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EFFECT OF AIR CONTENT OF SOIL ON AVOCADO TREE WATER STATUS AND GROWTH

R. Ferreyra[1], G. Selles[2], P. Maldonado[1], J. Celedón[1], P. Gil[1], C. Barrera[1] and A. Torres[1].

[1] Instituto Investigaciones Agropecuarias, Centro Regional V Región, Chorrillos 86, La Cruz; Chile. Correo electrónico: rferreyr@inia.cl
[2] Instituto Investigaciones Agropecuarias, Centro Regional La Platina. Santa Rosa 11610, Santiago, Chile. Proyecto financiado INNOVA- CORFO

Avocado trees evolved in andosol soils, which are considered the optimum type for tree growth due to their physical properties, mainly low bulk density (0.5 – 0.8 g cm^{-3}) and high macro porosity (approx. 46%). In Chile, avocado plantations are mostly located in fine textured soils, with bulk densities between 1.3 and 1.5 g cm^{-3} and macro porosities below 20%. Due to these soil conditions, severe problems of poor root aeration are observed, which in part may reduce production levels of the crop. The objective of this research was to study the effect of soil aeration in the root zone on avocado water status. The ultimate goal of this study was to generate information for developing irrigation management strategies for avocado orchards that optimize both air and water distribution in the soil.

The study was conducted during the 2004/05 production season. Two-year-old 'Hass' trees on Mexicola rootstock were used for the study. The treatments were T0: loam soil; T1: sandy soil; T2: sandy loam soil; T3: clay loam soil. Results showed that air levels in soil between 5% and 18% affected stomatal conductance but not stem water potential. Soil air content below 17% reduced the oxygen diffusion rate below 20 µg cm^{-2} min^{-1}, which is the threshold value for normal avocado tree development. In addition, macro porosity and ethylene content, and O_2 and CO_2 in the soil atmosphere were correlated.

Keywords: Aeration, avocado, stomatal conductance, steam water potential.

EFECTO DEL CONTENIDO DE AIRE EN EL SUELO EN EL ESTADO HIDRICO Y DESARROLLO DEL PALTO

R. Ferreyra[1], G. Selles[2], P. Maldonado[1], J. Celedón[1], P. Gil[1], C. Barrera[1] y A. Torres[1].

[1]Instituto Investigaciones Agropecuarias, Centro Regional V Región, Chorrillos 86, La Cruz; Chile. [2]Instituto Investigaciones Agropecuarias, Centro Regional La Platina. Santa Rosa 11610, Santiago, Chile. Proyecto financiado FDI.

El palto en sus orígenes se desarrolló en suelos andisoles, los cuales se consideran como óptimos para su crecimiento debido a las propiedades físicas que presentan, baja densidad aparente (0,5-0,8 g cm^{-3}) y alta capacidad de aire, (alrededor del 46%). En Chile las plantaciones de palto están ubicadas principalmente en suelos de textura fina con densidades aparentes entre 1,3 a 1,5 g cm^{-3} y con capacidad de aire, inferiores al 20%. Debido a lo anterior, se presentan serios problemas de asfixia radicular, situación responsable en gran medida de los bajos niveles de producción que presenta esta especie. El objetivo de este trabajo fue generar información que permita optimizar la relación aire – agua en el suelo a través del conocimiento del efecto que tiene la macroporosidad del suelo en el estado hídrico y crecimiento del palto.

El ensayo se llevó a cabo durante la temporada 2004-05. Las plantas utilizadas fueron paltos, variedad Hass, sobre patrón Mexícola, con dos años de edad. Los tratamiento fueron T0: suelo franco; T1: suelo arenoso; T2: suelo franco arenoso y T3: suelo franco arcilloso. Se pudo establecer que niveles de aire en el suelo inferiores a 17% afectaron la conductancia estomática, pero no el potencial hídrico xilemático. Que un contenido de aire en el suelo inferior al 17% limita la tasa de difusión de oxígeno bajo 20 µg cm^{-2} min^{-1}, valor que afectó el desarrollo del palto. Por otra parte se obtuvieron relaciones entre la macroporosidad y el contenido de etileno, O_2 y CO_2 en la atmósfera del suelo.

