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Canopy-Area Measurement of Plum Trees using Laser and Near-Infrared Imaging

Thomas Anken, Andrea Battiato, Agroscope Reckenholz-Tänikon Research Station ART, Tänikon 1, CH-8356 Ettenhausen, Switzerland

Dejan Seatovic, Vincent Meiser, Zurich University of Applied Sciences, Institute of Mechatronic Systems IMS, CH-8400 Winterthur, Switzerland

Jörn Selbeck, Leibniz Institute for Agricultural Engineering Potsdam-Bornim, Department of Crop Production, DE-14469 Potsdam, Germany

Florian Pforte, University of Kassel, Department of Agriculture Engineering, Nordbahnhofstr. 1a, DE-37213 Witzenhausen, Germany

ABSTRACT

The canopy area of a tree characterizes its assimilation area, and hence its water and nutrient requirement. The primary aim of the '3D Mosaic' international research project is to improve water and fertilizer management in orchards. To achieve this, canopy areas should allow for better, tree-based water and fertilizer management. The aim of this study was to further develop methods for measurement of the canopy area. In a plum orchard in Potsdam (DE) with 180 trees, two different methods were applied to measure the canopy area. The first consisted of a plane-laser (LiDAR) mounted on a frame which was driven through the orchard by a tractor. The second method was based on near-infrared (NIR) imaging with standard cameras. The near-infrared images allowed efficient image segmentation to aid in determining the leaf area, which was calculated via an average pixel area. Consequently, both the LiDAR and NIR methods express a relative rather than an absolute measurement of the canopy area. The comparison with the real leaf area showed that the two methods can be well calibrated. Both methods performed well over the two-year period. The measured canopy areas in 2011 and 2012 correlated with 0.91 and 0.88, respectively. The differences are explained by the fact that the laser changed position from one measured laser plane to the next, and the camera took only one image per tree, from a single position. Owing to the different perspectives from where the measurements were taken, protruding branches and leaves result in different shading effects, creating the above-mentioned variation.

Both methods are suitable for accurately measuring canopy size. Calibration of the relative measurement with the real leaf areas allows the leaf area to be calculated. Whereas the laser has the advantage of enabling easier data treatment, the camera system is much less expensive than the laser. Both methods would readily lend themselves to full automation, which opens up interesting opportunities for future tree-specific orchard management.

Keywords: Leaf area, plum tree, near infrared imaging, laser scanning, canopy area

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1. INTRODUCTION

The optimization of water use and fertilizer efficiency in commercial fruit growing is the main focus of the transnational ICT-AGRI ERA-NET '3D Mosaic' project. Tree-specific data are needed for tree-specific interventions as a key for attributing the adjusted amount of water and fertilizer to each tree. Besides climatological and soil-specific data, leaf area is an important tree-specific parameter, quantifying the photosynthesis and evaporation surface of a tree, and thus expressing its potential water and fertilizer requirement. Since measuring the real leaf area by counting every leaf is very labour-intensive, indirect measurements that correlate well with the leaf area are needed. Previous publications have reported a high correlation between the leaf area and the foliar biomass on the one hand, and the tree-silhouette area (projected area) on the other (Lindsey and Bassuk, 1992; Ter-Mikaelian and Parker, 2000). For this reason, the area of the canopy has been chosen to denote/describe the individual trees in the 3D Mosaic project. Two optical-imaging approaches with laser and camera respectively for estimating the area of the canopy (tree silhouette) were applied and compared with the real leaf area.

2. MATERIALS AND METHODS

2.1 The plum orchard

The plum (*Prunus domestica*) orchard used for this investigation is located in Potsdam, Brandenburg, Germany. The site covers an area measuring 25 m by 120 m on a gently sloping hillside, and is characterised by sandy soils (mainly Dystric Arenosols). In the upper first metre, the soil texture varies from loamy sand (1% clay, 12% silt, 87% sand) to sandy loam (13% clay, 15% silt, 72% sand). The plantation, with a total of 180 plum trees, consists of six rows of 30 trees each; the rows are oriented almost northeast-to-southwest. It is important to mention that the trees were planted in the non-overlapping pattern typical of this region. The distance between the rows is 5 m, whilst the intra-row distance between the trees is 4 m. A total of 156 trees of the cultivar 'Tophit plus' serve as productive trees, and 24 trees belonging to the cultivar 'Jojo' are used as pollinators. In 2011, the 'Tophit plus' trees were 4-5 years old, whilst all of the pollinator trees were 5 years old. All trees are drip-irrigated with the same amount of water. Each irrigation point delivers 1.6 l h^{-1} . Irrigation takes place for 30 min every second day, if necessary. The entire orchard was managed homogeneously for all trees.

