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Irrigation scheduling of avocado using phytomonitoring techniques

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Abstract

L.A. Gurovich, Y. Ton and L.M. Vergara. 2006. Irrigation scheduling of avocado using phytomonitoring techniques. Cien. Inv. Agr. 33(2):117-124. Phytomonitoring instrumentation for fine-tuning irrigation scheduling was used in a commercial avocado (*Persea americana* L.) orchard in Chile in 2001-2002 and 2002-2003 seasons. Soil water content, solar radiation, air and leaf temperatures, wind speed and relative humidity factors, as well as trunk, shoot and fruit growth were continuously monitored and irrigation scheduling strategies were implemented based on this information. Two main production goals were considered: yield increments and modification of fruit diameter distribution curves towards larger fruit sizes. Irrigation scheduling based on phytomonitoring information resulted in significant productivity and fruit size increments. The objective of this work is to provide a quantitative description of agronomic uses of phytomonitoring technology in fine tuning irrigation scheduling, based on actual continuously recorded field data.

Key words: Avocado, phytomonitoring, irrigation scheduling.

Introduction

Three techniques for scheduling irrigation on avocado (*Persea americana* L.) orchards have been used worldwide: 1. Soil moisture dynamics monitoring, 2. Evaluation of evapotranspiration by using standard Class A evaporation pan data and the Penman-Monteith model (Faber *et al.*, 1995), and 3. Dendrometry based on trunk diameter dynamics. The limitations of these techniques have been reported (Simonne *et al.*, 1992; du Plessis *et al.*, 1991 and Slabbert, 1987, Adato and Levinson. 1988; Kurtz and Guil, 1992).

The use of physiological parameters to asses the dynamics of plant water status has attracted the attention of many growers. This technique relates microenvironment edapho - environmental conditions within the orchard with its effects on plant growth. The phytomonitoring technique was developed for early and objective detection of crop stress such as water stress (Ton and Kleiman, 1987, Ton, 1997; Gurovich, 1997; Ton, 1997; Gurovich and Gratacos, 2003; Ton *et al.*, 2002, Ton *et al.*, 2004)

Plants express physiological responses to dynamic balance changes in the soil-plant-water-environmental system (SAPA). Growth rate, measured on trunks, shoots, leaves, flowers or fruits, is the most sensitive parameter that rapidly changes in response to any natural or artificial slight modification of SAPA´s balance (water absorption and transpiration relative rates). Most perennial plant species grow continuously throughout the growing season. Growth magnitude fluctuates from 0.01 to 1.00 mm·day^{-1}, under non limiting microenvironment and soil water conditions. Moreover, growth rates of any plant structure follow daily cycles, with maximum and minimum values that are specie and cultivar dependant.

Direct monitoring of growing plants, aimed at continuously keeping optimal soil water

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availability conditions to crops, in relation to a dynamic steady state of the soil-plant-climate system. This is becoming a world standard in precision agriculture (Ton and Kopyt, 2003; Gurovich and Gratacos, 2003). Modern irrigation scheduling methods are based on environmental factors, such as soil moisture monitoring and the calculation of crop water budgets using the Penman-Monteith equation or standard USWB class A evaporation pan.

Phytomonitoring techniques have been developed for an early, quantitative detection of plant responses to actual soil water availability, in order to define in real time, irrigation strategies to maximize plant growth. These techniques are based on task-specific combinations of various plant-related sensors, and corresponding data interpretation has been proposed for fine-tuning irrigation scheduling and other controllable crop factors (Ton and Kleiman, 1989; Ton, 1997; Ton, 2002; Kopyt *et al.*, 2001; Huguet *et al.*, 1992).

Limitations of soil water monitoring for irrigation scheduling were summarized by Van Leeuwen *et al.* (2001), in comparison with direct monitoring of trunk diameter micro-variations (dendrometric measurements). Phytomonitoring has been recognized as a reliable indication of mild water deficit in field-grown avocado trees (Grismer *et al.*, 2000; Farber *et al.*, 1995). Also, actual evapotranspiration based on the Penman-Monteith model or on class A pan evaporation data, can severely underestimate avocado water requirements (Arpaia and Hofshi, 1999).

