CITRUS SOIL MANAGEMENT CAN REDUCE THE DETERIORATION OF SOIL CONDITIONS AND IMPROVE SUSTAINABILITY PRODUCTION

C. Goñi and A. Otero cgoni@sg.inia.org.uy, aotero@sg.inia.org.uy

National Institute of Agricultural Research. Salto-Uruguay

Abstract

Long term traditional herbicide uses for soil management brings soil compaction, crusting, poor infiltration and week rooting trees, leading to orchard deterioration and poor soil sustainability. The amelioration of the soil properties and plant growing condition was evaluated on a young rainfed citrus orchard of Valencia late (NVA 036) grafted on *Poncirus trifoliate* rootstock during three years, planting on an Argisol Districo Ocrico soil. A combination of organic mulch (rows) and sod cultivation (between rows) were applied. A 75 cm wide row with two organic mulch sources was used: a) composted Eucalyptus wood chip (52 kg m^{-2}) with a C/N ratio of 1.5, and b) commercial compost (30 kg m^{-2}) with a C/N of 10. Between row treatments sod consisted in a) *Ornithopus compressus*, and b) *Lolium multiflorum*. The traditional herbicide application in the row and the spontaneous vegetation between rows were the control. Soil organic matter, nitrogen mineralization potential and soil biomass have not changed in the row for the first 4 years. However, the use of mulch significantly reduces the amplitude of soil temperature, at the 15 cm depth and holds up soil water availability more time than the herbicide application. During summer drought, stem water potential of the trees under mulch varies between -1.4 to -2.2 MPa compared with the - 3.5 to -3.8 MPa with the herbicide. Sod dry matter accumulation was variable between years, and has not significant effect in the physical and chemical properties to the present. Mulches have generated better tree growing conditions than the herbicide, resulting in significant increments in tree vigor, precocity, and yield. Wood chip mulch has increased 42% the accumulated crop yield, enhances fruit color and reduced the need of weed control. Mulch application seems to be a promising soil management measure for citrus young trees in this soil and climate conditions.

Keywords: citrus soil management, wood chip mulch, sod cultivation

Introduction

Since de 1980s, most fruit growers have maintained orchard drive lanes with mowed sod grass and treated tree rows with herbicides to suppress or eliminate weeds. However, this soil management has caused sign of erosion in the row and interrow area with thickness loss of the superficial horizon, the presence of a week root system and low water infiltration. The systematic weed control with herbicide has a deleterious effect in the soil structural stability and, in addition, it has begun to observe weed resistance problems. These soil management consequences have been observed in the northwest citrus production area of Uruguay. National regulations are pushing growers to adopt remediation solutions. Environmental compulsory certification for overseas market has increasing the expand concerns about the soil traditional management limitation and the expected loss in the crop sustainability (1). Despite the new available soil improvement management technic in modern citrus production, not all the measures are always easily practicable in established orchard. Conservational tillage systems minimize soil disturbance and maintain 30% cover with surface residue (2). Researchers reported that groundcover management system affect tree soil chemical, biological and physical properties (3), (4), (5) as well as differential effect in the tree growing root zone and soil microbial communities (6), (7). The use of mulch improves productivity in citrus mandarins and blueberries (8), (9) and in ornamental bushes (10) generating best conditions to plants (11). Surface mulch is probably an important mean for modifying soil temperature with plant residues (12); although in mulched soil can occur nutrient immobilization (13). Even with the advantages and disadvantages cited, they have been poor investigated in Uruguay. The aim of this work is to improve the actual soil management practices used and to investigate the effect of groundcover and mulch in the soil quality and the sustainability of the citrus crop production.

