

Full Length Research Paper

Estimation of orange yield in citrus orchard based on digital photography

Glauco de Souza Rolim, Lucas Eduardo de Oliveira Aparecido*, Rafael Vasconcelos Ribeiro and Alan Rodrigo Panosso

Universidade Estadual de São Paulo, Ciências Agrárias Jaboticabal, São Paulo, Brazil.

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The citriculture is an activity that has relevance in the Brazilian agribusiness. Many researchers have sought to develop methods for oranges yield estimation, however few are simple and accurate. Thus, the aim of this work is to develop a practical method to estimate number of fruits and fruit's mass per plant of sweet orange cv. "Valência" [*Citrus sinensis* (L.) Osbeck] orange grafted on 'Rangpur' lime (*Citrus limonia* Osbeck) rootstocks with North-South orientation using digital camera. Were taken 2 photos per plant in orange orchard, one for each face (southeast and northeast). The photos were visually analyzed by 3 assessors. In the harvest we quantify the number of fruits (NFR), medium fruits mass (MMF, g) and fruit's mass per plant (KFP, kg plant⁻¹). Were tested the number of photos needed to the estimations and what face could show greater accuracy. The number of fruits per plant can be estimated with high precision using 10 photos taken of the Northeast face of the trees. The estimation of the fruit's mass per plant it is also possible using 11 photos taken of the Northeast face of the trees.

Key words: Modeling, digital camera, Citrus, linear regression.

INTRODUCTION

The citriculture is an activity that has relevance in the Brazilian agribusiness (Brito et al., 2012). The citrus is considered one of the globalized segments of agribusiness, placing Brazil as the greater citrus producer, world market leader (Maria et al., 2013; Struiving et al., 2013).

The "Valência" orange shows great prominence in the Brazilian citrus industry (Pereira et al., 2014), because shows quality and fruit juiciness (Auler et al., 2009), high levels of organic acids, soluble solids and of yield (Pereira et al., 2014). The prior knowledge of yield level, before harvest, is essential to support farmers in decision

making (Triboni and Barbosa, 2004). The estimated yield provides valuable information in planning for agribusiness and is an important tool in farm sustainability (Zhang and He, 2013; Oliveira et al., 2013).

The estimated yield in orange is performed by direct and indirect methods (Triboni and Barbosa, 2004). In the direct method does field sampling to quantify the components of yield (Pino and Amaro, 1986; Ribeiro et al., 2008). However, in the indirect method we seek quantitative relationships between climatic (Aparecido et al., 2014), physiological and yield variables of orange, establishing simulation models to predict the growth,

*Corresponding author. E-mail: lucas-aparecido@outlook.com, Tel: +55 16 3209-2625.

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Figure 1. Photography of the face southwest in the orchard of orange "Valência".

development and yield (Mantovani et al., 2010; Oliveira et al., 2013). Paulino and Volpe (2001) using linear regression statistical methods related the yield orange "Pera" with some meteorological variables. Martins and Ortolani (2006) developed agrometeorological models to estimate the yield of "Valência" orange in location Matão, Sao Paulo and observed good performance of the model ($R^2 = 0.81$) when used phenological periods of pre-flowering, flowering and fruiting. The prediction of number of citrus fruits can be made from the number of reproductive structures in orange, Rolim et al. (2008) in a work conducted in Cordeiropolis, Sao Paulo, with an orange "Valência" showed a high precision values ($R^2 = 85$) and low error (MAPE = 15.2%).

Precision agriculture has been an important and efficient tool to estimate yield in Citrus, using techniques as: aerial photography (Whitney et al., 1999), multi-spectral image (Annamalai and Lee, 2003) and ultrasonic sensors (Zaman et al., 2006). However, obtaining the information by these methods is considered expensive and with quality variable mainly because the sensor sensitivity and the difficulty of processing data (Zaman et al., 2008). Thus, the use of other methods to estimate the yield of citrus, as the use of photography from digital cameras is becoming interesting.