Palabras clave: Aireación, aguacate, conductancia estomática, potencial hídrico xilemático.

1. INTRODUCTION

The Avocado productivity, under favorable environmental conditions, can be kept over 22 tons/ha (Whiley et al. 1988). In Chile, there are some orchards able to keep stable productions of approximately 25 tons/ha, however, the average productivity of adult orchards is about 9 tons/ha.

Originally, the avocado tree grew in Andisoils, soils derived from volcanic ashes. These soils provide the optimum conditions for avocado growth due to its physical properties, low bulk density 0,5-0,8 g/cm3, high macro porosity, 46%, high content of organic matter and soil pH between 5 and 6 (Aguilera et al. 1991). In chileans orchards, the avocado plantations grow mainly on fine textured soils, Alfisoles, with bulk densities ranging from 1,3 to 1,5 g cm^{-3} and low macro porosity of approximately 15%.

Although the avocado tree originally grew in soils with high macro porosity (Andisoils) and high rain fall, the roots are shallow, extremely suberized with very low hydraulic conductivity, low frequency of root hairs, high demand of oxygen and poor water intake. Due to this, when there is a lack of oxygen, even for short periods, this will derive in inhibition of leaves expansion, reduced roots and shoots growth, root necrosis, and a moderate to severe leaves abscission (Stolzy et al. 1967, Schaffer et al. 1992).

Other stress factors that have an influence on the low productivity of avocado trees, are alternate bearing, salinity, fertility, etc. but, above all, the wrong management of irrigation combined with a limited soil, are the most important factors that determine productivity of this crop. The above mentioned problem could be faced by using rootstocks tolerant to low soil air content and irrigation management techniques which optimize the air / water relation in the root zone. However, currently there is no information available indicating the way in which the existing different rootstocks perform when facing this problem. They have only been evaluated considering other aspects, such as *Phytophthora* and salinity resistance. Something similar occurs with the techniques to optimize the water / air relationship in the soil.

Due to this, the purpose of this paper is to generate information that may allow the optimization of the air / water relationship in the soil to improve the productivity of the avocado (*Persea americana* Mill), with the improvement of irrigation management, specifically according to the oxygen diffusion levels and macro porosity, where the water status and growth of the plant is affected.

2. MATERIALS AND METHODS

This work is part of a research presented at ActaHorticulturae, Ferreyra et al., 2007 (in press).

Experimental se up. The experiment was carried out during the 2004-2005 season, in Limache, V Region (32º59') lat. S, 71º16' long. W. The plants used were Avocado trees (*Persea americana* Mill), var. Hass, grafted on two years old Mexicola rootstocks. The trees were planted at a distance of 2 by 2 m, in 50 liters black polyethylene pots. The plants were watered by dripping, with one 4 l/h station per plant. Irrigation was managed with high frequency, with 6 pulses per day so as to keep the soil near field capacity.

Treatments. Plants were placed in four soils of different texture, each one corresponding to a treatment. T0: Pot with loam soil, (F); T1 Pot with sandy soil. (a); T2: Pot with loam soil and sand. (Fa); T3: Pot with loam soil and clay (FA). The experimental design was completely randomized, with four treatments and six repetitions per treatment.

Measurements.

- Soil air content and soil physics. The total porosity of the soil was obtained using the methodology described by Danielson et al. (1986) and the bulk density of the soil through the cylinder method. A description of porous space at field capacity was done according to Ball et al. (1991); The variation of air contents in the soil were obtained through the difference between the total porosity and the volumetric content of humidity of the soil (Gur et al. 1979, Ferreyra et al, 1985). Soil moisture was measured weekly with a Frequency Domain Reflectometry (FDR), Diviner 2000, at 20 centimeters depth.

- Plant Water status. The stem water potential (SWP) was measured using the pressure chamber method in covered leaves (Schakel et al. 1997) These measurements were carried out in three leaves per plant at midday (2:00 p.m.) twice a month, between December and January. Stomatal conductance of the leaves (gs) was determined using a steady state porometer, the Li-Cor LI-1600. Measurements were carried out weekly on three leaves per plant at midday (2:00 p.m.).