Material and Methods

The trial has conducted in a rainfed young orchard of Valencia [*C. sinensis* (L.) Obs.)] NVA 036 grafted on *P. trifoliate* (L.) Raf. The experimental site is a commercial orchard located in the northwest of Uruguay (32º S, 58º W), with an annual rainfall mean of 1300 mm, without a clear rainy/dry season. The soil is sandy loam with a total 80 cm depth, with a bulk density of 1.71 g cm^{-3}. The field capacity average (-0.01 MPa) and the wilting point (-1.5 MPa) are 0.10 m^3 m^{-3} and 0.08 m^3 m^{-3} within the 40 cm topsoil. At the beginning of the experiment, the soil nutrient availability was very low, with 5.5 pH, organic carbon in the range of 3.4 g kg^{-1} , P less than 20 µg P g^{-1} and K 1.1 mmol$_c$ dm^{-3} . The orchard was planted in 2008 with a tree spacing of 2 m within row by 6 m across row, resulting in a tree density of 833 trees per hectare. Soil preparation before planting was the common in the area and trees were placed on a ridge with a height of 50 cm. A combination of mulch application in the row and sod cultivation in the alley was used as treatments. The treatments included two types of groundcover and organic mulch. *Ornithopus compressus* and *Lolium multiflorum* were sawing alone as a legume and graminae at a seed density of 35 and 20 kg ha^{-1} respectively in between rows tree. The effect of the legume and graminae was compared with the spontaneous growing vegetation. A composted eucalyptus chip mulch at 52 kg.m^{-2} with a 1.5 C to N ratio and commercial compost with a 10 C to N ratio at a rate of 30 kg.m^{-2} were evaluated. All mulches were applied in a 75 cm strip at both side of the tree. Treatments were: 1) Composted Eucalyptus chip mulch + *Lolium multiflorum,* 2) Composted Eucalyptus chip mulch + *Ornithopus compressus,* 3) Commercial compost + *Lolium multiflorum,* 4) Commercial compost + *Ornithopus compressus,* and 5) Control, the natural spontaneous vegetation in the alley and the tree row managed with herbicide. Other mulch options were compared as observation plots like wheat straw, rice husk and a geotextil.

Fertilizer applications were made every year to the trees based in leaf and soil analysis. Phosphorus and potassium fertilizers were split three times a year during the first two years and nitrogen two times. Fertilizers had included a slow release nitrogen 26-0-0 (Entec), phosphorus (0-20-20-0) and potassium (0-0-60). To favor the groundcovers implantation the alley soil was fertilizer with N and P. The rest of the orchard management follows the standard practices of the area. Soil temperature, soil water content, nutrient availability, soil penetrometer resistance and weeds area cover were periodically measured. On the trees, it was evaluated the nutritional level, plant water potential (xylem), stomata conductivity, annual tree growth (trunk cross sectional area, and canopy volume), fruit yield and fruit quality.

Measurements in the soil: Soil samples for chemical analysis were taken at two depth 0-20 and 20-40 cm every year after harvest time. Samples were sent to the INIA-LE soil laboratory and analyzed by standard methods for nitrogen mineralization potential, organic C, particulate organic matter < 53 mm, and total soil biomass. To access soil strength a cone penetrometer (DIK 5520, Japan) was used in every plot up to 25 cm in the alley side in a perpendicular line to the row. The reading was taken every 40 cm from tree to tree. Four replications per alley treatment were used. Soil temperature was recorded every 5 minutes on the first 15-20 cm depth with a RT-1temperature sensor (Decagon Devices, USA) and the volumetric soil water content was recorded at 20 cm depth with an ECHO10 sensor (Decagon Devices, USA). Soil temperature and volumetric soil water content were measured in every treatment combination. Weed covered area was evaluated four times during the year with a degree scale 0 to 4 (0= less than 25% of the plot area cover by weeds, and 4 = > 75 to 100% of the plot area cover by weeds).

Measurements on the tree: Plant nutrient availability was measured by leaf mineral analysis of a composed 100 leaf sample per plot, taken from a non fruiting shoot on spring shoot 6 to 9 month old. Leave samples were analyzed for macro nutrients. Nitrogen was determined by Kjeldahl, potassium, calcium and magnesium by atomic absorption spectrophotometer. Tree water status was estimated through the stem (xylem) water potential (14). Three leaves per tree from two trees per plot treatment were bagged with black polyethylene envelopes and covered with aluminum foil and stabilized for three hours before readings prior to measurement (Ψstem).