Phytomonitoring is an integral combination of hardware (plant growth-related and environmental sensors, data loggers and data transmission units), software and application techniques (measurement protocols and data interpretation). This technology was originally developed by Russian and Israeli scientists (Ton and Kleiman, 1989, Nilov, 1993; Ton and Kopyt, 2003). Phytomonitoring combine modern microelectronics, computer and data transmission technologies. This technology enables real-time plant water status assessment in a nondestructive way. It is possible to register plant anatomic and physiological responses to micro-environmental conditions, modified by different agronomic management strategies. Results on experimental and commercial use of phytomonitoring have been published in Argentina, Australia, Brazil, Cyprus, Germany, Greece, Holland, Israel, Japan, Korea, Mexico, Philippines, Poland, Russia, Spain, South Africa, Ukraine, and USA during the last five years (Goldhammer *et al.*, 2000, Goldhammer and Fereres, 2001; Naor and Cohen, 2003; Ton *et al.*, 2004; Kopyt *et al.*, 2005).

Irrigation scheduling, based on phytomonitoring information is one of the most dynamic technologies introduced recently in fruit production (Wolf, 1996). Reports using trunk (Archer *et al.*, 2001; Goldhammer and Fereres, 2001; Kopyt *et al.*, 2005) shoot (Naor and Cohen, 2003, Ton and Kopyt, 2004) and fruit growth (Van Leeuwen *et al.*, 2001), have been published. Similarly, leaf and air temperature differentials (Wanjura *et al.*, 1993), plant water tension (Du Plessis, 1991; Archer *et al.*, 2001), sap flow (Haiyie *et al.*, 2003), stomata relative closing and opening dynamics, photosynthetic intensity and other real-time measurements have also been used.

The results reported in this paper were based on phytomonitoring instrumentation techniques with the aim to evaluate the response of avocado to fine-tuning irrigation scheduling in Chile.

Material and methods

Standard phytomonitoring systems (Phytech Ltd., Yad Mordechai, Israel) were installed in a 15-yr-old avocado orchard cv. Hass, located at Mallarauco, Central Chile. Plant-related measurement sets included four fruit growth sensors and two dendrometers, as well as environmental sensor sets consisting of soil moisture (time domain reflectometry sensors), solar radiation, air temperature, air humidity and wind speed sensors. All sensors were connected to a solar powered data logger installed within the orchard. Sensor data was collected with a laptop computer from the field data logger, and was analyzed with software provided by Phytech Co. Data was validated with information obtained from conventional automatic weather stations, soil tensiometers and neutron moisture probes.

Two adjacent visually representative trees, located in the middle of the experimental plot, were selected for deploying replicated sensors. Each tree was irrigated with different discharge rate microjets (35 and 47 $L\cdot h^{-1}$, respectively). Dendrometers were installed on the base of each trunk and fruit growth sensors were placed on representative fruits. Trunk and fruit growth were continuously monitored and data was integrated every 15 min and associated to trends on environmental conditions (Ton, 1997; Kopyt *et al.*, 2001; Gurovich and Gratacós, 2003, Ton and Kopyt, 2003). These data were used for short-term detection of physiological stress (trunk and fruit diameter growth and contraction rates), fine-tuning irrigation scheduling and for long-term analysis of plant water status and growth.