It is a method used in some crops, as Wheat (Pan et al., 2007), rice (Swain et al., 2008), blueberry (Zaman et al., 2008) and apple (Aggelopoulou et al., 2011). The main advantages are the low cost and small time of operation (Swain et al., 2007). Many researchers have been developing methods for estimation of yield orange; however few are simple and accurate. Thus, the aim of

this work is to develop practical method to estimate number of fruits and fruit's mass per plant of the "Valência" orange grafted in lime "Cravo", using digital camera.

MATERIALS AND METHODS

The experiment was conducted in a 16 years old orchard of orange "Valência" [*Citrus sinensis* (L.) Osb.] grafted in lime "Cravo" (*Citrus limonia* Osb.) spaced 8×5 m, with North-South row orientation, located in Cordeiropolis, State of Sao Paulo, Brazil ($22^\circ 32'S$, $47^\circ 27'W$ longitude and altitude 639 m). Plants were grown under natural environmental conditions, that is, non-irrigated and exposed to natural variations of solar radiation, air temperature and humidity. The soil is classified as rhodic haplustox (Ramos et al., 2010) and the predominant climatic classification following Thornthwaite (1948) is B₁1B₃a, humid mesothermic, without or with little water deficit and accumulated potential evapotranspiration in summer lower than 48% of the total annual.

The average dimensions of the trees were 3.7 m of height, 4.7 m diameter and 2.3 leaf area index producing canopy of about 300 m³. In March of the year 2012, we photographed 56 photos of 28 orange in the orchard (Figure 1), 2 photos per plant one for each face (Southeast and Northeast), using a digital camera with 8 megapixels. The number of fruits per plant (NFR) was visually evaluated by photographs that were quantified by 3 assessors (repetitions). After, the fruits were harvested to obtain the real values. The harvest was in December 12, 2012, quantified number of fruits per plant (NFR), medium fruits mass (MMF, g) and Fruit's mass per plant (KFP, kg plant⁻¹) by weighing process.

The minimum number of plants necessary for accurate estimation of NFR in the orchard was determined. We tested NFR and KFP with the re-sampling data increasing the number of plants (photos) up to 28. For each sample we made a linear regression analysis calculating the accuracy by the mean absolute percentage error (MAPE) and the precision by the adjusted coefficient of

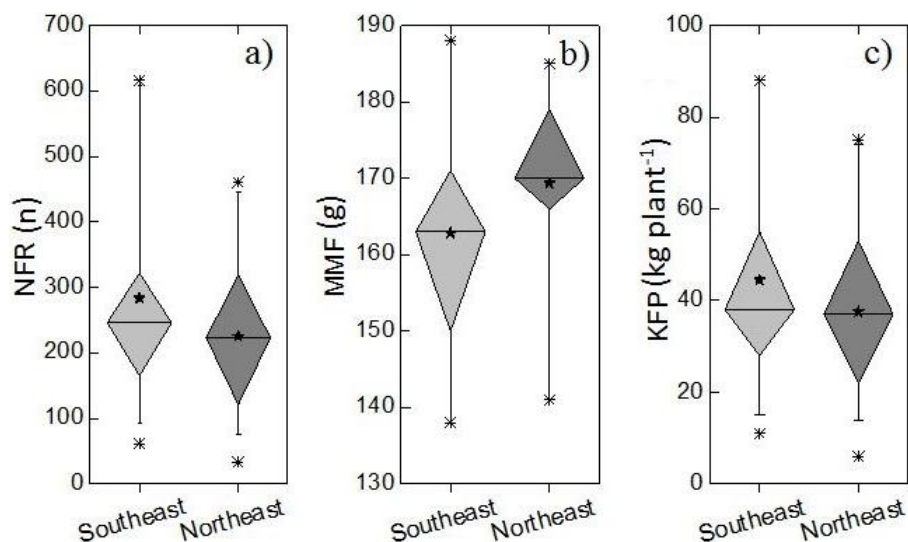


Figure 2. Observed number of fruits (NFR) per plant (a), medium fruits mass (MMF, g) (b) and fruit's mass per plant (KFP, kg plant⁻¹) of orange "Valencia" in Cordeiropolis, SP. The horizontal bar mean the median; the lozenge means 95% of the data, the upper and bottom star means the maximum and minimum absolute values and the vertical bars 99% of the data, the stars and asterisks means the average and absolute values, respectively.

