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Orchard's Soil Characterization and Nutrient Mobilization to Rocha Pear (*Pyrus communis* L.) Fruits †

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Abstract: Soil is a limited resource, being vital for plant production during the agricultural phase, and consequently a fundamental component of the agro-industrial sector. In a near future where efficiency in food production will be crucial to feed a growing population, agronomic strategies to ensure food quality needs to be tested and optimized with field trials. Taking this into consideration, in 2018, as part of the execution of a fortification workflow of Rocha pears (*Pyrus communis* L.), a field characterization was carried out before the beginning of foliar spraying, to identify possible limitations to the increase of calcium in fruits. Thus, in March, soil samples were collected from an orchard (i.e., a parcel with 500 m^2) located in the West region of Portugal, where this variety is largely produced. During sample analysis, humidity, organic matter, pH, electrical conductivity, colorimetric parameters by CIELab system (with and without organic matter) and mineral analysis by X-ray fluorescence (of soils and fruits at harvest) were assessed. Humidity values indicated an even irrigation on the orchard. Additionally, it was found that organic matter values influenced soil color. Electrical conductivity and pH values were within the recommended range for pomeids. Additionally, higher values of Ca and P prevailed in soils, while K and S contents remained higher in fruits. In conclusion, no major limitations were identified, and field characterization before Ca fortification workflow was useful to assess the orchard`s conditions and possible limitations to nutrient absorption by trees.

Keywords: chemical and physical parameters; colorimetric analysis; mineral analysis; orchard; soil analysis

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1. Introduction

Food is a necessity granted to consumers by agroindustries. However, in meads of an expected increase of global population, set to reach 11 billion people by the end of the century, and likely limitation of water and land resources, maximizing efficiency and reducing waste becomes crucial to achieve sustainability [1,2].

Agricultural land takes up 38% of the global land surface, from which two thirds are meant for livestock, and the remaining third is used as cropland (10% destined for permanent crops such as fruit trees) [2]. Calcium (Ca) is the third most important element present in soils, but sometimes its compounds can be unavailable for plant absorption due to its insolubility [3]. Furthermore, besides Ca availability in soils, other factors such as competition with other cations (such as magnesium (Mg) or potassium (K)), transpiration and root growth influence Ca absorption by plants [4].

Currently in Portugal, over 11,300 ha are destined to pear production [5]. It is mostly occupied with Rocha pear (*Pyrus communis* L.) orchards, a portuguese variety where more than half of an average annual production of over 170,000 tons, is exported [6]. This study hence focused on the physic-chemical assessment of an orchard of pears prior to the execution of a fortification workflow with Ca, to identify limiting factors to potential Ca increases in fruits, further considering mobilization of nutrients from soils to control fruits.

2. Materials and Methods

2.1. Soil Sampling

In an orchard established in Alcobaça, a Portuguese county in the West of Portugal, an agricultural parcel of 20 × 25 m (thus 500 m^2) was selected. From right to left, the tree rows were identified as Control (Ctr), $Ca(NO_3)_2$, Null and $CaCl_2$. In late March, following a rectangular greed of (5.70 × 4 m), a total of 16 soil samples were collected (four per row). After a brief cleaning from plants and major debris, 600–1000 g were collected from a dept of 30 cm into polyethylene bags for transport.

2.2. Humidity, Organic Matter, Colorimetric and Mineral Analysis

From each sample, humidity and organic matter (OM) were determined as depicted in [7], firstly drying the soil samples for 24 h at 105 °C, followed by a second step in which samples were heated at 550 °C for 4 h.

After the first and second steps, colorimetric parameters were determined using a Minolta CR 400 colorimeter (Minolta Corp. Ramsey, NJ, USA) as indicated in [8]. Lastly an X-ray fluorescence analysis was performed with an XRF analyzer (Thermo Scientific, Niton model XL3t 950 He GOLDD+, USA) to assess mineral levels in soils, as described in [9] and in fruits with minor changes. After a brief cleaning with deionized water, fruits were cut and put to dry (50 °C) until constant weight, following a compaction into pellets.

