Evaluations of Digital Technologies for Estimating Trunk Cross-sectional Area, Flower Cluster Number, Fruit Set and Yield of Apple

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Abstract

Chemical thinning is a common practice used in apple orchards. It entails an early reduction in tree crop load, resulting an improvement of fruit size, quality and return bloom. PACMAN (Precision Apple Crop Load MANagement) is an extremely effective method for successfully managing crop load. The fruit growth model is an essential tool in precision of crop load management. Currently, there are several private companies with digital tools to help use this model. The aim of this study was to evaluate two methods of predicting fruit set (Cornell MaluSim app and Farm Vision/Pometa digital scans). Trials were carried out in 18 orchards in Massachusetts, Michigan, New York, and North Carolina during two seasons (2022 and 2023). In each orchard block we selected 5 homogeneous trees and counted the total number of blossom clusters/tree. Fruit set was determined after natural fruit drop or at harvest. Standard chemical thinning spray applications were made in all trials between 6 and 8 mm fruit king diameter. The fruit diameters were evaluated every 4 and 7 days after application at all locations. There were significant correlations between final fruits harvested and predicted fruit set with both systems. The R^2's were between 0.7 and 0.8. When the number of fruits at harvest was lower than 200 fruits/tree the predicted fruit set with both systems was very accurate (1:1). However, when the number of fruits at harvest was higher than 200 fruits/tree both systems overestimated the number fruits at harvest. These methods of predicting fruit set within 7 days of spraying a chemical thinner will allow growers to obtain actionable information to guide precision crop load management with less effort compared to the current manual measurement.

Keywords: *Malus X domestica,* Pometa, Farm Vision, computer vision system, trunk cross section area (TCSA), bloom intensity, fruit growth rate model, yield estimation

INTRODUCTION

Precision crop load management is the single most important and difficult management strategy in apple orchard (Robinson *et al.*, 2023a). There are 3 management practices that have a large effect on crop load: 1) pruning, 2) chemical thinning and 3) hand thinning (Gonzalez Nieto *et al.*, 2023b; Robinson *et al.*, 2013). Precision crop load management begins with precision pruning to leave on the tree a preset flower bud load before bud break, followed by precision flower and fruitlets chemical thinning with sequential applications and ends with precision hand thinning to leave the target of number of fruits per tree (Figure 1). Three predictive models are used in the US to inform crop load management decisions, timing, rate and efficacy of chemical application (Figure 1).

1. The pollen tube growth model (PTGM) based on the growth rate of apple pollen tubes as influenced by weather to improve the timing of applications of caustic flower thinning agents (Figure 1) (Allen *et al.*, 2021; Dennis, 2000; Peck *et al.*, 2016; Yoder *et al.*, 2013).
2. The carbon balance model (MaluSim) is used to predict the timing, rate and thinning efficiency of post bloom thinning chemicals based on forecasts of weather conditions (Lakso and

Robinson, 2015). The model is a dynamic simulation of apple tree carbohydrate supply and demand to predict the efficacy of post bloom thinning chemicals (Figure 1).

3. Fruit growth rate model (FGRM) is used to predict the post bloom thinning efficacy after the chemical applications and determine additional sprays are needed. The does this by assuming slower growing fruitlets will fall off and faster growing fruitlets will persist (Greene *et al.*, 2013) (Figure 1).