A portable Scholander type pressure chamber (DIK 7000-Japan, (15) was used to measure the stem water potential. Leaf stomata conductivity (gs) was measured in four leaves on two trees per plot treatment in a non wind days from 9 to 10 am with a leaf porometer (AP4 Delta T, UK). Efficiency of the leaf photosystem II (PSII) was accessed through the measurement of the quantum yield efficiency of the PSII (Yield), and the maximum quantum efficiency of the PSII (Fv/Fm). A modulated fluorometer (OS5 FL. Opti-Sciences, USA) was used to access the yield and the Fv/Fm test. Three leaves of two trees per plot were used to access the yield and Fv/Fm). For the Fv/Fm test the leaves were dark-acclimated for at least 0.45 h with leaf clips before the measurement. For yield test the leaves were at daylight. Saturation light intensity and duration were previously adjusted to these environmental conditions to reach saturation of the photosystem antenna. Fruit crop yield was expressed as total fruit mass per tree and number of fruits per tree. Fruit quality was measured by standard laboratory methods for total (16). Alternate bearing was evaluated using the instability index proposed by (17)). Tree trunk cross sectional area was recorder every year after harvest at a permanent marked height (15 cm above the rootstock).

The experiment: A randomized experimental plot design was set up with four replicates for each treatment. Each plot consisted of 6 trees in the row. Data were subjected to ANOVA. Means were separated by Duncan's multiple range test (DMRT) at $p<0.05$. Analyses were carried out using GLM procedure with SAS software (18).

Results and Discussion

Weather conditions. The experimental plants were subjected to contrasting water regime during the first establishment years. During the first year (2008-09), the plants suffered a severe drought stress during the summer season. In the next year (2009-10) plants got through the occurrence of an intense rainfall period during late spring and summer season. The annual rainfall and evaporation pan 'class A' from the beginning of the growing season to the next (from August to next August SH) were 738.5 mm and 2067 mm for 2008-2009, while during 2009-2010 were 1905 y 1735 mm respectively. The third year was drier again with 978.5 mm of rainfall and 1955.7 mm of evaporation.

Soil. Surface mulch is probably an important mean for modifying soil temperature with plant residues (12). In our condition, the addition of both type of mulch on the tree soil row has produced significant changes in the soil temperature at the 15 cm depth (Figure 1). Mulched soils had a smaller range between maximum and minimum daily temperature than the herbicide (Control). Mulch maximum mean temperature was 3 to 3.5 ˚C less than soil with herbicide. This decreasing effect was similar for winter and summer season. Modifications in soil temperature regimen directly affect not only root growing and development, but also net radiation balance in the soil surface (12).

Soil water refilling profile is very important in rainfed crops; differences between soil management practices make substantial improvements in a non irrigated crop like the present. In addition, to the soil temperature effect, mulched trees decelerated the soil water loss (Figure 2), increasing the incoming water in to the soil and maintained the soil water content to the highest values. No huge differences were evidenced between the mulch of Eucalyptus chip and compost. Both type of mulch has reduced slowly the soil water and in addition to more stable soil temperature environment, they generate a better water conservation practice than the herbicide bare soil.

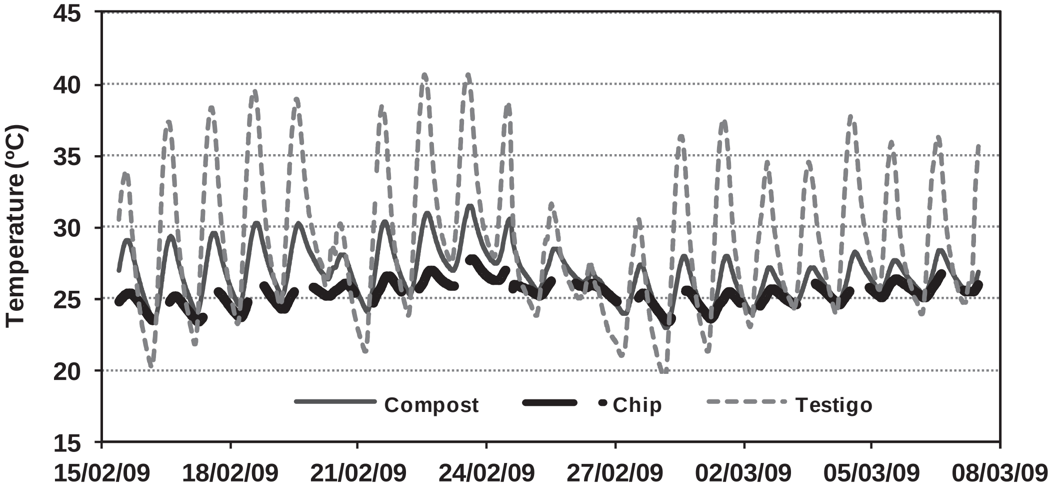

Figure 1. Soil temperature among the control and mulch treatments in the row area at 15 cm soil depth.

