-0.16	0.71	0.05	0.68	-0.13
Bulk density	-0.21	0.14	-0.24	0.14	0.68	0.41
CEC	0.11	0.76	-0.11	0.85	0.08	0.71

OM: organic matter; EC: electrical conductivity; K: exchangeable K; SAR: Na adsorption ratio; CEC: cation-exchange capacity.



●=sites, □= group mean, ○= 95% confidence ellipse of group mean.

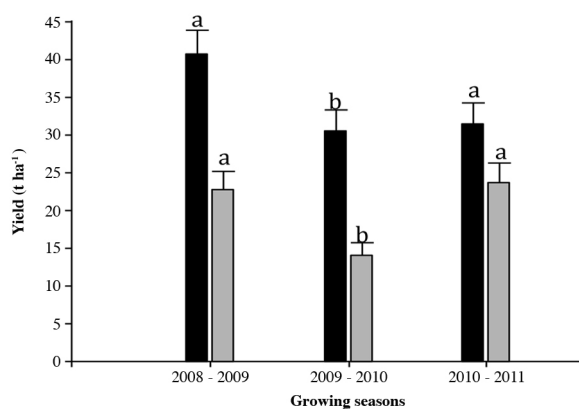
Figure 1. Consensus configuration of experimental sites according to factorial multiple analysis considering (a) edaphic, (b) yield, and (c) fruit maturity variables. (a) and (b) are based on three growing seasons (2008-2009, 2009-2010, and 2010-2011) while (c) is based on two growing seasons (2008-2009 and 2009-2010).

Yield

Dimension 1 and dimension 2 of the MFA explained 86.9% of the total inertia. Correlations between yield variables and dimensions are presented in Table 3. The configuration of sites in the principal plane of the MFA is presented in Figure 1b. Group labels correspond to soil groups identified in the MFA of soil properties. There is an overlapping of means from groups 1, 2, and 3 while group 4 and 5 differ from each other as well as with other groups. The ANOVA results for two response variables, total yield and commercial yield, reported differences for the main effects of growing season ($P = 0.002$ for total yields and $P = 0.0002$ for commercial yield) and soil groups ($P < 0.0000$ for total yield and $P < 0.0000$ for commercial yield), and no interaction between them. Considering the growing season effect, we found that total yield was higher in the first and third season, and commercial yield was lower in the second season (Figure 2). Yield was also different among soil groups (Table 4). Total yield was higher in soil groups 1 and 2, intermediate in groups 3 and 4, and lower in group 5. Commercial yield was also higher in soil groups 1 and 2, but intermediate values were found only in group 3, and the lowest values were obtained in groups 4 and 5. When fruits were classified according to commercial size and soil group (Figure 3a), we observed a similar fruit size distribution in group 1 and 2. Groups 4 and 5 were characterized by a higher percentage of small fruits (size 180). If we compare across growing seasons (Figure 3b), we can see that in 2009-2010 we obtained higher percentage of small fruits (size 180).

Table 3. Correlation coefficients between principal dimensions and yield variables for each growing season.

Variable	2008-2009		2009-2010		2010-2011	
	Dim1	Dim2	Dim1	Dim2	Dim1	Dim2
Total yield, kg pl ⁻¹	0.87	-0.51	0.74	0.66	0.91	-0.38
Commercial yield, kg pl ⁻¹	0.99	-0.04	0.99	-0.04	0.98	-0.14
Commercial yield, %	0.78	0.62	0.76	-0.64	0.76	0.65



Different letters on bars corresponding to the same response variable, total yield (black) or commercial yield (grey) indicate significant differences between growing seasons according to Tukey test ($P < 0.05$).

Figure 2. Total and commercial yields for growing season. Vertical bars correspond to standard error. Growing seasons $n = 30$.

Internal maturity indices

The configuration of sites in the principal plane of the MFA is presented in Figure 1c. Group labels correspond to the soil groups identified in the MFA of soil properties. The first two dimensions accounted for 78% of the total inertia. Soil groups 4 and 5 presented larger variability and soil groups 3 and 1 overlapped. Correlations between quality variables and dimensions are presented in Table 5.