2.2 Near-Infrared Imaging

From June to August 2011 and again in August 2012, the 180 plum trees in the test orchard were photographed individually. The image-acquisition equipment used is described in Table 1. A light filter was mounted in front of the camera lenses to obtain near-infrared (NIR) images. Thus, a wavelength range between the cut-on edge of the filter (750 nm) and the sensitivity limit of the CCD sensor (approx. 1100 nm) was used. In this area, the green-leaf structure exhibits maximum reflectance (Slaton et al. 2001). In 2011, a top-down perspective was chosen (Figure 1). The trees were photographed

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from above, with the camera attached to a cantilever at a fixed height of 3.5 m. The cantilever was connected to a tractor. In 2012, the photographs were taken from the side of the trees. The camera was mounted on a University of Hohenheim-designed autonomous platform which drove automatically from tree to tree, automatically taking photographs (Figure 2). To permit an efficient separation of trees and background, a black canvas was placed behind each tree. In 2012, the images were taken from the left and right side of the trees. To facilitate direct comparison with the laser-scanner system, relatively distortion-free lenses were chosen.

Table 1 Description of the cameras used

	2011	2012
Camera	USB 2.0 CCD monochrome camera with a Pentax 4.8mm F1.8 c-mount lens, IDS AG, Obersulm, Germany	CCD mono, 8-bit Grasshopper2, Point Grey, Richmond, CA
Resolution [pixels]	768 x 576	1600 x 1200
Angle of view (vertic./horiz.)	96.36°/74.46°	70°/55°
Filter used	750 – 1100 nm (limit of the camera)	715 - 1100 nm (limit of the camera)
Camera's height above ground	3.5 m	1.77/1.97 m
Camera's direction of view	Above tree: top-down view	Lateral direction (tree profile)

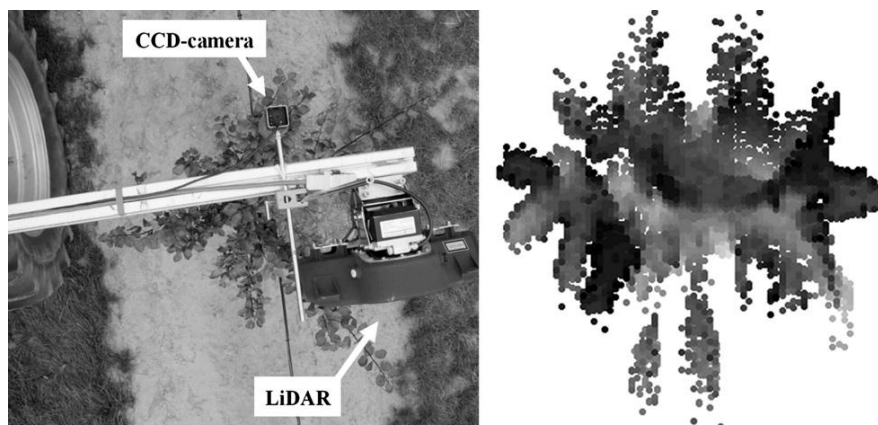


Figure 1: Arrangement of LiDAR and CCD camera in 2011, with a top-down view.

2.1 Segmentation of the images into areas with and without leaves

During image acquisition, varying degrees of cloudiness and sunshine intensity caused rapid changes in outdoor illumination conditions. A basic thresholding procedure used in 2011 on the whole proved insufficient to segment the images into tree canopy and

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background. Because constructing some sort of protection around the camera's field of view was not an option, a software approach was chosen to deal with the fluctuating appearance of the plum trees caused by the changing light conditions. A sequential arrangement of a minimum-distance and a maximum-likelihood classification in terms of the histogram and textural features of the images was implemented according to Pforte et al. (2012).



Figure 2: Arrangement of the cameras on the University of Hohenheim-designed autonomous platform (left) and the laser on the tractor in 2012.

In 2012, a black canvas was used to facilitate segmentation (Figure 3). This approach improved segmentation significantly. A threshold value was chosen as a function of the sunshine exposition in order to optimize the leaf-background separation. A proper ranging of the threshold among five values allowed a homogeneous detection for all pictures. No further clustering or segmentation steps were applied to quantify the canopy area. The distance between the camera and the row of trees (3 m) as well as the angle of view of the camera ($70^{\circ}/55^{\circ}$) were used in 2012 to calculate the average pixel size.



Figure 3: Near-infrared imaging: 2011 (left): pictures were taken from a top-down view. In 2012 (right) data were taken sideways-on in combination with a black canvas as a background.