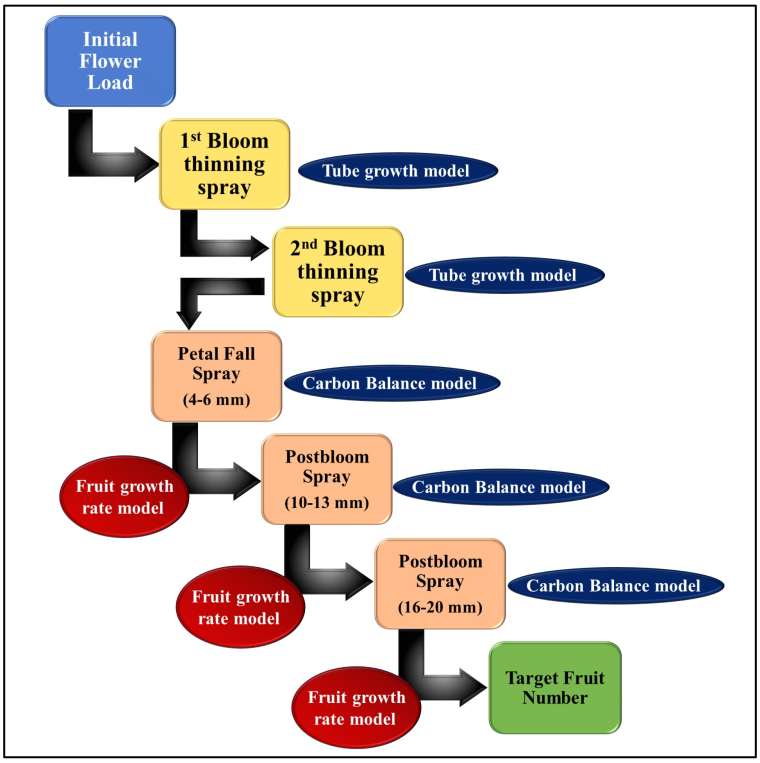

Figure 1. Flow chart of precision thinning program to achieve a target crop load (Robinson et al., 2013).

Widespread adoption of fruit growth rate model has been limited because it requires manual measurements the diameter of 375 fruitlets at 3 and 7 days after application (Gonzalez Nieto et al., 2023b). Recent advancements in digital technology are a means to automate steps in precision crop load management. In the last 2 years, several private companies have been developing digital tools to accomplish the task of measuring fruitlet diameter. The aim of this study was to compare the traditional manual method of predicting fruit set with the FGRM using the Cornell MaluSim app and the digital method of Farm Vision/Pometa scan.

MATERIAL AND METHODS

Eighteen experiments were conducted in 2022 and 2023 in commercial apple (*Malus domestica* Borkh.) orchards in Massachusetts (5 exp. 2022), Michigan (4 exp. 2022), New York (3 exp. 2022 and 5 exp. 2023), and North Carolina (1 exp. 2022). Mature and uniform apple trees of 'Gala', 'Fuji' and 'Honeycrisp' were used in all trials. In each trial, standard a chemical thinning spray applications was made when fruitlets were between 6 and 8 mm fruit king diameter. Four days and seven days after the chemical spray application, manual measurements of fruitlet diameter and whole tree scans using the video function of an iPhone according to the Pometa protocol.

In in addition to the fruit diameter measurements either manually or digitally, in each orchard we:

1. Selected five representative trees,
2. Counted the total number of blossom clusters per each tree,
3. Counted the number of flowers per cluster,

4. Determined fruit set after natural fruit drop or at harvest by counting the final number of fruits/tree and calculating the ratio of fruits/cluster.

To calculate expected fruit drop using the FGRM we used the MaluSim app which was developed by Cornell University (https://malusim.org/) and includes the fruitlet growth rate model, apple carbohydrate model, and an irrigation model (Figure 2). The FGRM calculated according to the description by (Greene et al., 2013). The Pometa scanning was done using companies recommendations and equipment: (smart iPhone 14 with a stereo video camera, and enhanced GPS location identifier) described by (Gonzalez Nieto et al., 2023b) (Figure 3).The same trees used to estimate thinning efficacy using the manual MaluSim FGRM method were used for the Pometa estimation of thinning efficacy. The cell phone videos were uploaded to the Pometa web site for processing. After 24 hours the results of the processed videos were available at the company's website. (Figure 3).