determination (R^2 adjusted, Cornell and Berger, 1987) for Northeast and Southeast face and sum of both among observed and estimated values (Equations 1 and 2, respectively). We used the standard deviation values to analyze the stabilization of the estimations. The face of the plant canopy that provided the best stabilization of the precision and accuracy with minimum number of photos (NPH) was the selected to develop the estimation method:

$$MAPE = \frac{\sum_{i=1}^{NPH} \left(\left| \frac{Y_{est_i} - Y_{obs_i}}{Y_{obs_i}} \right| \times 100 \right)}{NPH}$$

$$R^2_{adjusted} = \left[1 - \frac{(1 - R^2) \times (NPH - 1)}{NPH - k - 1} \right]$$

Where, Y_{est_i} : estimated value; Y_{obs_i} : observed value; Y_{est-C} : variable estimated by linear regression between the observed value (Y_{obs_i}) and estimated (Y_{est_i}); k : number of independent variables in the regression.

RESULTS AND DISCUSSION

The Southeast face in the "Valência" orange showed 21% more number of fruits (NFT) than Northeast face (Figure 2a), providing greater fruit's mass per plant (KFP) (Figure 2c) and lower MMF (Figure 2b). As Hafle et al. (2009) stated this inverse relationship between NFT, KFP and MMF occurs due the font-drain relationship in the plant. Fewer fruits reduce competition between them promoting an increasing of MMF.

The face "Valência" orange selected to estimate the NFR was the northeast, because the estimated values (photo) showed higher precision and accuracy and

stabilization occurred with lower number of photos (NPH) in comparison to the other faces facilitating the applicability of the method. The stabilization in the northeast face occurred from 7 NPH showing an average precision of 0.6 (Figure 3a). The southeast face and sum of the faces (NE+SE) the stabilization occurs only after 20 and 17 NPH, respectively (Figure 3b and c).

Evaluating the accuracy (MAPE) of estimated values in relation to those observed, the northeast face showed higher stabilization as well. This occurred from 7 NPH, showing an average accuracy of 35% (Figure 3d). The estimated values of southeast face and sum of the faces, do not demonstrated stability until the maximum NPH used in resampling (28 photos) (Figure 3e and f).

The validation analysis for NFR models using northeast faces showed distinct values of accuracy (MAPE). For example the model with 7 NPH could estimate NFR with an error of 8.1%, and the model with 10 NPH had 3.7% of error (Figure 4). Then we understand that a minimum of 10 photos of the Northwest face should be taken for practical applications.

The model selected for estimating NFR was $y = 4.189x - 437.8$ calibrated with high precision with $R^2_{adj} = 0.96$, showing a significant linear regression ($p < 0.01$) (Figure 5a). The same model tested with independent data showed high accuracy with $MAPE = 4.0\%$, showing that is possible the estimation of the NFR "Valência" orange in function of the 10 NFR by northeast face photos. For example, in the validation of this linear model an average of 330 fruits per plant (final value) there is an error of ± 12 fruits, a low value of error in field conditions.