Table 4. Means of yield variables by soil groups based on three growing seasons: 2008-2009, 2009-2010, and 2010-2011.

Variable	Soils groups				
	G1 (3) ^a	G2 (7)	G3 (5)	G4 (10)	G5 (5)
Total yield, kg cm ⁻² per TCSA	0.034a	0.034a	0.029b	0.026b	0.009c
Commercial yield, kg cm ⁻² per TCSA	0.023a	0.023a	0.015b	0.001c	0.005c
Commercial/total yield, %	70.0a	70.0a	62.0b	40.0c	55.0c
Total yield, t ha ^{-1(b)}	39.5a	47.1a	33.6b	35.5b	12.0c
Commercial yield, t ha ⁻¹	28.6a	33.2a	20.3b	15.1c	7.3c

^aNumber of sites.

^bTotal yield corresponds to a density of 1250 plants ha⁻¹.

Different letters in each row indicate significant differences between soil groups according to Tukey test ($P < 0.05$).

TCSA: trunk cross-sectional area.

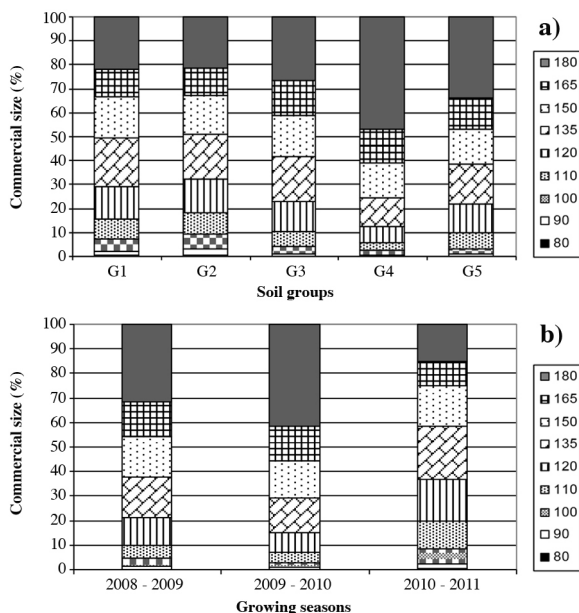


Figure 3. Commercial fruit size in number of fruits over total by soil groups (a) and growing season (b). Fruit size indicates number of fruits per 18.2 kg box.

Flesh firmness and titratable acidity presented significant interaction effect between soil group and growing season ($P = 0.01$ and $P = 0.004$, respectively) (Table 6). Soluble solids presented only significant effect of soil group ($P = 0.00001$) with groups 1 to 4 being significantly lower (11%) compared to group 5 (14%).

Table 5. Correlation coefficients between principal dimensions and internal maturity indices variables for growing seasons 2008-2009 and 2009-2010.

Variable	2008-2009		2009-2010	
	Dim1	Dim2	Dim1	Dim2
Flesh firmness	0.87	-0.41	0.86	0.40
Soluble solids	0.95	0.03	0.91	0.17
Titratable acidity	0.36	0.92	-0.70	0.70

DISCUSSION

Characterization of soil groups

Taxonomically, soils pertained to order Aridisols, suborder Cambids, and order Entisols, suborders Orthents and Fluvents. The predominance of the aquic subgroup in both orders indicated drainage problems with different degrees of hydromorphism. Table 7 shows means of edaphic variables for each group.

Table 6. Means of flesh firmness and titratable acidity by soil groups and growing season.

Variable	2008-2009					2010-2011				
	G1	G2	G3	G4	G5	G1	G2	G3	G4	G5
Flesh firmness, kg cm ⁻²	9.42ab	8.96a	10.36bc	9.53ab	11.42c	9.55ab	9.27ab	9.37ab	9.86ab	10.97c
Titratable acidity, g % malic acid	0.543ab	0.580ab	0.510a	0.712c	0.613ab	0.629ab	0.649bc	0.663bc	0.607ab	0.549ab

Different letters in each row indicate significant differences between groups of soils and growing seasons according to Tukey test ($P < 0.05$).