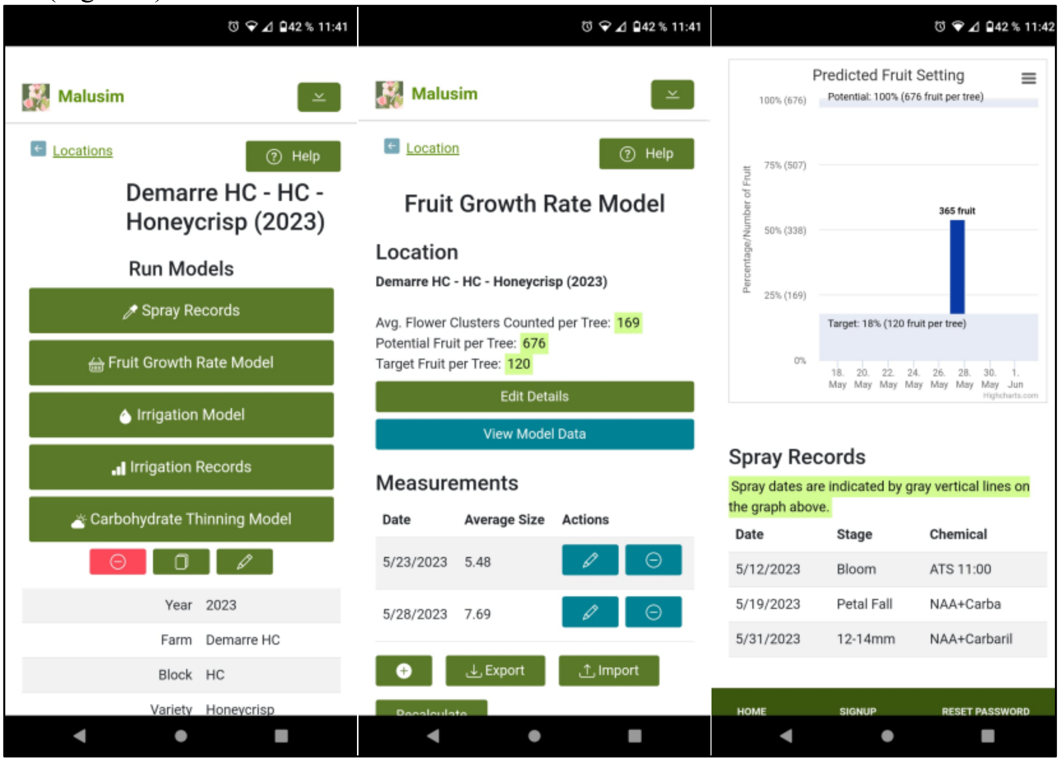

Figure 2. Flower set estimation with the MaluSim app at one location in New York in 2023.

