Evaluation of Peach Tree Growth Characteristics Under Different Irrigation Strategies by LIDAR System: Preliminary Results

M. Pascual
Universitat de Lleida
Departament d’Hortofructicultura
Botànica i Jardineria
Av Rovira Roure 191, 25198 Lleida Spain

J. Rufat
Institut de Recerca i Tecnologia Agroalimentàries
Centre UdL-IRTA, Tecnologia del Reg Av Rovira Roure 191, 25198 Lleida Spain

J.M. Villar
Universitat de Lleida
Departament de Medi Ambient i Ciències del Sòl
Av Rovira Roure 191, 25198 Lleida Spain

J. R. Rosell, R. Sanz and J. Arnó
Universitat de Lleida
Department of Agro-forestry Engineering
Av Rovira Roure 191, 25198 Lleida Spain

Keywords: LIDAR, fruit production, tree volume

Abstract

In a four-year experiment on peach (*Prunus persica* L. Batsch ‘Andross’) for fruit processing, canopy volume and tree shape were evaluated by scanning trees with a Light Detection and Ranging (LIDAR) system: a non-destructive system based on low cost laser technology. A relationship was obtained between the measured LIDAR tree volume and yield and fruit weight, suggesting that LIDAR offered a good way to evaluate fruit tree production capacity. The tree volume estimation system performed well when it was used as a component in the statistical analysis of the effects of irrigation strategy on productivity.

INTRODUCTION

An important issue in fruit tree culture and research relates to canopy volume and tree shape and their effect on yield, fruit quality and other related plant physiological parameters. In fruit trees, several processes are sensitive to environmental and cultural constraints, including: root growth, canopy growth, flower bud differentiation, fruit set, fruit cell division, fruit expansion and fruit maturation (Chalmers et al., 1981; Naor, 2006). Seasonal tree growth and yield are linked to several factors. This variable expresses both dynamics and intensity and affects the growth of trees in both the short- and long-terms, accumulating the effects of the previous years (Goldschmidt and Lakso, 2005). For this reason, it is recommended to conduct experiments on fruit trees over several years in order to know the annual and long-term effects.

Trunk cross-sectional area (TCSA) has been the major variable used in technical and scientific works related with tree fruit growth and yield, because it is easy to measure, although its precision is quite low for orchard prediction purposes (Lepsis and Blanke, 2004, 2006). Its most important flaw is its poor ability to estimate effects on canopy characteristics such as plant size and foliar density and the effects of past growth seasons. TCSA has, however, been successfully used in some regional fruit production forecasting models (Miranda et al., 2008).
The volume of the tree and its shape have been studied in order to develop crop load forecasting models and improve the efficiency of pesticide application (Culver and Till, 1967; Ruegg and Viret, 1999), but these methods are slow and expensive. For these and other reasons, shoot growth is often used to evaluate tree growth, and even as a means of evaluating growth models.

In recent years, new technologies have been applied to evaluate canopy volume and structure, including the use of ultrasonic systems in citrus (Zaman et al., 2006) and laser-based systems in forest and ecology (Kotchenova et al., 2004) and orchards (Rosell et al., 2009a, 2009b).

The purpose of this study was to evaluate differences in canopy volume and soil canopy projection and their relationship with yield and fruit weight in an irrigated peach experiment.

MATERIALS AND METHODS

Tree scanning was carried out in the canopy of a nine-year-old commercial peach orchard (cv. ‘Andross’) during maturity (July) in the fourth year of an irrigation and nitrogen factorial experiment. The irrigation treatments were: full irrigation, stress in fruit growth phase II (pit hardening) and stress in fruit growth phase III (expansive fruit growth). The nitrogen treatments involved applying doses of 0, 60 and 120 kg ha\(^{-1}\). The peaches were grown for processing in the horticultural zone of Lleida (Spain). Trees were grafted onto GF-305 rootstock, planted at 5 x 2.8 m, and trained to a free palmette. The trial was arranged in a randomized complete block design with four replications and three tree plots. The fruits on the experimental trees were not thinned.

Six plots subjected to the N-60 treatment, and full irrigation and phase II stress were scanned with a tractor–mounted LIDAR system (LIDAR model LSM 200, Sick, Düsseldorf, Germany, Fig. 1) to determine the volume and shape of each tree and calculate its canopy horizontal projection (Fig. 2). The data collected were then processed with specific software (Rosell et al., 2009b) and analyzed to determine the relationship between tree volume and tree productivity.