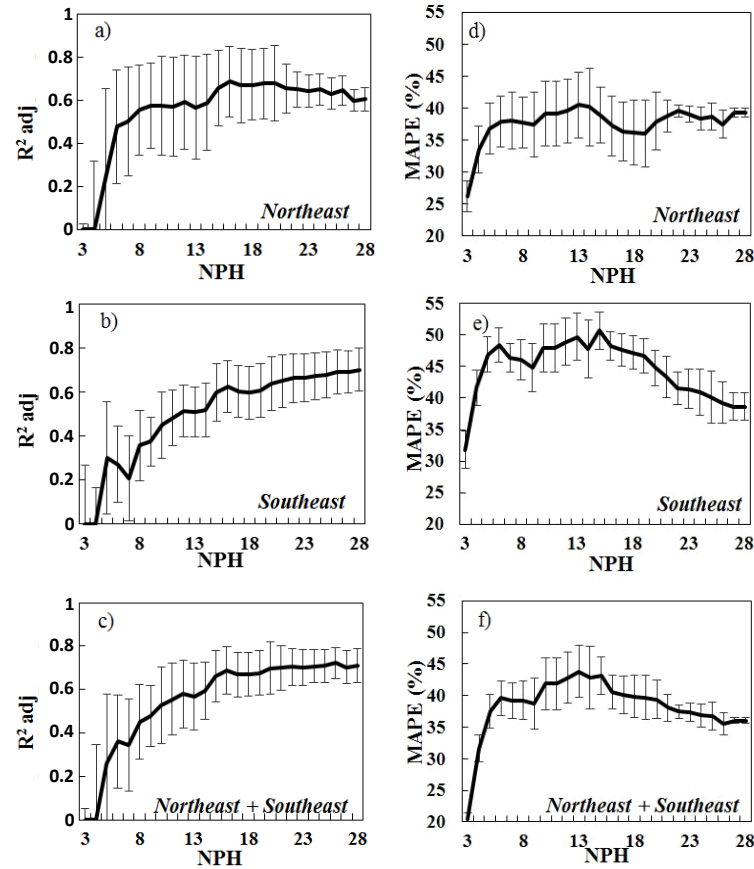


Figure 3. Evaluation of the precision (R^2 adjusted) and accuracy (MAPE) by resampling in models of number of fruits (NFR) estimation in function photos number (NPH) taken in the northeast (a), southeast (b), and the sum of the northeast and southeast faces (c). The vertical bars mean the standard deviations of the R^2_{adj} of different samples.

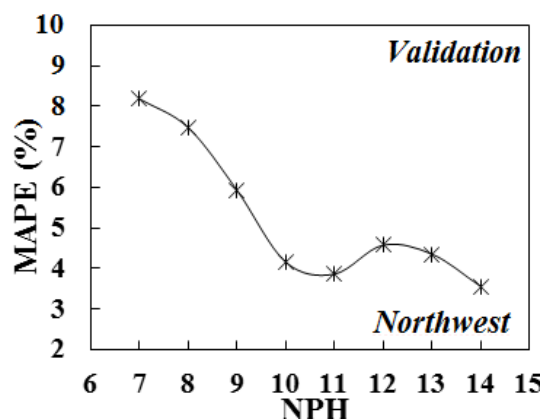


Figure 4. Validation of the accuracy of models developed to estimate number of fruits (NFR) with different number of photos (NPH).

The Northeast face was used as well for medium fruit mass per plant (KFP) estimation, because estimated values showed a stabilization of R^2_{adj} with a minimum

NPH (Figure 5). The stabilization occurred with 8 photos of the northeast face with average values of $R^2_{adj} = 0.65$ (Figure 6a). In the other faces, the stabilization occurred