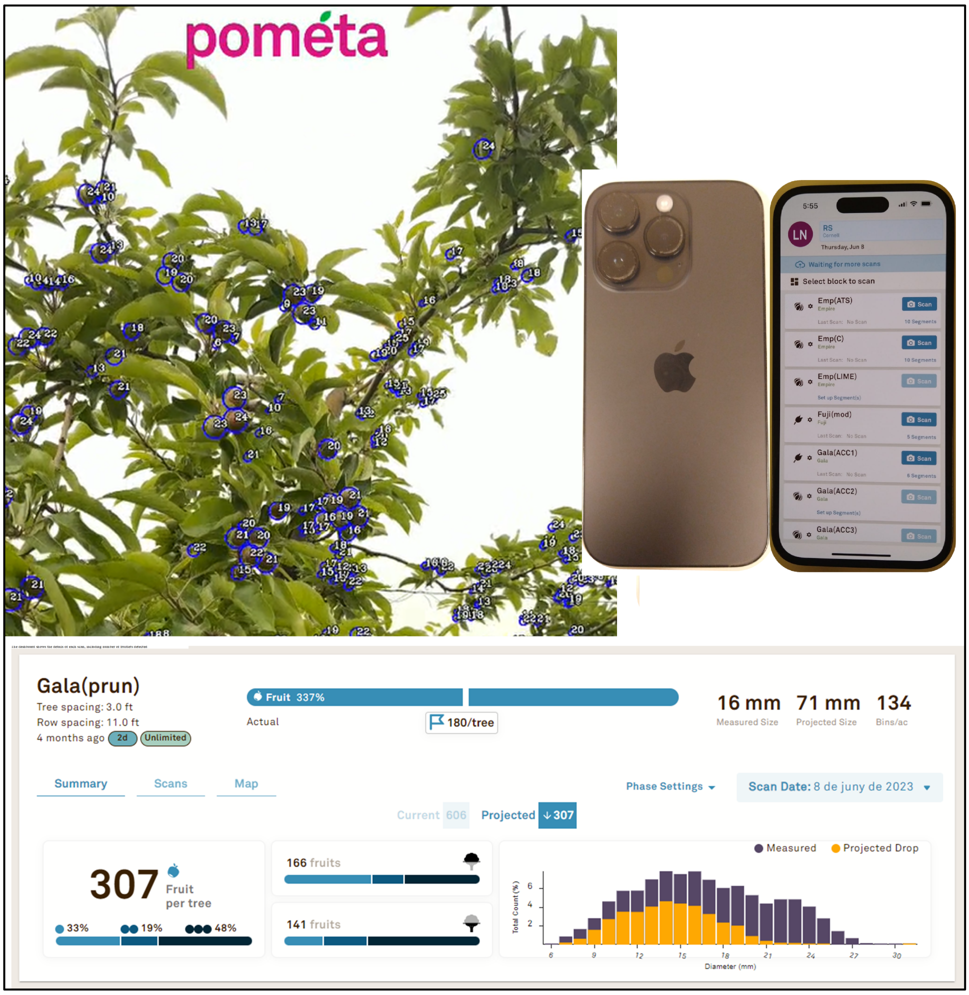

Figure 3. Fruitlets detected with the Pometa vision system and information derived from the scans in New York in 2023. Blue dots on the tree in the photograph indicate detected fruitlets. The dashboard shows the details of each scan, including number of fruitlets detected, fruit size, and the adjusted number of fruitlets expected to persist (purple bars in graph) or abscise (yellow bars).

Data were analyzed by linear regression analysis using SAS 9.4 (SAS Institute Inc., 2009) to evaluate the accuracy of the vision systems in estimating thinning efficacy compared to manual measurements.

RESULTS AND DISCUSION

There were significant positive linear relationships between predicted fruit set early in the season (June, post-thinning) using both the MaluSim and Pometa systems and final fruit harvested (Figure 4). Both methods showed accurate predictions when the final number of fruit at harvest was lower than 200 fruit/tree (near 1:1), concurring with Penzel and Kröling (2020), Costa *et al.* (2018) and McArtney and Obermiller (2010) (Figure 4). However, when the number of fruits at harvest was higher than 200 fruit/tree both systems overestimated the number fruit at harvest which concurs with the results of Rufato *et al.* (2014). Our results also suggest that when the number of fruit is high, natural fruit abscission later in June and early July is greater than when fruit load is lower (Gonzalez Nieto et al., 2023b). That is, the overestimation with high fruit numbers per tree is likely due to the higher natural fruit drop after the chemical thinning window has passed (Lordan et al, 2019).

Despite the overestimation of final fruit number when crop load is high, our results showed that both the manual model (MaluSim) and the computer vision system of Pometa are correlated and the estimates with the computer vison system were very close to the estimates with manual measurements

(Figure 5). When the number of predicted fruit was higher than 200 fruit/tree both systems showed the same prediction of number of fruit (Gonzalez Nieto et al., 2023b) (Figure 5). But, when the number of estimated fruit was lower than 200 fruit/tree the Pometa system overestimated more than the MaluSim app (Gonzalez Nieto et al., 2023b) (Figure 5). Thus, the vision system with a cell phone camera will likely become a preferred method estimating thinning efficacy in the future since it requires less time and provides easy interpretation of the results.

The objective of precision agriculture is to reduce the variability in an orchard through variable management and thereby increase the crop value (Blanco *et al.*, 2023). Validation of new precision technologies is a critical step before adoption by fruit growers (Gonzalez Nieto *et al.*, 2023a; Robinson *et al.*, 2023b). Greene et al. (2013) developed the fruit growth rate model to predict the efficiency of thinning and to inform decisions on the necessity of more thinning sprays. The model uses the growth rate of tagged and measured fruitlets to predict the percentage that will abscise. This model requires manual measurements which take about two hours of work per orchard on each date plus the time used to select and mark all clusters. The Pometa vision system uses the same concept of the fruit growth rate model but uses computer vision to measure the fruit diameters. The time required to use the Pometa system is about 10 min per block.