Negative deviation of trunk and fruit diameter trend in response to combined influence of gradually reducing soil moisture and cyclic daily variations of vapor pressure deficit (VPD) or actual crop evapotranspiration (ETc), has been reported as a good indicator of soil water deficit. In order to quantitatively describe the effect of environmental factors on growth and productivity, data collected by phytomonitor sensors every 15 min was statistically analyzed using a normal least squares multiple linear regression model, on which dependent variables were fruit and trunk growth rates. This information was arbitrarily segmented into three 2-month periods, from October 2002 to March 2003 (spring and summer seasons in Chile). The model can be represented by the following equation for trunk or fruit growth rate:

$$Y = \beta_0 + \beta_1 \cdot RH + \beta_2 \cdot AT + \beta_3 \cdot SM + \beta_4 \cdot SR + \beta_5 \cdot VPD \qquad (1)$$

with:
Y, trunk or fruit growth rate, was evaluated every 30 min; HR = air relative humidity (%); AT = air temperature (°C); SM = Soil moisture (%); SR = Solar radiation ($W\cdot m^{-2}$), VPD = Vapor pressure deficit (KPa).

Values of F (test for global significance at $p=0.05$) for β coefficients in equation (1) represented the statistical relevance of each independent variable, when considered simultaneously. Individual t-Student values were analyzed for each β coefficient, to evaluate its individual validity as significant parameter estimators, as well as its physical meaning. Multiple linear regression coefficients (r^2) indicate the goodness of fit and the relative variability explained by the model. We included only weather parameters with significant t-Student values to represent trunk and fruit growth models (equation 1). Thus, the relative effect of each weather parameter can be assessed, enabling us to predict growth rates for a specific combination of weather data.

Results and discussion

The cumulative on Penman-Monteith ETo and ETc throughout the season, evaluated with phytomonitor information, are indicated in Figure 1. Weather data included air temperature and relative humidity (VPD), wind speed, atmospheric pressure and solar radiation. Also, it was considered a 0.7 Kc value for a fully developed 15-yr-old avocado orchard that received microjet irrigation, yielding 14 $ton\cdot h^{-1}\cdot year^{1}$. The ETc estimations defined water depths applied every second day, enabling to keep soil water potentials between 15 and 25 kPa, determined with tensiometers placed at 30 cm soil depth.

It was interesting that after January 7, 2003, daily ETc values increased significantly, and were highly correlated ($r^2 = 0.946$) to

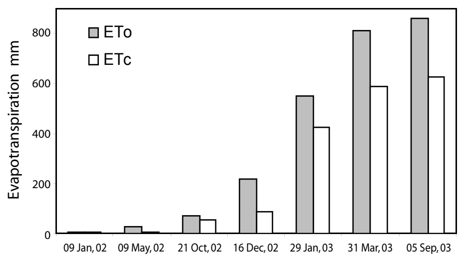

Figure 1. Potential (ETo) and actual (ETc) evapotranspiration obtained for a 15-yr-old avocado (*Persea americana*) orchard cv. Hass, based on phytomonitor information, Mallarauco, Chile.

Figura 1. *Evapotranspiración potencial (ETo) y real (ETc) en un huerto de paltos (*Persea americana*) cv. Hass, basada en información obtenida con fitomonitores, Mallarauco, Chile.*

fruit diameter increments (Figure 2). Actual cumulative daily fruit growth based on the integration of 30 min growth rates, showed a three phase fruit growth process: initial slow growth, virtual growth detention, followed by midsummer rapid growth. These results were coincident with those of Olalla *et al.*, 1992, based on manually operated dendrometers.

Data presented in Figures 3A, B and C was obtained directly from the phytomonitor software, indicating that fruit diameter sensors can detect day and night contractions and expansions. The effect of differential irrigation water depths applied was detected by these sensors. In this particular field test, the lower water depth (35 $L{\cdot}h^{-1}$, microjet) determined a larger fruit rate increment, as compared to fruit growth rate measured in the 47 $L{\cdot}h^{-1}$ irrigated tree.

Fruit diameter contraction was clearly related to micro environmental conditions. Fruit contraction was almost negligible in low vapor pressure deficit (VPD) days (e.g. October 14, January 13 and March 2), as compared to fruit contraction obtained in high VPD days (e.g. October 12, January 12 and March 25). Soil water content fluctuated between irrigation events; no saturation conditions and a rapid water internal drainage were detected. The day before each irrigation event, soil water content was still satisfactory to maintain fruit growth. A successful attempt of saving water tested by the grower, adopting an irrigation strategy. This involved a change from twice-a-day irrigation regime to one daily watering event, with lower water discharge emitters. Since trunk and fruit growth were not affected, it was concluded that the second daily irrigation was superfluous.

