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

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In the Upper Río 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, physic-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.
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 Noël 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 Apicarian 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 physico-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 tree¹1 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 reflects conditions of water deficit throughout the year (CIL, 1991). The annual average temperature of the warmest month (January) is 21.9 ºC and of the coldest month (July) is 5.7 ºC. 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) | Structure Type | Texture | Classes | Grade | Coarse fragments, % | Motiles | Consistence | Dry | Wetter | Coarse Torrilluvents, coarse-loamy family |
|----------|------------|----------------|----------------|---------|---------|-------|-------------------|---------|-------------|-----|--------|-----------------------------------------|
| Ap       | 0-20       | 10YR 4/3       | Fa             | B1      | F       | Mod   | -                 | -       | Fr          | LA | LP     | MLC                                     |
| Bw       | 20-40      | 10YR 5/2       | fl              | B1      | F-a Med | Mod   | -                 | -       | Fr          | LA | LP     | LC                                      |
| C1       | 40-75      | 10YR 6/3       | f               | Structureless | -     | Commons | Fr          | LA | LP         | FC  |
| C2       | 75-100+    | 10YR 7/3       | f               | Structureless | -     | Abundant | Fr          | NA | NP         | MLC |
| Tyopic Aquicambids, fine-silty family | | | | | | | | | |

| Horizons | Depth (cm) | Color (Munsell) | Structure Type | Texture | Classes | Grade | Coarse fragments, % | Motiles | Consistence | Dry | Wetter | Oxyac Torrilluvents, coarse-loamy family |
|----------|------------|----------------|----------------|---------|---------|-------|-------------------|---------|-------------|-----|--------|-----------------------------------------|
| Ap       | 0-20       | 10YR 4/3       | f               | B1      | Fa Med  | Mod   | -                 | -       | Fr          | LA | LP     | LC                                      |
| AC       | 20-40      | 10YR 5/2       | fl              | B1      | Fa Med  | Mod   | -                 | -       | Fr          | LA | LP     | LC                                      |
| C1       | 40-75      | 10YR 6/2       | f               | Structureless | -     | Commons | Fr          | LA | LP         | MC  |
| C2       | 75-100+    | 10YR 7/3       | f               | Structureless | -     | Abundant | Fr          | NA | NP         | MLC |
| Tyopic Torriorthents, sandy-skeletal family | | | | | | | | | |
| Ap       | 0-16       | 10YR 5/2       | f               | B1      | F       | D     | 5                 | -       | Fr          | LA | NP     | -                                       |
| C1       | 16-32      | 10YR 5/3       | f               | Structureless | 30    | -       | Fr          | NA | NP         | -   |
| 2C2      | 32-50      | 10YR 6/2       | A               | Structureless | 70    | -       | Fr          | NA | NP         | -   |
| 3C3      | 50+        | -              | A               | Structureless | 80-90 | -       | -             | NA | NP         | -   |

| Horizons | Depth (cm) | Color (Munsell) | Structure Type | Texture | Classes | Grade | Coarse fragments, % | Motiles | Consistence | Dry | Wetter | Tyopic Fluvaquents, coarse-silty family |
|----------|------------|----------------|----------------|---------|---------|-------|-------------------|---------|-------------|-----|--------|-----------------------------------------|
| Ap       | 0-20       | 10YR 5/2       | fl              | B1      | F       | Mod   | -                 | -       | Fr          | LA | LP     | LC                                      |
| C1       | 20-40      | 10YR 6/2       | fl              | Structureless | -     | Commons | Fr          | LA | LP         | FC  |
| C2       | 40-50      | 10YR 6/2       | fl              | Structureless | -     | Abundant | Fr          | LA | LP         | FC  |
| C3       | 50-78      | 10YR 6/2       | fl              | Structureless | -     | Abundant | Fr          | LA | LP         | FC  |

Texture: fa: clay loam; fal: silty clay loam; f: silty loam; f: loam; fa: sandy loam; A: sandy; Structure: Type: Bl 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 (pontentiometric 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 collinearity 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 Pagès (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      | -0.55     | 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      |
| CO₃Ca            | 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     |
| CO₂Ca            | 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.
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 |
|--------------------------------|-----------|-----------|-----------|
| Total yield, kg pl⁻¹            | 0.34      | 0.29      | 0.10      |
| Commercial yield, kg pl⁻¹       | 0.28      | 0.24      | 0.10      |
| Commercial yield, %             | 0.28      | 0.24      | 0.10      |

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

| Soils groups | Variable | G1 (3) | 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       | 0.023a   | 0.023a | 0.015b | 0.011c | 0.005c |
| Commercial/total yield, %       | 0.07a    | 0.07a  | 0.07a  | 0.07a  | 0.07a  |
| Total yield, t ha⁻¹             | 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   |

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.
Flesh firmness and titratable acidity presented significant interaction effect between soil group and growing season \( (P = 0.01 \text{ and } P = 0.004, \text{ respectively}) \) (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\%).

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 or 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, scare reddish spots were observed in the profile below 50 cm depth due to

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

| Edaphic variable | G1 (3) | G2 (7) | G3 (5) | G4 (10) | G5 (5) |
|------------------|--------|--------|--------|---------|--------|
| 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 | 7.11 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  | 468.0b | 382.0bc | 390.0bc | 234.0c |
| 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 |

| Edaphic variable | Surface horizon | 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 |

| Number 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 \( (P < 0.05) \). |

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

| Variable | G1 (3) | G2 (7) | G3 (5) | G4 (10) | G5 (5) |
|----------|--------|--------|--------|---------|--------|
| Flesh firmness, kg cm\(^{-2}\) | 9.42ab | 8.96a  | 10.36bc | 9.53ab  | 11.42c |
| Titratable acidity, g % malic acid | 0.543ab | 0.580ab | 0.510a  | 0.712c  | 0.613ab |

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

Titratable 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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