Table 7. Means of edaphic variables by soil groups based on three growing seasons: 2008-2009, 2009-2010, and 2010-2011.

Edaphic variable	Soils groups				
	G1 (3) ^a	G2 (7)	G3 (5)	G4 (10)	G5 (5)
Surface horizon					
OM, g kg ⁻¹	30.5 b	30.6 b	29.5 b	39.2 a	34.1 ab
Sands, %	25.9 c	31.8 b	34.9 b	23.2 c	57.2 a
Silt, %	43.7 ab	40.8 b	45.7 ab	49.8 a	27.7 c
Clay, %	30.4 a	27.4 c	19.4 b	27.3 c	15.1 d
pH	7.29 a	7.42 a	7.71 b	7.68 b	7.02 c
EC, dS m ⁻¹	1.1 bd	2.0 bd	3.7 c	6.1 a	0.7 d
K ⁺ , mg kg ⁻¹	897.0a	585.0b	663.0b	585.0b	312.0c
CaCO ₃ , %	2.7 bd	3.5 b	5.0 c	6.0 a	1.7 d
Bulk density, t m ⁻³	1.23 a	1.13 a	1.13 a	0.88 b	0.98 b
CEC, cmol, kg ⁻¹	32.4 a	32.0 a	27.5 b	33.5 a	26.1 b
Subsurface horizon					
Silt, %	49.4a	50.6a	56.4a	59.5a	29.4b
Clay, %	21.5a	23.8a	16.5b	22.7a	12.1b
pH	7.3b	7.59b	7.6b	7.8a	6.8c
EC, dS m ⁻¹	1.7c	4.6b	5.2b	10.8a	0.4c
K ⁺ , mg kg ⁻¹	819.0a	468.0b	382.0bc	390.0bc	234.0c
SAR	1.6b	8.34c	7.24c	18.0a	1.2b
CaCO ₃ , %	3.3b	5.5c	5.5ca	6.9a	2.5b
Bulk density, t m ⁻³	1.28	1.26	1.34	1.24	-
CEC, cmol, kg ⁻¹	30.6a	30.1a	25.2b	25.9b	24.4b

^aNumber of sites.

OM: organic matter; EC: electrical conductivity; K: exchangeable K; SAR: Na adsorption ratio; CEC: cation-exchange capacity.

Different letters in each row indicate significant differences between soil groups according to Tukey test ($P < 0.05$).

Group 1 included 10% of sites. Soils corresponded to order Aridisols classified as Typic Aquicambids, fine-silty family, they were deep soils that had predominantly loamy clay texture on the surface and loamy-loamy silty texture in the subsurface. They were free of salts and had a neutral pH with a high level of organic matter (30.5 g kg⁻¹) for the Upper Rio Negro Valley area (Aruani et al., 2001). Both horizons were very well supplied with K (897-819 mg kg⁻¹). The calcium carbonate content indicated slightly calcareous soils (FAO, 2009).

Group 2 included 23% of sites. They corresponded to the same soil and texture classification of group 1 in both horizons. These were deep soils, slightly saline in the subsurface layer, and with a slightly alkaline pH (Soil Survey Manual, 1995). Group 1 and group 2 presented higher percentages of clay and CEC levels than other groups. Soils were well supplied with organic matter but contain 35% less K than group 1. The percentage of calcium carbonate was moderate (3.5% to 5.5%) (FAO, 2009). In groups 1 and 2, height of water table was below 100 cm in winter and remained between 80 and 90 cm during the vegetative period; however, scarce reddish spots were observed in the profile below 50 cm depth due to

fluctuations in the capillary flow during the irrigation season.

Group 3 comprised 16% of sites. Soils corresponded to order Entisols classified as Oxyaquic Torrifluvents, coarse-loamy family. These were deep soils with predominant loamy textures in both horizons, with a slightly alkaline pH and slightly saline content in both horizons. Soils were well supplied with organic matter, and K content ranged from 382-663 mg kg⁻¹ (Table 7). The percentage of calcium carbonate was moderate (FAO, 2009). As well as in groups 1 and 2, we observed capillary flow fluctuations below 50 cm of depth caused by the irrigation system. The water table remained between 80 and 90 cm, during the vegetative period.