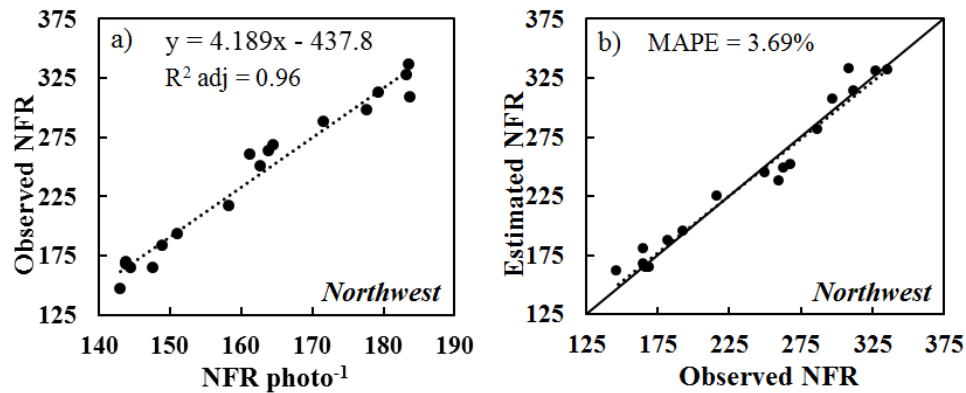


Figure 5. Calibration of the model to estimate the number of fruits per plant (NFR) in relation to NFR per photos (a) and validation of the model performance (b).

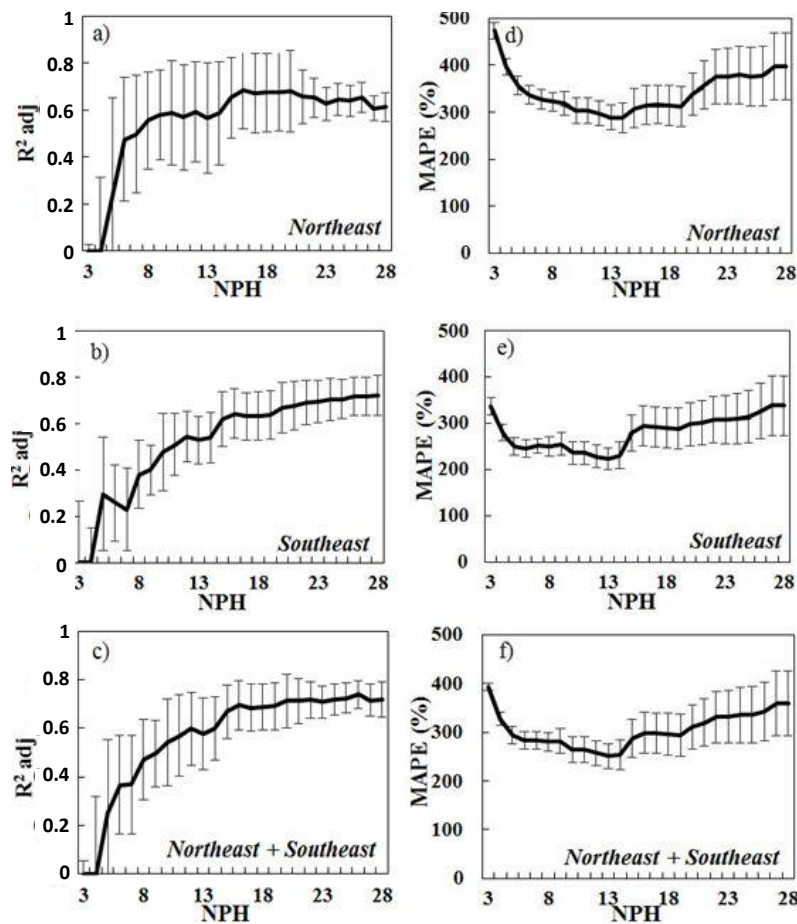


Figure 6. Evaluation of the precision (R^2 adjusted) the accuracy (MAPE) by resampling in models of average fruit's mass per plant (KFP) estimation in function photos number (NPH) taken in the northeast (a), southeast (b), and sum of the northeast and southeast faces (c). The vertical bars mean the standard deviation of different samples.

with 21 and 17 NPH for southeast and sum of the faces, respectively (Figure 6b and c). The MAPE values in this

analysis had a different pattern in comparison to NFR and the values were higher up to 400% (Figure 6d, e