According to data of Figure 4, for the same periods described in Figure 3, trunk diameter sensors can detect day and night contraction-expansion. These sensors can also detect the effect of differential irrigation water depths applied. However, daily trunk growth rates were significantly smaller than daily fruit growth rates. In this particular field test, the lower water depth applied (35 $L{\cdot}h^{-1}$, microjet) determined a larger increment in trunk diameter growth rate, as compared to values obtained on tree that were irrigated with 47 $L{\cdot}h^{-1}$.

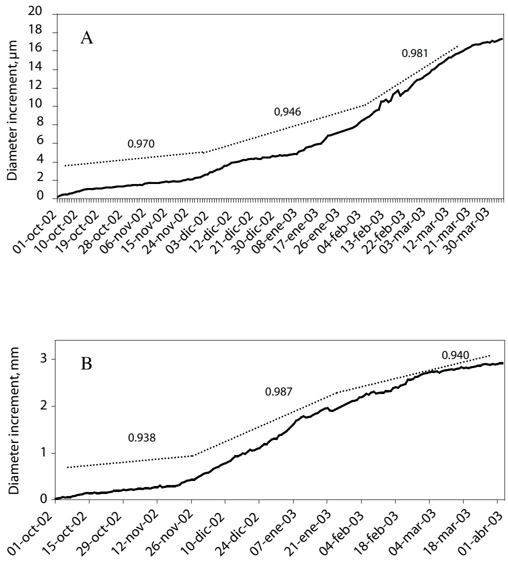

Figure 2. Cumulative diameter increments obtained on avocado (*Persea americana)* cv. Hass throughout the season. A. Fruit B. Trunk. Phytomonitor data collected every 30 min, Mallarauco, Chile. Numbers on the graphics indicate the determination coefficients (r^2), for each linear regression, in the three stages of fruit and trunk growth.
Figura 2. *Incrementos acumulativos del diámetro de troncos de palto (*Persea americana*) cv. Hass, durante la temporada de producción. A. Fruto. B. Tronco. Datos del fitomonitor colectados cada 30 minutos. Mallarauco, Chile. Los números sobre el gráfico indican los coeficientes de determinación (r^2) de las regresiones lineales, en los tres estados de crecimiento de frutos y tronco.*

Day and night contraction-expansion of trunk diameter was related to microenvironmental conditions. On days with low VPD (e.g. October 14, January 13 and March 27), trunk contraction was almost negligible in relation to trunk contraction in days with high VPD (e.g. October 12, January 12 and March 25). Soil water content prior to each irrigation event, was not a limiting factor for trunk growth.

Figures 3 and 4 showed the inverse effects of VPD on trunk and fruit growth rate, due to its diurnal contractions, resulting from tissue water losses (Ton and Kopyt, 2003; Ton, *et al.*, 2003a, b). On the other hand, in the range of soil water contents prevailing in this experimental field throughout the season, the effects on growth rate were not statistically significant ($p = 0.05$) (Table 1). Negative β coefficients presented in Table 1, indicated an inverse effects of each environmental variables on trunk and fruit