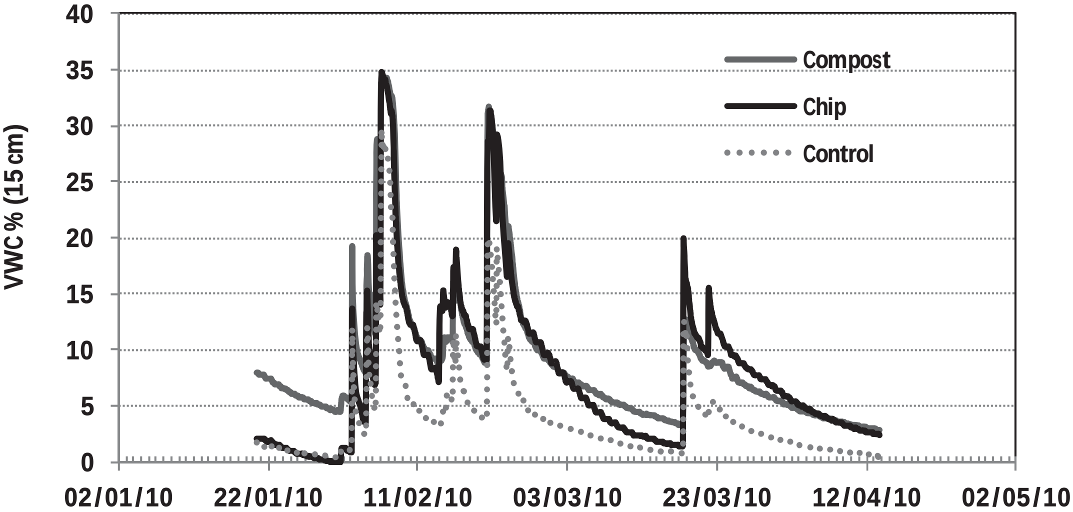

Figure 2. Volumetric water content evolution in the row area at 15 cm soil depth.

Sod cultivation treatments in the alley have not yet a consistent effect on the soil properties nor the plants. Sod dry matter accumulation was variable between years and it has not a significant effect in the physical and chemical properties to the present (table 1). Soil organic matter, nitrogen mineralization potential and soil biomass have not changed in the row area during these initial three years of treatments.

Nutrient released from sod residue mineralization was insufficient to produce significant changes in soil conditions. Residue mineralization may be recycled itself and was not available to the citrus trees mainly due to the low soil buffer capacity. However, root system effect in soil penetrometer resistance difference between sod species opens an interrogation on the long term effect (Figure 3-4).

Table 1. Mulch effect on the soil organic matter, nitrogen mineralization potential and soil biomass measured in the first 0 to 20 cm soil depth.

Soil nutrient availability					
		2008	2009	2010	2011
	0-20 cm		C. org g kg^{-1}		
Chip		3.4 ns	3.5 ns	6.1 ns	4.9 ns
Compost		3.4	3.5	5.9	4.8
Control		3.4	3.5	7.4	3.8
			NPM mg kg^{-1} N-NH$_4$		
	0-20 cm				
Chip		4 ns	6 ns	9 ns	9 ns
Compost		4	7	6	11
Control		3	6	12	14
			Biomass µg C g^{-1}		
	0-20 cm				
Chip		-	15.3 ns	-	18.2 ns
Compost		-	16.1	-	20.0
Control		-	14.9	-	16.3

Means in the columns followed by different letter are significantly different according to a Duncan's MRT ($p<0.05$). n.s. Non significant differences.