- Oxygen diffusion rate and soil atmosphere. The oxygen diffusion rate (ODR) was measured using a platinum electrode, in accordance with the methodology developed by Letey et al (1964), at the end of the season. The soil atmosphere was sampled through "point-source soil atmospheric sampler", in accordance with the methodology described by Staley (1980). With this purpose, a tube was inserted in each pot, 30 cm deep. Samples were taken at the beginning of March and were analyzed by means of gas chromatography for oxygen, carbon dioxide and ethylene.

Leaf area index (LAI): The measurements of LAI were made with a light interception sword PAR.

Analysis de data: The results were analyzed statistically through ANDEVA and to obtain separately the average mean, multiple comparison tests were applied. Data were analyzed with the statistical package SAS (SAS Institute, Cary, North Carolina, USA).

3. RESULTS AND DISCUSSION

Soil air content. The variation of soils air content (Ea), during the irrigation season, is shown in table Nº 1. The Ea of the four treatments diminishes slowly during the season, being the loam soils (T0, T2 and T3) the ones with lower values (16.61, 22.67 and 18.01%) compared with sandy soil (T1 with 32.43%). The Ea decreased until the beginning of October when it stabilized. All the treatments, except for T2, presented lower Ea than those found when soil was at field capacity. The loam soil (T0) showed during October an average Ea of 7,46% while the sandy loam soil (T2) a 20.44%; the clay loam soil (T3) a 14,36% and the sandy soil (T1) a 29,08%.

Effect of the air content of the soil over the plants water status

The effect of the air content of the soil over the plant water status was evaluated by means of Stem water potential (SWP) and Stomatal conductance (gs)

- Steam water Potential (SWP). Table 1 shows the SWP and Ea in the different treatments. In general, the SWP was more negative as the season went by. This could have been due to the effect of low vapor pressure values over SWP, however, the SWP values varied between -0.33 and -0.66 MPa, which indicate that the plants were not submitted to water stress. Ferreyra et al (2006) indicate that the SWP values during midday, for Hass Avocado Trees, with good supply of water, fluctuates between -0.4 and -0.5 Mpa. Sterne et al. (1977) point out that the stomatal closure, for Bacon variety, occurs when it reaches a SWP of -1.2 MPa. At the same time, Bower et al. (1978) indicate that in the cv. Edranol, the stoma closes when SWP is of -0.9 MPa. As it was previously said, the plants were not submitted to water stress and the SWP was not affected by the different soil air contents.

- Stomatal (stomatal) Conductance (gs). The stomata respond to an important number of variables, including environmental as well as internal factors, that explain the complexes answers of plants to regulate water loses (Wiilams et al. 1994). Among these factors we can quote the water status of the plant (water potential); air vapor pressure deficit (DPV), air temperature, solar irradiation and abscisic acid in the leaves (Williams et al. 1994).

Table Nº 2 shows the average values of gs for the periods with lower and highest vegetative growth. The gs values are lower when the vegetative growth decreases and are higher during the period of greater growth, this could be attributed to an increase of demand of assimilates by the plant during this stage. Studies carried out by Ferreyra et al. (2002) indicate that in peach trees the gs trend was to increase during the phase of greater growth of the fruit (phase III) compared to previous stages. This could be attributed to a larger demand of assimilates by the fruits itself, which would stimulate a greater stomatal conductance (gs).

The average gs found in sandy soils, with an average Ea of 29%, is 0.43 cm s^{-1}, while in loam soils with an average Ea of 7.38%, gs decreased to 0.19 cm s^{-1}. Scholefield (1980) reported values for gs measured at similar hours to those of this trial, between 0.22 and 0.28 cm s^{-1} with SWP -1.3 Mpa. The effect of Ea over gs and not over SWP must be due to the fact that the stomas respond to the water state of the plant as well as to the environmental variables, like non hydraulic signals coming from the root system, which can be associated to the generation of abscisic acid, ABA (Glenn, 2000). The results obtained in SWP and gs, are in agreement with those given by Schaffer et al. 1992, that indicate that the reduction of evapotranspiration caused by the excess of water in the soil, is probably the result of a reduced stomatal conductance instead of a hydraulic effect.