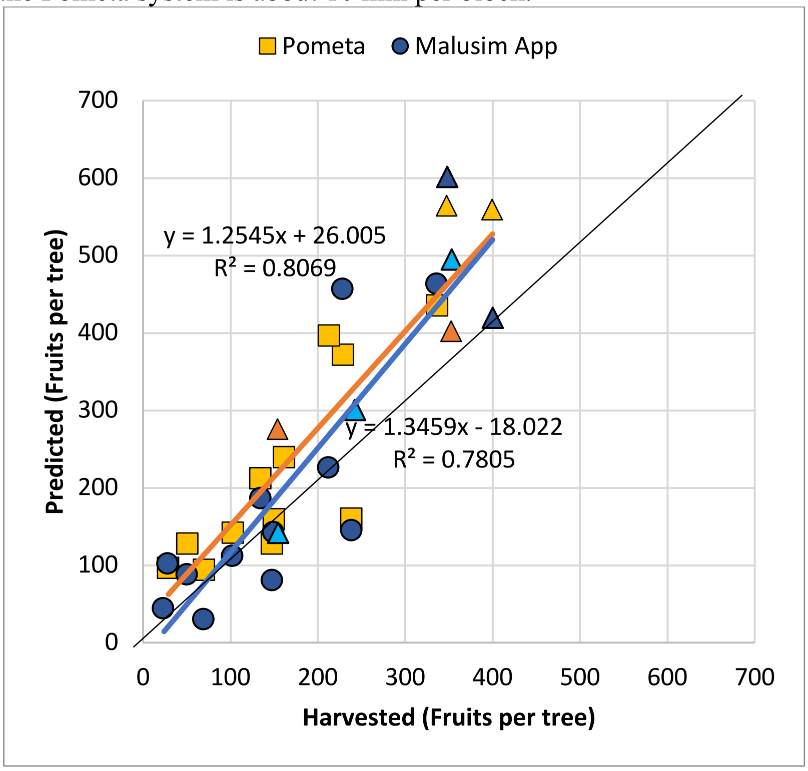

Figure 4. Relationships between the actual fruit number per tree at harvest in September 2022 and 2023 and the predicted fruit number per tree using the fruit growth rate model with the MaluSim app or the Pometa computer vision system at 7 days after a chemical thinning spray in May 2022 and 2023. Orange and light blue triangles were 2 applications of thinning chemicals. The dots and squares data were published in Gonzalez Nieto et al. (2023b) with data from 2022. Triangles were data of 2023. Each symbol represents 1 orchard. All linear correlations were significant at $P<0.01$.

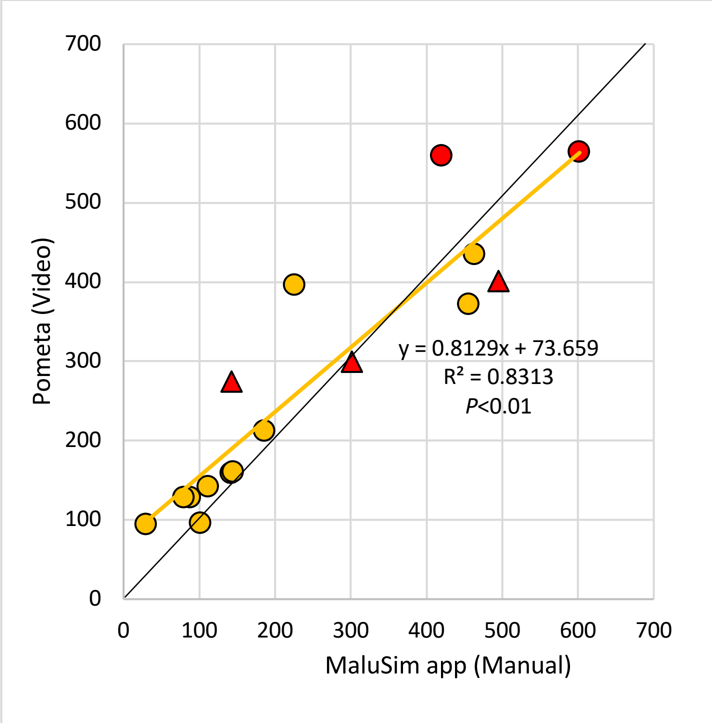

Figure 5. Relationship between predicted number of fruits per tree with the MaluSim app and the Pometa computer vision system in 2022 (yellow dots) and 2023 (red dots and triangles). Triangles were 2 applications of thinning chemicals. The yellow dots was published in Gonzalez Nieto et al. (2023b) with data from 2022. Each data point represents 1 orchard.

CONCLUSIONS

The use the vision system to estimate thinning efficiency generated accurate predictions and usable data for the growers. The fruit growth rate model using the MaluSim app and the Pometa system showed accurate predictions of thinning efficacy when the crop load was lower than 200 fruit/tree. However, our results suggest that when the number of fruit at harvest was higher than 200 fruit/tree both the MaluSim and the Pometa systems predicted higher number fruit at harvest than actually harvested. Overall, the vision system of Pometa using a cell phone needed less time than the MaluSim method of manual measurements of fruit diameters and provided easy interpretation of the results. We believe the smartphone system offers advantages such as low cost, quick access, and simple operation in addition to accuracy.

Acknowledgments

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