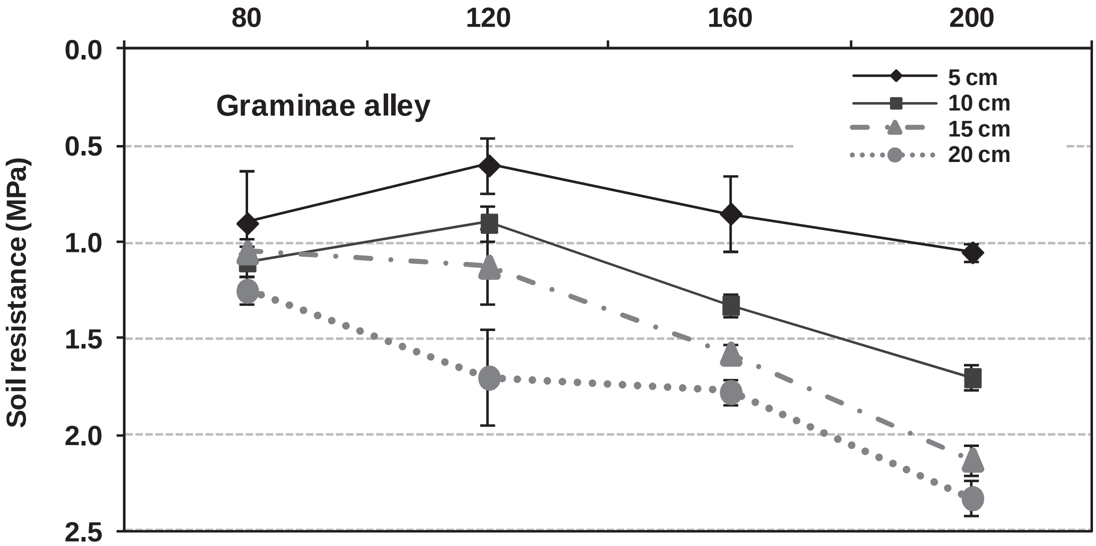

Figure 3. *Lolium multiflorum* effect on soil resistance measured perpendicular to the trunk distance in the interrow at the first 20 cm soil depth. Bar represents the standard error of the mean. n=4.

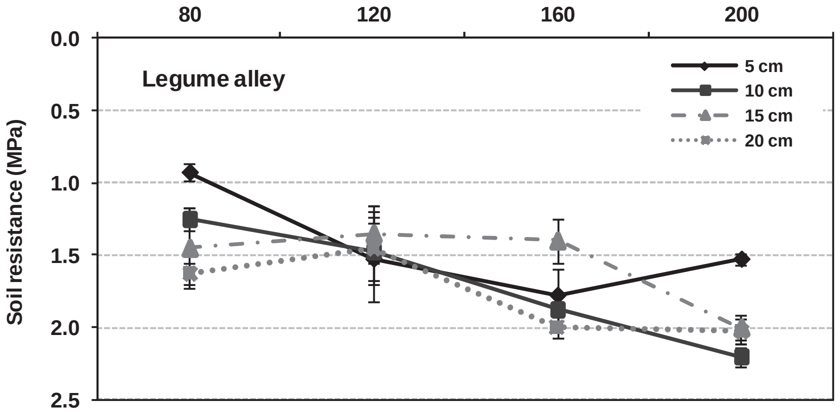

Figure 4 *Ornithopus compressus* effect on soil resistance measured perpendicular to the trunk distance in the interrow at the first 20 cm soil depth. Bar represents the standard error of the mean. n=4.

Plants. Mulches on to the tree row create better environment soil growing for the young citrus trees. The mulch effect is evidenced in the young citrus tree water status during a strong drought period. As expected, plant water potential varies among row treatments (mulches vs. herbicide). Herbicide treated trees (control) and compost mulch trees rolled their leaves and they maintained a moderate to severe defoliation during the period of drought stress. Trees with Eucalyptus chip mulch have a significant higher stem water (Ψ_{stem}) potential (Figure 5). Citrus trees without irrigation with chip mulch overcame the stress period with minor consequences. The observed water potential difference (Ψ_{stem}) between row treatments was complementary and consistent with the significant differences observed in leaf stomata conductivity (gs) during the whole day (Figure 6.). Mulches generally increase g_s to water vapor reflecting the improvement of soil water availability (10). Chip mulched trees delayed the closing of leaf stomata. The use of chip mulch probably generated a better root development (hypothesis to confirm) and more favorable conditions to C assimilation (A_{CO2}) which may explain the best results obtained on yield with chip mulch. Trees subjected to water and temperature stress may have reduced photosynthetic capacity and restricted carbohydrate supply for growth (19). The chlorophyll fluorescence analysis of the photosystem II (PSII) gave us a clue to this point (Figure 7). The chlorophyll fluorescence parameter Fv/Fm represents the maximum efficiency of the PSII, and it is very sensitive to any oxidative stress which is usually associated to drought or heat stress. Leaves of chip mulched trees were the most efficient. Chlorophyll maximum quantum efficiency (Fv/Fm) is significant higher than the control and composted mulch tree treatments.