2.3. Electrical Conductivety, and pH Analysis

After humidity, electrical conductivity (EC) and pH of soil samples were assessed with a potentiometer (Consort, C6030, Belgium) according to [7].

2.4. Statistic

A One-way ANOVA ($p \leq 0.05$) was performed to compare tree rows, while a Tukey test was conducted, considering a 95% confidence level.

3. Results

Overall, the agricultural parcel presented values that ranged between 13.0–22.2% for humidity, 1.7–4.6% for OM, 105.6–328.0 µS cm^{-1} for EC and 5.2–7.8 for pH (Figure 1).

For colorimetric parameters, before the first step (Figure 2), average values of L, a* and b* varied between 38–53, 3–5, 12–16 respectively, with line $CaCl_2$ being significantly higher than Ctr, and Null significantly inferior to $Ca(NO_3)_2$ and Ctr for parameters L and a* respectively. After the second step (Figure 2), values varied between 40–51, 13–16, and 18–24 respectively, with significant differences occurring for L and b* parameters, between lines $CaCl_2$, $Ca(NO_3)_2$ and Ctr, and $CaCl_2$ being significantly higher than Ctr respectively.

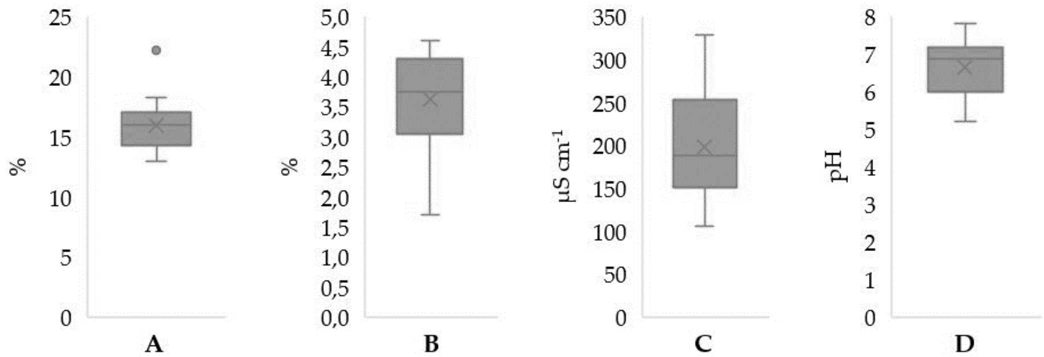

Figure 1. Boxplots of humidity (**A**), organic matter (**B**), electrical conductivity (**C**) and pH (**D**) of soil samples (n = 16) from the orchard of *Pyrus communis* var. Rocha from Alcobaça, Portugal.

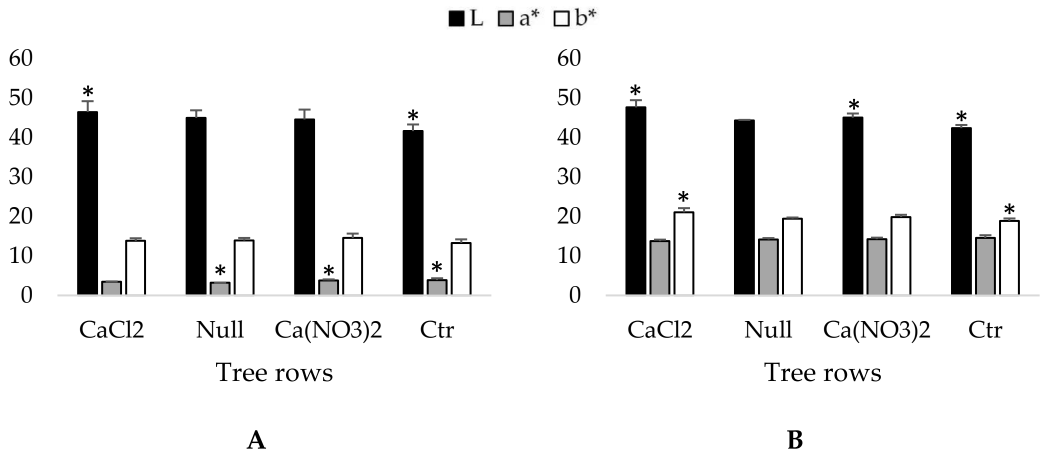

Figure 2. Average (n = 3) of colorimetric parameters (L, a* and b*) for each tree row (n = 4) from the orchard before (**A**) and after (**B**) organic matter removal. Asterisk (*) represents significant differences between tree rows for each color parameters.