Group 4 comprised 33% of sites. Soils were classified as Typic Fluvaquents, coarse-silty family. These were moderately deep soils that were limited by the presence of the water table at 70 cm depth during the vegetative period but such level fell below 100 cm in winter. These soils were homogeneous and had a silty loamy texture throughout the profile. They differed from the above groups in being slightly saline (6.1 dS m⁻¹) in surface, and moderately saline (10.8 dS m⁻¹), sodic (RAS 18) with a high 34% of ESP in the subsurface horizon. The pH was slightly alkaline. This group had the highest content of OM, and K content similar to group 3. According to Grattan and Grieve (1998), soils with a good nutritional status can counteract the negative impact of salts on fruit production. Soils in group 4 had a high calcium carbonate percentage (6.0-6.9%) (FAO, 2009), and marked hydromorphic symptoms below 40 cm.

Group 5 consisted of 16% of all sampled sites. Soils were classified as Entisols, order Typics Torriorthents, sandy-skeletal family, and subsoil with high content of coarse elements (80%). These soils were moderately deep (50 cm) with two sites being shallow (30 cm). They contained a high percentage of sand, thus being somewhat excessively drained. They were well supplied with OM, contained lower concentrations of K compared to other groups, and had a neutral pH. They were non saline soils with low bulk density, and low percentage of calcium carbonate (1.7%-2.5%).

Relationships between soil characteristics and tree yield

Fruit growth is largely conditioned by internal (plant), and external (management and environmental) factors. With regard to external conditions, Sharples, (1980) showed that physical and chemical properties of soils and climatic factors affect the rate of ripening and cooking qualities of pears grown in South Africa, North America, and southeastern England. Stino et al. (2011) determined that one of the soil variables that directly influence the fruit growth phase is K⁺, which serves to maintain the fundamental condition of turgidity of cells. A good K⁺ nutrition in the fruit is associated with good equilibrium

between acids and sugars content, good ripening, and good eating quality (Marcelle, 1995). Fallahi et al. (2010) determined that K fertilization increased fruit size, yield, and acidity in four apple cultivars. In this research, foliar analysis of the selected plants (data not shown) reported K levels between 1.5%-1.7%, such levels are considered normal for pear 'Williams' (Sánchez, 2007).

Soil groups 1 and 2 had higher commercial yields (70%) (Table 4) and were associated with soils that had higher K⁺ content, CEC, and percentage of clay in both horizons as well as lower saline levels, all these variables have a positive effect in fruit size (Merwin and Warren, 1994).

Soils in group 3 had lower level of commercial production (62%) than those in groups 1 and 2. Soils in group 3 presented the highest percentage of sand, lower CEC, 50% more salt in the surface horizon and 12% in the sub-surface horizon, and lower content of K⁺. Bronwyn et al. (1995) obtained a 30% reduction in yield of pear trees 'Williams' and a higher proportion of small fruits, in soils with similar salt concentration to soils studied in group 3.

In group 4 the high salt effect and high prevalence of Na mainly in the second horizon, negatively affected the commercial production (Aruani et al., 2011). Although groups 4 and 3 had similar total production, only 40% was commercial yield in group 4 (Table 4). Analogous situation were recorded by Grattan and Grieve (1998) and Khayyat et al. (2007). In saline soils, Rhoades et al. (1992) stated that yield losses start with EC values greater than 2 dS m⁻¹ and rise up to 20% with values greater than 4 dS m⁻¹ within the first 150 cm soil depth. Yields were reduced by 13% in citrus and 30% in plums with conductivities less than 3 dS m⁻¹ (Mass, 1986). In group 5, fruit production was affected by the low soil effective depth.