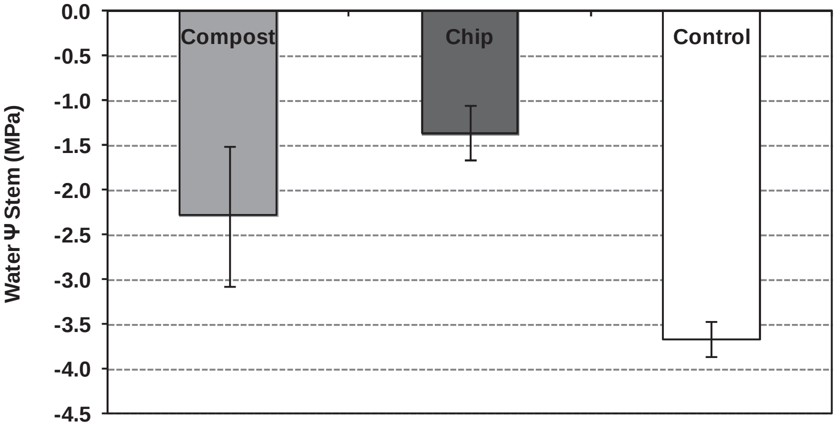

Figure 5 Stem water potential (Ψ_{stem}) between mulch treatments during a severe drought stress period (December 2008). Bar represents the standard error of the mean.

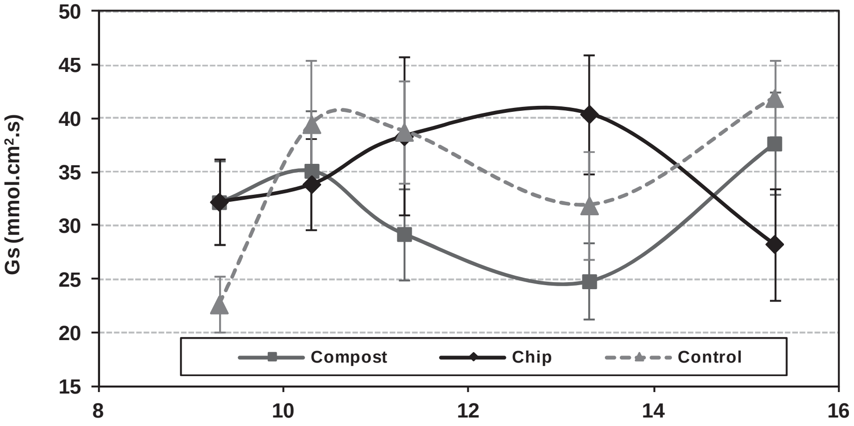

Figure 6 Leaf stomata conductance (gs) during a typical summer day. (December 2010) Bar represents the standard error of the mean.

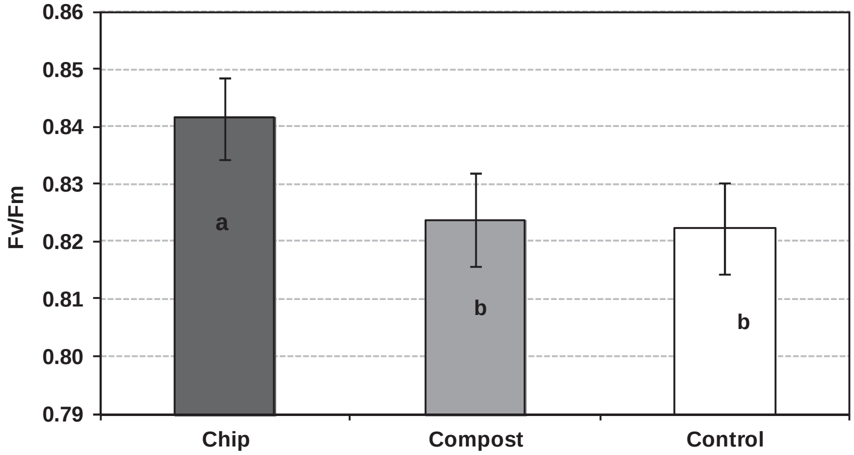

Figure 7 Maximum quantum efficiency of the photosystem II between mulch treatments. Bar represents the standard error of the mean.