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2.1 Laser sensor - LiDAR

As an alternative to the camera systems, a light-detection and ranging (LiDAR) laser scanner (Ibeo ALASCA XT, Automobile Sensor GmbH, Hamburg, DE) was chosen to measure the canopy area. The built-in laser has a wavelength of 905 nm and generates short, rapid-fire pulses transmitted by a tilted rotating mirror. A photodiode inside the scanner records the reflected laser pulse of a target. The laser-scanner transmits and analyses up to four echo pulses for different target distances over a period of one measurement pulse. This LiDAR almost completely eliminates sources of disturbance such as raindrops and dust. The orchard trees were reconstructed by coordinate transformation of the laser-scanner readings. The third dimension is added by the forward movement of the tractor. A more detailed description can be found in Selbeck et al. (2010).

2.2 Canopy area determined by laser

Newly developed evaluation software counted the hits on the tree canopy. To obtain the necessary point-cloud reconstruction, a basic coordinate transformation for the special case $\varphi = 0^\circ$ for the LiDAR angle to the z-axis was derived from the general coordinate transformation used by Selbeck et al. (2010). The point-to-point distance in the inner regime (0° to $\pm 16^\circ$) was as small as two consecutive points with a gap of less than 3 mm at a 2m distance from the scanner. As this is smaller than a typical leaf, no leaf was missed if it was visible from the laser scanner's perspective. The trees were reconstructed as shown in Figure 1.

Although the measurements with the LiDAR and the camera were obtained separately because the continuous driving speed formed the third dimension of the laser scans, it was necessary to stop the tractor at the centre of each tree for image acquisition. To check the constancy of speed when driving uphill or downhill, the LiDAR measurements were obtained from both adjacent machine tracks of each row of trees, and the entire tree area was scanned. Travelling speed was adjusted to 1.2 km/h.

2.3 Estimating the real leaf area

In order to calibrate the above methods for determining the canopy area, the real leaf area was calculated by manually counting all the leaves and measuring the surface area of sampled leaves. To avoid unreasonable damage to the orchard, just one 2-year-old branch was removed from each of the chosen trees. The branches were taken from a partially shaded position in each case. After the branches were removed from the trees, the leaves were plucked and scanned using the Leaf Area Meter (CI-202, CID Inc., USA). It provides values for area, length, width and perimeter of the scanned leaf, and calculates the shape factor and aspect ratio. The individual leaf areas were used to calculate the average leaf area of each of the branches, serving as an estimate of the average leaf area of the tree in question. In 2011 and 2012, 30 and 60 trees, respectively, were examined in this manner. Eleven people equipped with handheld mechanical counting devices counted the number of leaves on each of the 180 trees over a two-day period at the end of June 2011 and 2012. The total leaf area per tree was estimated by

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multiplying the mean leaf area obtained from the removed branches by the number of leaves per tree. In addition to contributing to the development of the irrigation model, this estimate of the leaf area serves as an absolute reference for comparison with the results of the indirect methods used.

3. RESULTS AND DISCUSSION

3.1 Correlation between LiDAR and camera system

The data obtained from both camera and LiDAR readings were of very high quality. Neither slight differences in driving speed and vehicle tilt due to uphill/downhill travel or unevenness of the terrain, nor the movement of the branches by the wind, appear to have had a noticeable effect on the LiDAR or camera readings. In the analysis below, for each tree, the average number of LiDAR hits and images measured from both sides of the rows has been used. The direct comparison of the LiDAR and camera systems is given in Figure 4, where the readings of both sensors are plotted against each other in 2011 (correlation 0.91) and 2012 (correlation 0.88) for all 180 plum trees. The correlation for both years and both angles of view is good. Although the variation in the data tended to increase with an increase in tree size in 2011, this was not the case in 2012. Because different angles of view and equipment were used in both years, it is not possible to attribute the different behaviour to the effect of the year or to the behaviour of the different equipment. Despite this, there were high correlations between the two optical systems in both years, which is indicative of the robustness of the two methods used.

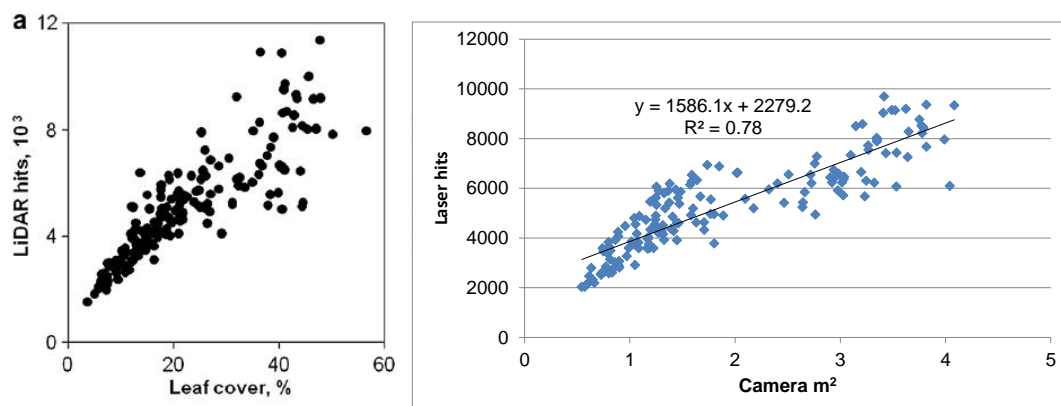


Figure 4: Relation between canopy area detected by the camera (leaf cover) and number of LiDAR hits in 2011 (left) and 2012 (right).