The sensibility of the avocado tree to hypoxia conditions and to water deficit compared with other fruit trees, has been partially explained as a series of physiological replies that occur very fast after the soil is saturated or dried, caused by a possible hormonal unbalance that involves abscisic acid (ABA) (Sterne et al, 1977, Bower et al. 1978, Scholefield et al., 1980 and Schultze, 1986). However, recent publications indicate that the physiological answer to sub-normal conditions of water availability can be caused by reduction of the stomatal conductance and to CO2 partial pressure within the intercellular space of the leaves, in accordance with the studies of Ploetz y Schaffer, (1989), Shaffer et al., (1992) y Schaffer y Whiley, (2003).

<u>Effect of the air content of the soil over Oxygen diffusion and the concentration of gases in the soils' atmosphere.</u>

<u>- Effect of the air content of the soil over the diffusion of Oxygen.</u> The sandy soil (T1) registered a superior oxygen diffusion rate (ODR) in an 80% more than the loam soils (T0, T2 and T3) (Table 2), which presented values lower than 0,2 µg $cm^{-2}min^{-1}$. Other studies have shown that the roots of certain varieties of avocado trees, such as Scott, Duque, and Topa Topa, did not grow when the oxygen diffusion rate was less than 0.20 µg $cm^{-2}min^{-1}$ (Valoras et al. 1964). On the other hand, Stolzy et al. (1967) informed that avocado plants of the Mexicola variety, which grow in soils with an oxygen diffusion rate lower than 0. 17 µg $cm^{-2}min^{-1}$, had their root systems

damaged between 44% to 100%. The loam treatments (T0; T2 and T3) were under this limit, which is in accordance with the differences found in gs, Table 2, shows what values of ODR of 0.20 µg $cm^{-2}min^{-1}$are obtained when Ea is of approximately 17%.

<u>- Effect of the air content of the soil over concentration of gases in the soils' atmosphere.</u> In Table 3, it can be observed that in sandy soils (T1) the concentration of CO_2 is lower than in loam soils (T0, T2 and T3). The percentage of CO_2 in sandy soils, did not surpass the 0,5% while in loam soils this value was higher than 1%. Menge et al, (2000) indicate that concentrations of about 0,03% of CO_2, are found in well drained soils, what favors the growth of the avocado tree, while the poorly drained soils can present levels close to a 16%. The percentage of O_2 in sandy soils (T1), was approximately 20%, while in loam soils this vale was lower than 10% (Table 3). Studies performed by Valoras (1964) indicate that plants growing with oxygen levels of less than 1%, will wilt and die (dry). With a 5% level of O_2, the plants can survive but at the same time they show burns on the tip of the leaves. This was also confirmed by Stolzy et al., (1967) who indicate that at Oxygen levels lower than 5%, in the soil might damage and kill the root of avocado trees.

<u>- Effect of the soil air content in the vegetative growth of avocado plants.</u>
Table 3 shows the effect of treatments in the growth of avocado plants, expressed as Leaf Area Index (LAI), where is possible to see that plants that grew in soils with more than 29% of air, they presented a greater LAI than plants that were developed in soils with air content equal or minor that 22%.

4. CONCLUSIONS

- Decrease of the air content in the soil's atmosphere, within the studied ranges, affect the stomatal conductance of plants , but not the stem water potential.
- With air levels in the soil between 7% and 22%, avocado plants present a stomatal conductance of around 0.23 cm s^{-1} and with air levels in the soil higher than 29%, the stomatal conductance increases to values of around 0. 43 cm s^{-1}
- Avocado plants in soils with macro porosities of 29.87%, show a larger stomatal conductance than plants in soils with macro porosities of 14,1 and 17,3%.
- Air content values in the soil lower than 17%, limits the diffusion rate of Oxygen under 20 µg $cm^{-2}min^{-1}$, which would affect avocado tree growth.