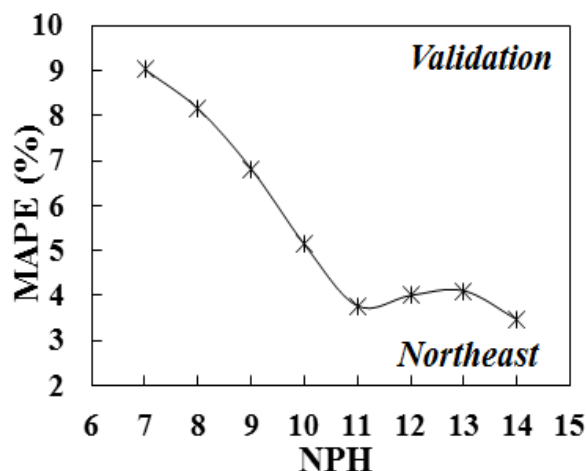


Figure 7. Evaluation of the accuracy of models developed to estimate fruit's mass per plant (KFP); NPH = number of photos.

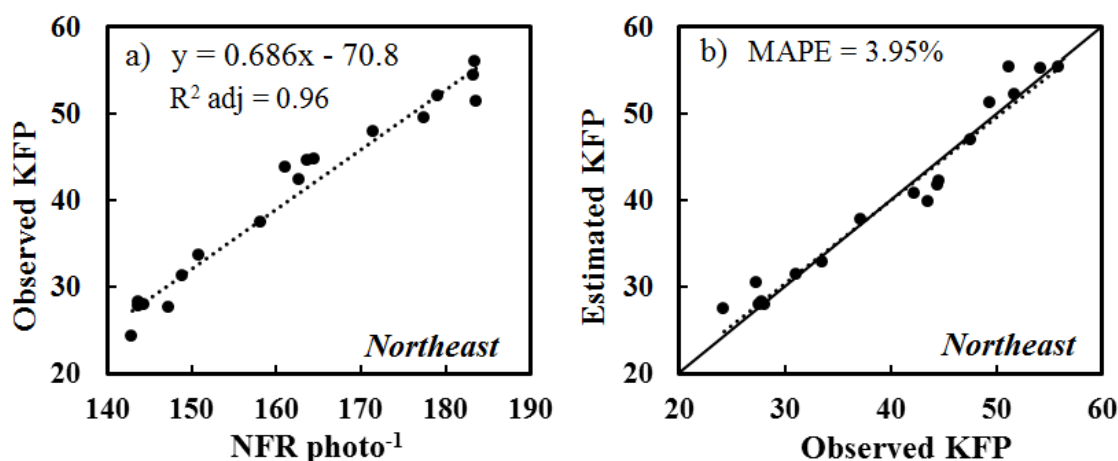


Figure 8. Model to estimate the number of fruits per plant (KFP) in relation NFR per photos (a) and evaluation of model performance (b).

and f). The minimization of MAPE was between 8 and 13 NPH. The higher values were not a problem because this analysis was used solely to find the better NPH for a following regression adjustment.

The validation analysis for KFP models using northeast faces showed high sensibility to the NPH (Figure 7). For example the model with 7 NPH could estimate KFP with an error of 9.0%, and the model with 11 NPH had 3.9% of error (Figure 7). Then we understand that a minimum of 11 photos of the Northwest face should be taken for practical NPH estimations.

The model selected for estimating KFP was $y = 0.686x - 70.8$ calibrated with high precision with $R^2_{adj} = 0.96$, showing a significant linear regression ($p < 0.01$) (Figure 8a). The same model tested with independent data showed high accuracy with $MAPE = 3.95\%$, showing that

is possible the estimation of the KFP “Valência” orange in function of the 11 NFR by northeast face photos (Figure 8b). An error of 3.95% for KFP indicates in a plant with 55 KFP there is a variation of ± 2.1 kg, a low error value for an adult plant.

Conclusion

This method is a valuable tool to estimation of the number of fruits per plant fruit's mass per plant. The number of fruits per plant can be estimated with high precision using 10 photos taken of the northeast face of “Valência” orange with a maximum error of 3.7%. The estimation of the fruit's mass per plant it is also possible with a maximum error of 3.9%, using 11 photos taken of

the northeast face of “Valência” orange.

Conflict of Interest

The authors have not declared any conflict of interest.

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