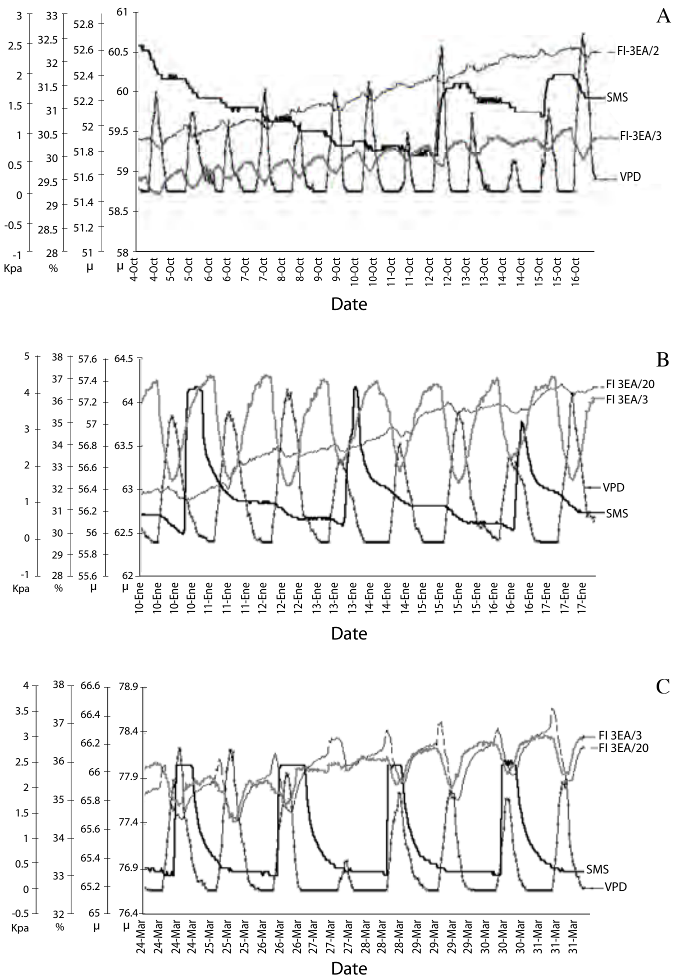

Figure 3. Avocado fruit diameter increment in relation to vapor pressure deficit (VPD) and soil moisture (SM). Mallarauco, Chile. A. 04 - 16 October 2002. B. 10 - 17 January 2003 and C. 24 - 31 March 2003.
Figura 3*. Incremento en el diámetro de frutos en relación con el VPD (déficit de presión de vapor) y SM (humedad del suelo). Mallarauco, Chile. A: 4 al 6 de octubre 2002. B: 10 al 17 de enero 2003 y C: 24 al 31 de marzo 2003.*

growth rate, due to its effects on diurnal tissue temporary water loss.

Results presented in Figure 3 and 4 and in Table 1 confirmed by data of Table 2, showing determination coefficients (r^2) for linear multiple regressions for fruit and trunk growth rates, in relation to environmental data collected by Phytomonitor sensors every 15 min, considering each growth stage independently.

For spring and early summer (Southern hemisphere), environmental data may be used to predict trunk growth rate, but it does not explain accurately fruit growth rate. During late summer months, additional factors, unrelated to environmental variables seem to be affecting trunk and fruit growth rates; physiological increments in photosynthetic sugars and oil contents in the fruit, and changes on the relative sap flow rate between xylem and phloem, characteristic to ripening stage, can be accounted for low r^2 values presented in Table 2. It is also possible that a linear model for environmental data effects on trunk and fruit growth rates is inadequate.