Relationships between soil characteristics and internal maturity indices

The recommended internal maturity indices values to start the harvest of 'Williams' pears in the Upper Rio Negro Valley were: flesh firmness between 8.62 and 9.52 kg cm⁻², total titratable acidity between 0.3 and 0.4 g % malic acid, and soluble solids higher than 10% (Calvo et al., 2010). Flesh firmness and titratable acidity were the most affected indices by soil texture and chemical composition in groups 2 and 3, whereas titratable acidity and SS were affected in fruits obtained from plants with saline (group 4) and hydric stress (group 5), with consequent depreciation in fruit quality.

Fruits in group 2 presented an appropriate flesh firmness value according to the harvest date set for the region in both growing seasons (Table 6). However, fruits in group 3 in 2009 and in group 4 in 2010 should have been retained in the plants for a longer period due to flesh firmness values > 9.52 kg cm⁻² at harvest time in order to reach an optimal maturity level for storage and

commercialization. Flesh firmness depends on soil levels of Ca^{++} and K^+ (Benítez et al., 2005; Sánchez, 2007). It has been shown that Ca interacts with other elements and plays a central role in cell functioning, a high Ca level in pear is associated with slower degradation of the cellular structure (Bangerth, 1974). Group 2 presented lower Ca concentrations in terms of % calcium carbonate than group 3 and group 4 (Table 7), this could explain the lower flesh firmness values found in fruits from such group. Even though group 4 presented similar K^+ content to group 2, group 4 contains 71% more calcium carbonate, then this condition could allowed the fruit to keep its firmness for a longer period. Also, group 3 presents 43% more Ca^{++} than group 2 and a higher K^+ concentration, it could explain the high firmness caused by synergism of both nutrients.

The highest flesh firmness was observed in group 5, related to soil physical characteristics: shallow, with 57% of sand and high percentage of coarse fragments. This increased firmness is associated with a greater elasticity of cell wall caused by dehydration. Fruits that contain less volume of water generate a higher concentration of soluble solids (Benítez et al., 2005).

Titrate acidity was higher in group 4 in 2009 (Table 6). Salt stress to which plants were subjected in this group creates defense mechanisms such as significantly reducing the osmotic potential of the fruit, increasing soluble solids concentration to prevent dehydration, and increasing levels of titratable acidity, organic acids and DM content (Musacchi et al. 2006). Soils that had more than 35% ESP showed an increase in the percentage of soluble solids, titratable acidity, and flesh firmness (Aruani et al., 2011). These results agree with Hudina and Štampar (2005), who noted that content of sugar and organic acids depends on plant genotype, environmental conditions and are influenced by irrigation system and soil nutrients availability. Hudina and Štampar (2002) shown that P and K foliar nutrition in pear ‘Williams’ resulted in higher levels the SS and organic acids (malic, citric), and improved the quality and life of stored fruits. According to Lombardi et al. (2000) and Parra-Coronado et al. (2006), acidity is a heterogeneous parameter in fruits of the same age. In spring 2010, the cloudy and cool environmental conditions increased acidity of fruits in all soil groups compared to the previous growing season (Table 6).

The percentage of SS from groups 1 to 4 (11%) was different from group 5 (14.8%). This value is directly related to an accelerated process of maturation at the official harvest date, influenced by less retentive and warmer soil characteristics. During maturation, cementing substances (protopectins and pectin) that give fruit turgor are transformed into water-soluble pectic acids and other substances, producing the characteristic softening of ripe fruit (Parra-Coronado et al., 2006).

CONCLUSION

The results of this investigation showed that the selected set of edaphic variables (percentages sand, silt and clay, pH, electrical conductivity, potassium, calcium carbonate, bulk density, Na adsorption ratio, and cation-exchange capacity allowed us to differentiate soil groups and to determine their influence on total yield, commercial size, and fruit internal maturity at harvest of pear trees ‘Williams’. Deep, homogeneous soils with clay loam textures, good supply of potassium and low salt content are recommended to obtain good commercial yields in the Upper Rio Negro Valley. In addition, soil characteristics influenced flesh firmness and percentage of soluble solids of fruits.

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