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6. TABLES AND FIGURES

TABLE 1. Effect of the soil air content in the steam water potential. Different letters indicate significant differences (ANOVA, Tuckey's ttest α=0.05

Date	**6-12-04**	**10-12-04**	**26-1-05**	**13-2-06**	**7-3-06**
Treatment	SWP (MPa)				
T0	-0.34 a	-0.54 a	-0.51 a	-0,98 a	-1,08 a
T1	-0.37 a	-0.57 a	-0.49 a	-0,52 a	-0,79 a
T2	-0.36 a	-0.34 a	-0.55 a	-0,63 a	-0,95 a
T3	-0.33 a	-0.48 a	-0.66 a	-0,60 a	-1,12 a

T0= Loam; T1= Sandy; T2= Loam sandy; T3= Clay loam

TABLE 2. Effect of the soil air content in the stomatal conductance (gs). Different letters indicate significant differences (ANOVA, Tuckey's test α=0.05

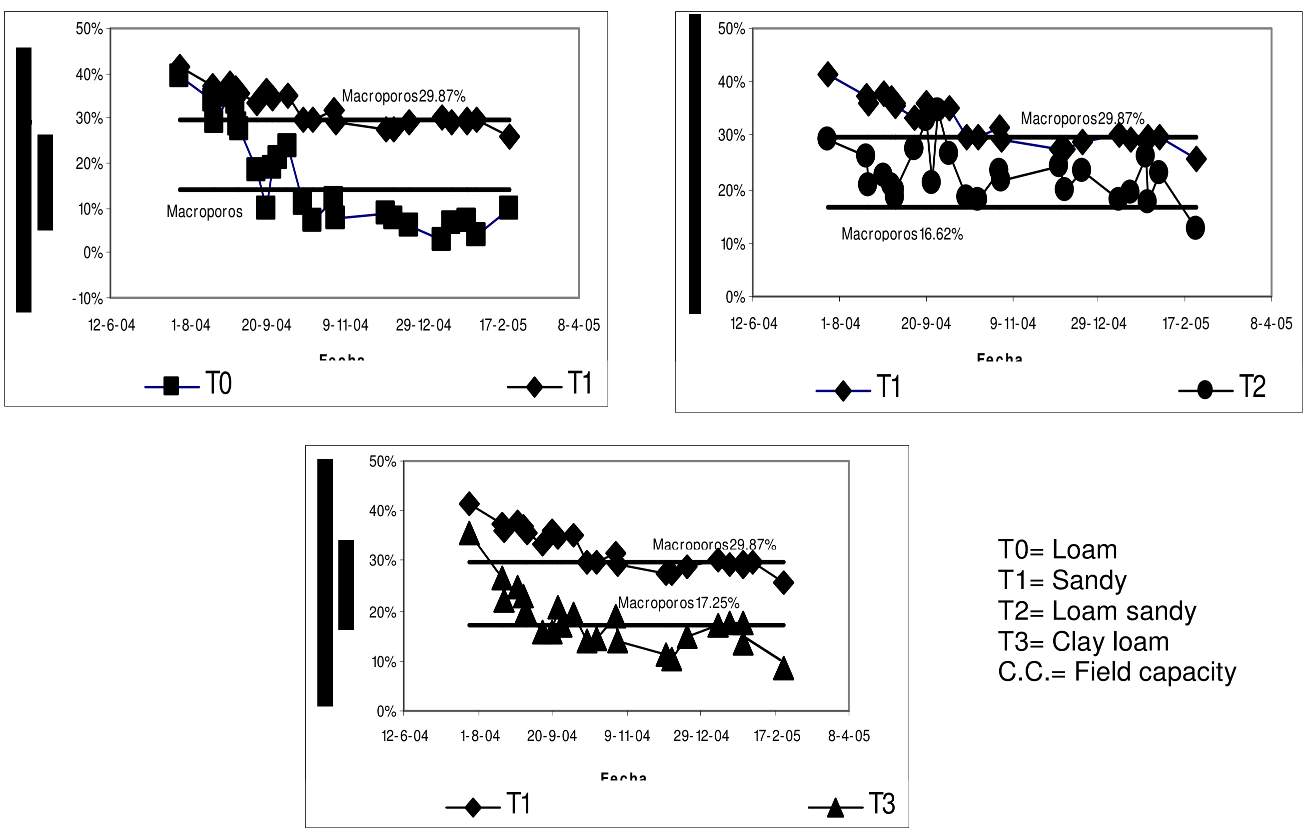
Date	**26-1-05**	**4-2-05**	**7-3-06**	**30-1-06**	**6-2-06**	**7-3-06**
Treatment	**Gs (cm s^{-1})**					
T0	0,27a	0,1a	0,05 a	0,15 a	0,23 a	0,05 a
T1	0,72b	0,41b	0,50 b	0,90 b	0,72 b	0,50 b
T2	0,27a	0,21ab	0,28 ab	0,65 b	0,47 ab	0,28 ab
T3	0,30a	0,19ab	0,16 ab	0,54 ab	0,37 ab	0,16 ab