Most short term studies in orchard soil management have shown that treatments involving mulches to suppress tree row weeds led to increase tree growth, fruit yield during the first year after planting compared to weedy treatments (3), (8). In our conditions the use of mulch has generated better tree growing conditions (tree vigor, precocity, and yield) than the herbicide control (table 3-4).

Table 3. Effect of mulch treatments in yield components and instability index (2008-2011).

	Yield kg.pl^{-1}			Cumulative	Instability
	2008-09	2009-10	2010-11	Yield kg.pl^{-1}	Index
Chip	5.9 a	16.0 a	20.26 a	41.36 a	0.42 ab
Compost	4.0 ab	11.4 b	14.67 b	29.38 b	0.37 b
Control	2.3 b	10.7 b	15.68 b	29.07 b	0.44 a

Means in the columns followed by different letter are significantly different according to a Duncan's MRT ($p<0.05$). n.s. Non significant differences.

Table 4. Effect of mulch treatments in yield components (2008-2011).

	Fruit number			Fruit wt (g fruit^{-1})		
	2008-09	2009-10	2010-11	2008-09	2009-10	2010-11
Chip	35 ns	79 a	124 a	171.8 a	204.7 ns	160.9 ns
Compost	30	58 b	92 b	131.5 b	196.0	163.5
Control	16	55 b	88 b	139.0 b	194.7	178.8

Means in the columns followed by different letter are significantly different according to a Duncan's MRT ($p<0.05$). n.s. Non significant differences.

Eucalyptus chip mulch has increased 42% the accumulated crop yield, enhances fruit color (data no shown) possibly to the soil temperature reducing amplitude. Leaf mineral nutrient concentration has not change during the first two year. This suggests that nutrient status was predominantly influenced by the annual fertilization rate rather than from treatments differences.

Table 2. Evolution on leaf nutrient concentration in Valencia orange (NVA036) grafted on *P. trifoliate* as affected by mulch treatment.

Leaf nutrient concentration			
	Nitrogen g kg^{-1} DW		
	2009	2010	2011
Chip	28.2 c	27.9 ns	30.5 ab
Compost	31.2 a	28.0	31.5 a
Control	29.1 b	27.5	29.5 b
	Phosphorus g kg^{-1} DW		
Chip	1.22 ns	1.60 ns	1.64 ns
Compost	1.29	1.48	1.60
Control	1.23	1.56	1.68
	Potassium g kg^{-1} DW		
Chip	11.2 ns	15.0 ns	8.4 b
Compost	9.00	13.8	8.4 b
Control	9.50	14.7	10.3 a
	Calcium g kg^{-1} DW		
Chip	39.1 ns	37.0 ns	41.0 a
Compost	38.0	36.0	39.6 ab
Control	34.9	32.1	34.8 b
	Magnesium g kg^{-1} DW		
Chip	3.7 ns	3.1 b	4.3 ns
Compost	4.3	3.8 a	4.9
Control	4.2	3.7 a	4.6

Means in the columns followed by different letter are significantly different according to a Duncan's MRT ($p<0.05$). n.s. Non significant differences

Little changes have begun to observe in the leaf nutrient concentration of N, K and Ca row treatment in the last year. However, leaf levels are still in optimum range. Significant differences between mulch treatments in weed control were observer over the past three years experiment. Weed control expressed as percentage surface area covered by weeds varied with treatments and fluctuated in relation to the growing season. Chip mulch has reduced the need of herbicide application for two years. However the compost mulch increased significantly the infestation and need of weed control, perhaps due to the quality process of manufacturing. Chip mulch application reduced the need of weed control compared to the compost mulch and the herbicide.