Regarding mineral content of soils and fruits at harvest (without any foliar sprays) (Figure 3), Ca and phosphorus (P) were superior in soils, while K and sulfur (S) presented higher values in fruits.

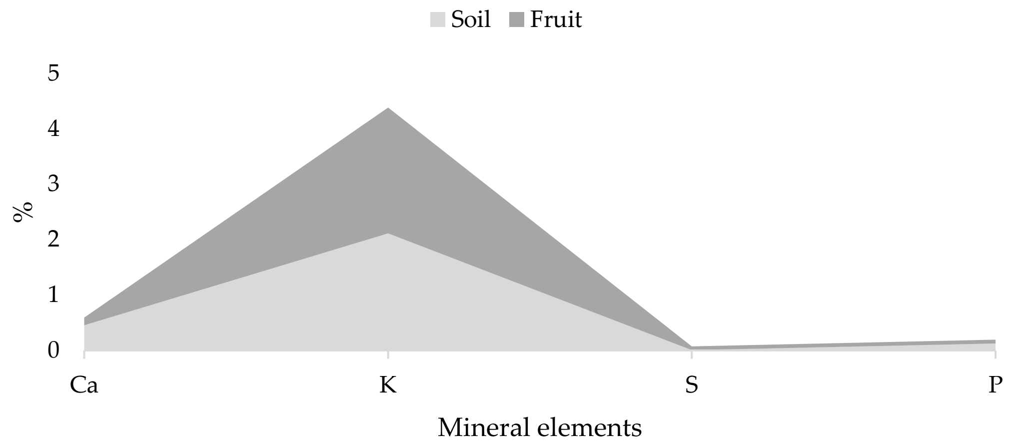

Figure 3. Average content of Ca, K, S and P from soil (light gray), and fruits without foliar sprays at harvest (dark gray), collected from the orchard of *Pyrus communis* var. Rocha from Alcobaça, Portugal.

4. Discussion

Humidity can depend on precipitation, hydric needs (for adequate functioning of plants metabolism), field drainage and irrigation methods [10]. For this agricultural parcel, and excluding the outlier value (Figure 1), there was a variation of 5.3% between samples suggesting an adequate drainage system, preventing excessive water accumulation or demonstrating a good surface water runoff, overall indicating an even irrigation of the trees [11]. This can be due to the drop-to-drop irrigation system performed in the orchard, which is advised for orchards in general, to assure nutrient assimilation from soils and consequent healthy development of fruits [11].

Organic matter is an indicator of soils quality, influencing nutrient availability, water drainage and color [12], and low values are typical for Portuguese soils [11]. Our values were on average in accordance with another study [13], where OM values of 8 different Rocha pear orchards located in the West region of Portugal, varied between 2.46% to 4.68%, with only one sample from our parcel being outside this range. Regarding soils color, in general, L parameter indicated soil samples with a predominance of darker color (less brightness), a slight contribution of red (a*) and yellow (b*). This tendency increased after OM removal, except for L parameter, and on average, a* had a higher difference than b* parameter. This indicates that OM contributes to the color of soils, being in accordance with other authors [12] as previously mentioned, and its presence caused a decrease of a* and b* parameters, while L was not majorly affected.

Ion accumulation in soils varies with the application of fertilizers and evapotranspiration processes. Additionally, soils with higher salinity values could lead to an increase of energy spent by plants for water absorption, and consequently influence nutrients absorption and transport [14]. The EC values from this field were inferior to 600 $\mu S\ cm^{-1}$, being in accordance with the recommended value for orchards with these trees (pomeids) [11]. Overall, pH values were between 6–8 (except 3 values) which is an adequate interval for agricultural practices [15] since most nutrients are easily absorbed by vegetation. However, Ca and S tend to be less available at a pH of 5 or lower. Although the same can also occur for K, for this nutrient and P, their availability also decreases for higher values of pH [16].