In conclusion, these results demonstrate the

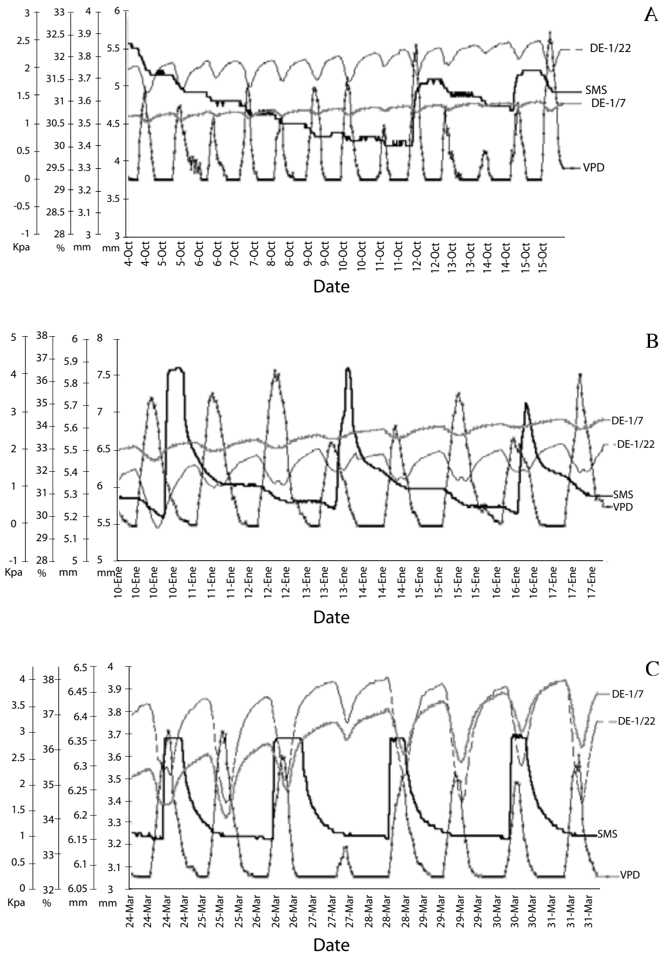

Figure 4. Avocado trunk diameter increment in relation to vapor pressure deficit (VPD) and soil moisture (SM). Mallarauco, Chile. A. 04 - 16 October 2002, B. 10 - 17 January 2003 ans C. 24 - 31 March 2003

Figura 4. *Incremento en el diámetro de troncos en relación con el VPD (déficit de presión de vapor) y SM (humedad del suelo). Mallarauco, Chile. A: 4 al 6 de octubre 2002. B: 10 al 17 de enero 2003 y C: 24 al 31 de marzo 2003.*

potential of phytomonitoring technique to fine-tuning the irrigation schedule on avocado orchard. The statistical approach used validated this technique as an efficient prediction tool for avocado irrigation scheduling. Advantage of dynamic monitoring is most apparent in irrigation decision-support applications. In trial-and-error mode, this technique enables to evaluate plant response shortly after modification of irrigation regime. Then, the grower can either maintain a new favourable regime or resume the previous one in case of no or negative effect. There are two possible ways to realize a trial-and-error session. At first, the indicators of plant state may be compared in time, i.e. before and after the modification of irrigation regime. This method requires maintaining a single factor condition during the trial. The short response time of the phytomonitoring measurement technique allows meeting this requirement in most of cases. The shorter is the trial, the lesser is the risk of foreign factor interference. The second method presumes two plots to be compared, the examined plot and the reference one. In that case, the single factor condition is not so strict. At the same time, it doubles the number of sensors required that may be considered as a certain disadvantage of the method.

Table 1. β coefficients for equation 1.
***Cuadro 1**. Coeficentes β para la ecuación 1.*