T0= Loam; T1= Sandy; T2= Loam sandy; T3= Clay loam

TABLE 3. Effect of the soil air content in growth of avocado plants expressed as Leaf Area Index (LAI) Different letters indicate significant differences (ANOVA, Tuckey's test α=0.05

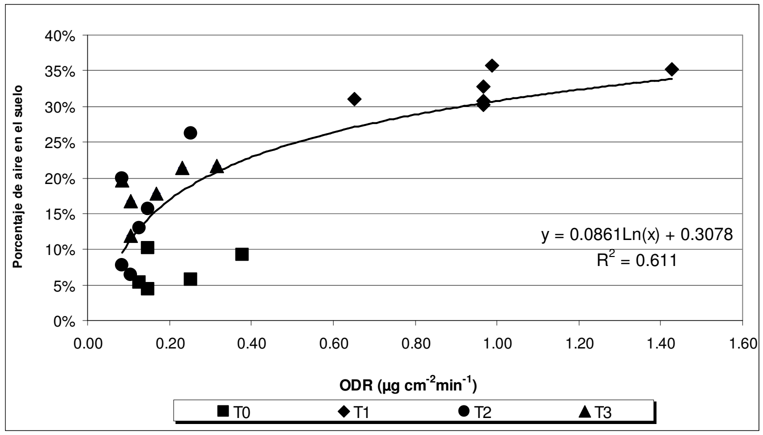
Treatment	LAI
T0	1,70 a
T1	4,74 b
T2	2,93 ab
T3	3,44 ab

T0= Loam; T1= Sandy; T2= Loam sandy; T3= Clay loam



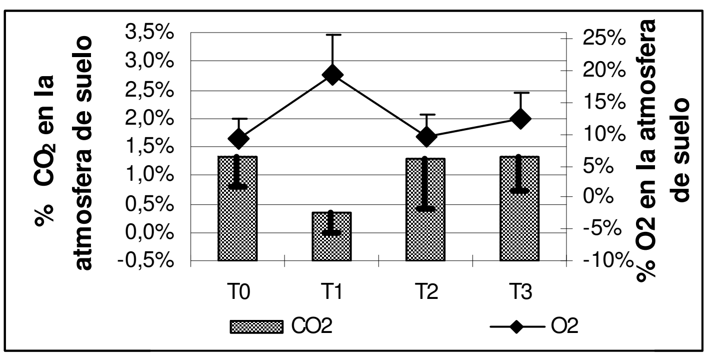
T0= Loam
T1= Sandy
T2= Loam sandy
T3= Clay loam
C.C.= Field capacity

FIGURE 1. Changes in the soil air content (% volume base), during the experimental season in all treatments.



T0= Loam; T1= Sandy; T2= Loam sandy; T3= Clay loam

FIGURE 2. Relation between Oxygen Diffusion rate (ODR) and the air content of the soil (Ea).



T0= Loam; T1= Sandy; T2= Loam sandy; T3= Clay loam

FIGURE 3. CO_2 and O_2 concentration of the soil atmosphere in all treatments. Vertical lines show Standard deviation.