Plants appropriate development and growth can be related to 17 elements, that can be acquired from soils, and P, K, Ca and S are required in larger quantities [17]. When considering these four elements, and their usual content in soils, literature [18] indicates a prevalence of K (0.2–3%) and Ca (0.2–1.5%) in comparison to P and S (0.01–0.1%), with our soil values (Figure 3) being in accordance with these proportions. In soils, organic compounds can comprise P and S, while Ca and K, are a part of inorganic particles [16]. The higher value of K in soils can be related to its capacity of adsorption to soil particles, resulting in a reserve and thus, remaining available for plant absorption since it is not easily leached [16]. However, at higher concentrations, this nutrient has an antagonist impact on the absorption of two other cations, namely Mg^{2+} and Ca^{2+} [19]. As previously mentioned, Ca is the third most important mineral in soils [3], therefore being a common soil mineral, with dolomite, calcite and gypsum being indicated has the main source of this mineral [20]. The decline of S content in soils can be associated with the decrease of its content in fungicides, fertilizers, pesticides and industrial activity (SO_2 emissions) [21]. In soils S content fluctuates, cycling between organic (95%) and inorganic forms, from which sulfate (SO_4^{2-}) presence accounts for less than 5% of total S in soils [17,21]. Phosphorus scarcity in agricultural soils is also increasing, however like K and nitrogen (N) (accordingly NPK fertilization), these nutrients are crucial for crops to reach their reproductive stage, with P and N revealing a synergetic interaction and having had a crucial role in food productivity increases [17]. Phosphorus (HPO_4^{2-}, $H_2PO_4^{-}$) S (SO_4^{2-}), Ca (Ca^{2+}) and K (K^+) are acquired by plants in their ionic form [17,18].

For plants, the adequate proportion of elements should pass by K > Ca > P > S [16], and regarding mineral content in pear fruits, K is present in larger quantities in comparison to P and Ca [22], with the same tendency occurring for our data (Figure 3). These results can not only be related to absorption and translocation processes, and hence mobility in plants, but also physiological functions of these minerals. In plants, Ca and S are classified as immobile, while K and P are classified as mobile [16], and although K is present in larger quantities in the phloem, it is also present in the xylem, whereas Ca mobilization to fruits is mainly associated with the xylemic tissues [23]. Both function as cofactor for enzymes, with Ca performing not only structural roles, but also functioning as a secondary messenger, while K influencing cell turgor and electroneutrality [16]. During early stages, mineral apport to fruits is done via the xylem, but with maturity, photoassimilates transport via the phloem increases. Thus, Ca content in fruits tends to be dependent of early stages, remaining stable or even slightly diminishing, while mobile ions such as K^+ and HPO_4^{2-} are transported to the fruit during all growing season (via xylem and phloem) [24]. Phosphorus is also a component of enzymes, cell membranes and other macromolecules such as nucleic acids, thus being involved in energy production (ATP and ADP), photosynthesis and carbohydrate metabolism [16,17]. Sulfur is involved in amino acids (being a part of two) and proteins synthesis, and plants can acquire it not only from soils but also by leaves [16]. Thus, S translocation to protein synthesis places such as fruits as glutathione is also reported [16].

5. Conclusions

Considering this parcel`s characteristics, no major limitations were identified, deeming it adequate for the implementation of a foliar spray workflow. The presence of organic matter influenced colorimetric parameters of soils. The results further showed, no constraints to nutrient absorption due to the presence of an adequate irrigation system, no necessity of additional energy spent by trees during nutrient absorption from soil, and pH values adequate for nutrients availability. Hence, not arising concerns with water limitations or salinity during nutrient absorption by roots. The mineral values from the soil and fruit were in accordance with literature, and availability, interactions, transport and physiological functions contribute to their proportions.

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