Environmental parameters	Trunk 35 DE - 1/22[1]	Trunk 47 DE - 1/7[1]	Fruit 35 FI – 3 EA/20[1]	Fruit 47 FI - 3 EA/3[1]
		October – November, 2002		
Air relative humidity	$-2.76\cdot10^{-4}$*	$-2.62\cdot10^{-4}$* [2]	$-1.28\cdot10^{-4}$* [2]	$-4.95\cdot10^{-4}$* [2]
Air temperature	$1.98\cdot10^{-4}$*	$2.20\cdot10^{-4}$*	$2.00\cdot10^{-4}$	$-3.59\cdot10^{-4}$*
Soil water content	---	---	---	$2.47\cdot10^{-4}$
Solar radiation	$-2.76\cdot10^{-5}$*	$-2.46\cdot10\text{-}5$*	$-9.41\cdot10^{-6}$*	$-7.30\cdot10^{-5}$*
Wind speed	---	---	---	$7.49\cdot10^{-3}$*
Vapor pressure deficit, VPD	$-8.50\cdot10^{-3}$*	$-7.88\cdot10^{-3}$*	$-8.61\cdot10^{-3}$*	---
Constant	$2.84\cdot10^{-2}$*	$2.62\cdot10^{-2}$*	$1.41\cdot10^{-2}$*	$4.98\cdot10^{-2}$*
		December 2002 - January, 2003		
Air relative humidity	$-3.62\cdot10^{-4}$*	$-1.30\cdot10^{-4}$*	$1.03\cdot10^{-5}$	$-1.42\cdot10^{-3}$*
Air temperature	$-3.55\cdot10^{-4}$*	$-2.98\cdot10^{-4}$*	$-7.01\cdot10^{-4}$*	$-1.17\cdot10^{-3}$*
Soil water content	---	$-6.56\cdot10^{-5}$	$2.07\cdot10^{-4}$	---
Solar radiation	$-3.43\cdot10^{-5}$*	$-2.15\cdot10\text{-}5$*	$-6.42\cdot10\text{-}6$*	$-1.48\cdot10^{-4}$*
Wind speed	---	$1.86\cdot10^{-3}$*	$2.91\cdot10^{-3}$*	$1.53\cdot10^{-2}$*
Vapor pressure deficit, VPD	$-4.49\cdot10^{-3}$*	---	---	---
Constant	$4.52\cdot10^{-2}$*	$2.22\cdot10^{-2}$*	$8.59\cdot10^{-3}$	$1,59\cdot10^{-2}$*
		February - March, 2003		
Air relative humidity	$-2.70\cdot10^{-5}$*	---	---	---
Air temperature	$4.42\cdot10^{-5}$	---	---	---
Soil water content	$4.74\cdot10^{-5}$	---	---	---
Solar radiation	$-7.86\cdot10^{-6}$*	$-1.67\cdot10^{-5}$*	---	---
Wind speed	$7.59\cdot10^{-4}$*	$1.28\cdot10^{-3}$*	---	---
Vapor pressure deficit, VPD	---	$2.21\cdot10^{-3}$*	---	---
Constant	$9.69\cdot10^{-4}$	$1.35\cdot10^{-3}$*	---	---

[1] Sensors. *Sensores.*
[2] Means followed by * were significantly different (p = 0.05). --- indicate that the specific parameter was not considered in the model, in order to maximize the ANOVA F value.
*Promedios marcados con el símbolo * son significativamente diferentes (p = 0,05). El símbolo --- indica que el parámetro específico no fue considerado en el modelo, para maximizar el valor F del ANDEVA.*

Resumen

Sensores de fitomonitoreo para una programación precisa del riego fueron utilizados en una plantación comercial de paltos (*Persea americana* L.) en Chile en las temporadas 2001-2002 y 2002-2003. El contenido de agua del suelo, la radiación solar, las temperaturas del aire y de la hoja, la velocidad del viento y la humedad relativa del aire, así como el diámetro del tronco, brotes y frutos se monitorearon en forma continua y se implementó estrategias de riego programado, sobre la base de esta información. Se consideró dos objetivos productivos: aumento de rendimiento y modificación de las curvas de distribución de diámetro para obtener una mayor proporción de frutos grandes. El riego programado basado en la información del fitomonitor tuvo como resultado un incremento significativo en productividad y en el diámetro de los frutos. El objetivo de este trabajo fue proporcionar una descripción cuantitativa de los usos agronómicos de la tecnología de fitomonitoreo para el ajuste preciso del riego programado, basado en datos reales registrados en forma continua al interior de una plantación.

Palabras clave: Fitomonitoreo, riego programado, paltos.

Table 2. Determination coefficients (r^2) for the linear regression model.
***Cuadro 2.** Coeficientes de determinación (r^2) para el modelo de regresión lineal.*

Growth stage date	Trunk 35 Sensor DE - 1/22	Trunk 47 Sensor DE - 1/7	Fruit 35 Sensor FI - 3 EA/20	Fruit 47 Sensor FI - 3EA/3
Oct - Nov	0.6130	0.5977	0.118	0.416
Dec - Jan	0.6189	0.6317	0.169	0.418
Feb - Mar	0.1604	0.3126	>0.1000	>0.1000

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