Multiple linear regressions were used to relate tree yield and mean fruit weight to tree volume, trunk cross-sectional area (TCSA) and the number of fruits per tree. The observed relationships were then evaluated with a linear regression procedure (JMP Version 7, SAS Institute Inc., Cary, NC) using the backward stepwise elimination option. A complementary analysis of covariance was performed to test the effect of irrigation on yield and fruit weight.

The validity of the model was tested by coefficient of determination, mean square error (MSE) and the prediction sum of squares (PRESS). The variance inflation index (VIF) was calculated to detect co-linearity among the variables.

RESULTS AND DISCUSSION

The results of multiple regression models are presented in Table 1. They show that the yield of trees was closely related to fruit load (number of fruits by tree) and to the volume of the tree, rather than TCSA. The PRESS criterion was used to evaluate the predictive capability of the model and the sum of squared residuals (SSE) was used to estimate the goodness of fit of the model. Acceptable values were only obtained for the yield model. The predictive capability of the model was calculated as \(R^2_{\text{pred}} = 1 - \frac{\text{PRESS}}{\text{SSE}}\). It was concluded that, albeit with few observations, the model for yield
was robust and offered sufficient explanatory power. However the model for fruit weight offered only a limited capacity for prediction.

The accurate measurement of tree volume by LIDAR allows its introduction into statistical models for analyzing the effects of treatments that influence tree growth. For instance, LIDAR permitted an accurate analysis of the influence of irrigation on yield and fruit weight responses (Table 2). Data was subjected to an analysis of covariance model (ANCOVA) with the covariates; number of fruits per tree and tree volume. When tree volume was included in the model, the results obtained showed that differences were not attributable to irrigation strategies. This result was consistent with a lack of stress in fruit growth phase II period due to spring rainfall preventing tree stress under this irrigation strategy.

The results of the interaction between IRRIG x LOAD is associated with influences on vegetative growth induced by previous year’s water restriction during phase II fruit growth.

In conclusion, low cost LIDAR systems offer a more efficient and accurate way to measure tree vegetative growth than other techniques. Tree volume data derived from LIDAR can be used in statistical and simulation models that allow a more appropriate interpretation of experimental results.

ACKNOWLEDGEMENTS
This study was financed by INIA project RTA2005-00065.

Literature cited

Tables

Table 1. Stepwise backward regression model for fruit yield and fruit weight in relation to fruit load (LOAD), canopy volume (Vol) and trunk cross sectional area (TCSA).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Yield Unstandardised coefficients</th>
<th>F Prob.</th>
<th>VIF (1)</th>
<th>Fruit weight Unstandardised coefficients</th>
<th>F Prob.</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOAD</td>
<td>0.0902</td>
<td>&lt;0.0001</td>
<td>1.23</td>
<td>0.1587</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>Vol</td>
<td>0.9300</td>
<td>0.0069</td>
<td>1.00</td>
<td>1.765</td>
<td>0.0026</td>
<td>1.05</td>
</tr>
<tr>
<td>TCSA</td>
<td>0.5072</td>
<td>.</td>
<td></td>
<td>0.9575</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>Model R2</td>
<td>0.846</td>
<td></td>
<td></td>
<td>0.441</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R2 pred</td>
<td>0.70</td>
<td></td>
<td></td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) VIF: variance inflation factor

Table 2. Analysis of covariance (ANCOVA) model for fruit yield as a function of irrigation treatment (IRRIG), the covariables tree volume (Vol) and number of fruits per tree (LOAD), and the test for slope heterogeneity.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Fruit weight F Prob.</th>
<th>Tree yield F Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCK</td>
<td>0.0152</td>
<td>0.0177</td>
</tr>
<tr>
<td>IRRIG</td>
<td>0.9607</td>
<td>0.9923</td>
</tr>
<tr>
<td>LOAD</td>
<td>0.0497</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Vol</td>
<td>0.0009</td>
<td>0.0006</td>
</tr>
<tr>
<td>Heterogeneity of slopes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRRIG*Vol</td>
<td>0.1350</td>
<td>0.0638</td>
</tr>
<tr>
<td>IRRIG*LOAD</td>
<td>0.0790</td>
<td>0.0120</td>
</tr>
<tr>
<td>Model R2</td>
<td>0.948</td>
<td>0.981</td>
</tr>
</tbody>
</table>
Fig. 1. LMS-200 LIDAR is a 2D laser scanner. 3D measures are obtained with the displacement of the laser sensor along the direction (Z) parallel to the hedgerow at a known constant speed.
Fig. 2. Vertical view (above) and horizontal view (below) of a scanned plot of trees.