3.2 Comparison of real and estimated leaf area

As a reference, both systems were compared with the results of the manual leaf-area calculation of the individual trees. The respective scatterplots are presented in Figure 5. In both cases, the correlations with the leaf surface area were approximately of the same magnitude. In 2011, the manual count resulted in a Pearson's correlation of 0.78 for the LiDAR and 0.75 for the camera (Pforte et al. 2012). In 2012, the regression produced a

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coefficient of determination (R^2) of 0.80 (LiDAR) and 0.87 (camera). The slightly higher correlation of 2012 as compared to 2011 might be an effect of the difference between angles of view in both years.

This close correlation between area of the canopy and the real leaf area corroborates the results of both Lindsey and Bassuk (1992) and Ter-Mikaelian and Parker (2000).

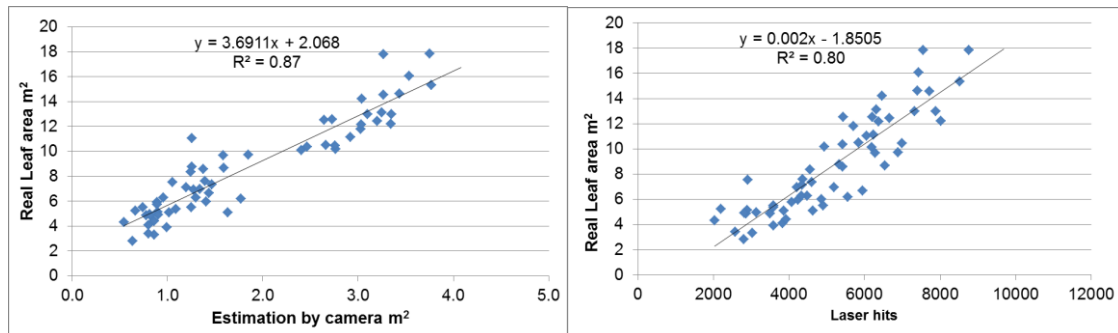


Figure 5: Real leaf area, determined by counting all the leaves and multiplying them by the leaf size of a sample, expressed as a regression of the camera and laser readings in 2012.

The number of leaves and the average size of the leaves of a tree are not correlated. Only a minor trend of increasing leaf size with an increasing number of leaves was detectable (Figure 6).

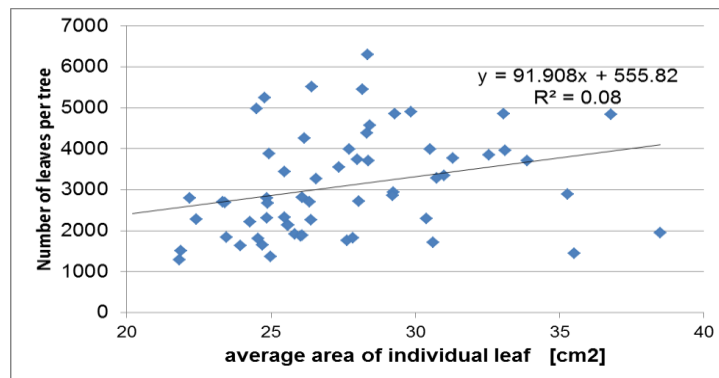


Figure 6: Correlation between number of leaves and average leaf size in 2012

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4. CONCLUSIONS

The automated measurement of the canopy by means of a LiDAR laser scanner system and a two-dimensional near-infrared image analysis system worked well under field conditions. Both methods are capable of accurately measuring the canopy area. It was also possible to calibrate the two methods with the real leaf area. The laser has the advantage of making data treatment easier, whilst the camera system is considerably less expensive than the laser. The segmentation process was greatly improved by the use of a black canvas as a backdrop when the camera took photographs from the side. The inconvenience here is that a canvas must be placed behind each tree; this could be done manually, or with a vehicle. Compared to measurements taken from a top-down view, this method has the advantage of being suitable for use in orchards equipped with anti-hail nets. The slightly higher correlation between real leaf area and the laterally-determined canopy area also indicates a slight advantage for this angle of view. Both methods have a high potential for full automation, which opens up interesting opportunities for future tree-specific orchard management.

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