Conclusions: During the first three years of establishment of a citrus orchard, the evaluation of *Ornithopus compressus* and *Lolium multiflorum* as cover crops did not change the soil chemical and physical conditions. However, the use of chip mulch as a row treatment seems to be a promising soil management measure for citrus young trees in this soil and climate conditions. Chip mulched trees have significant increase on yield production, fruit color and weed control.

Literature

Goñi, C. 2007. Oportunidades para el manejo de suelo en cítricos, con una óptica de conservación y mejora. INIA. SAD 517: 26-33.

Soil Science Society of America. 2005. Glossary of soil science terms. <http:/www.soils. org/sssagloss/>

Merwin, L.A. and W.C. Stiles. 1994. Orchard groundcover management impacts on apple tree growth and yield and nutrient availability and uptake. J. Amer. Soc. Hort. Sci. 119:209-215.

Sanchez, E.E., A. Giagetto, L. Cichon, D. Fernandez, M.C. Aruani and M. Curetti. 2007. Cover crops influence soil properties and tree performance in an organic apple

(Malus domestica Borkh) orchard in northern Patagonia. Plant Soil 292:193:205.

St Laurent A., L.A. Merwin, and J.E. Thies. 2008. Long term orchard ground cover management system affect soil microbial communities and apple replant disease severity. Plant Soil 304: 209-225.

Yao, S.R., L.A. Merwin, G.W. Bird, G.S. Abawi and J.E.Thies. 2005. Orchard floor management practices that maintain vegetative or biomass groundcover stimulate soil microbial community composition Plant soil 271: 377-389.

Morlat, R. and A. Jacques. 2003. Grapevine root system and soil characteristics in a vineyard maintained long term with or without interrow sward. Amer. J. Enol. Viticul. 54:1-7.

Abouziena, H.F., I.M. El-Metwally, S.D. Sharma, and M. Sing. 2008. Comparison of weed suppression and mandarin fruit yield and quality obtained with organic mulches, synthetic mulches, cultivation and gliphosate. HortScience 43(3)795-799.

Burkhard, N., D. Lynch, D. Percival and M. Sharifi. 2009. Organic mulch impact on vegetation dynamic and productivity of highbush blueberry under organic production. HortScience 44(3)688-693.

Cregg, B.M. and R. Schutzki. 2009. Weed control and organic mulches affect physiology and growth of landscape shrubs. HortScience 44(5)1419-1424.

TerAvest, D., J.L. Smith, L. Carpenter-Boggs, L. Hoagland, D. Granastsein and J.P. Reganold. 2010. Influence of orchard floor management and compost application timing on nitrogen partitioning in apples trees. HortScience 45(4)637-642.

Van Doren, D.M. Jr. and M.R. Allmaras. 1978. Effect of residue management practices on the soil physical environment, microclimate, and plant growth. 49-83. In crop residue management system. W. R. Oschwald (ed). ASA. Spec. Pub. N° 31 Amer. Soc. of Agron. Madison. Wisc.

Teasdale, J.R., and C.L. Mohler. 2000. The quantitative relationship between weed emergence and physical properties of mulches. Weed Sci. 48:385-392.

Barry G.H., W.S. Castell and F.S.Davis. 2004. Rootstock and plant water relations affect sugar accumulation of citrus fruit via osmotic adjustment. J. Amer. Sco. Hort. Sci. 129(6):881-889.

Scholander, P.E., H.T. Hammel, E.D. Bradstreet and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

Wardowski, W., J. Whigham, W. Grierson and J. Soule. 1995. Quality test for Florida citrus. Univ. Florida Coop. Ext. Serv., SP99, Gainesville, FL, 17p.

Monselise, S.P. and E.E. Goldschimdt. 1982. Alternate bearing in fruit trees. In: J. Janick (ed.). Hort. Rev. Vol 4:128-173. Timber Press, Portland, Ore..

SAS Institute Inc. 1990. SAS users guide. SAS/STAT, version 6. SAS Inst. Inc. Cary, NC.

Syvertsen, J.P. and J. Lloys. 1994. Citrus. In: Handbook of Environment Physiology of Fruit Crops. Vol. 2: Sub-Tropical and Tropical Crops. B. Schaffer and P.C. Andersen (eds). CRC Press, Boca Raton, FL, 65-99.