Studies in Precision Crop Load Management of Apple

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Abstract

We are conducting a USA national SCRI project to develop precision crop load management strategies and machines to manage the number of fruits per tree to exactly the economic optimum. We have done physiological experiments to define the biological potential of yield and fruit size of 'Gala' and 'Honeycrisp' apple cultivars in 4 climates (West, Mid-West, North-East and South-East USA) to estimate the economic optimum number of fruits per tree. Our results show that the dry, high light climate of WA generally can support a higher crop load than the eastern USA growing regions. Our multi-location experiments have shown that leaving too many flower buds during pruning results in lower crop value than the optimum flower bud number. Optimum flower bud number in our studies of 'Gala' and 'Honeycrisp' was between 1.5-2.0 flower buds per final target fruit number. To achieve the optimum fruit number per tree we employ: 1) precision pruning to remove flower buds to a pre-determined flower bud load; 2) precision chemical thinning through sequential chemical thinning sprays guided by the use of computer models to adjust the dose and timing of chemical application and to assess the effect of the chemical sprays shortly after application to inform re-application; and 3) precision hand thinning to guide human workers to leave an exact number of fruits per tree. We are developing computer vision to streamline the counting of buds, flowers and fruitlets. The information from each tree is geo-referenced and is uploaded to the cloud and then can be communicated to human workers to guide their work in reducing crop load to the optimum level.

Keywords: *Malus* × *domestica*, fruit size, crop value, chemical thinning, pruning, computer vision

INTRODUCTION

Crop load management is the single most important yet difficult management strategy that determines the annual profitability of apple orchards (Robinson, et al., 2013). The number of fruits that remain on a tree directly affects yield, fruit size and the quality of fruit that are harvested, which largely determines crop value. Poor or inadequate thinning will reduce profitability in the current year and can result in inadequate return bloom in the following year. Management of crop load is a balancing act between reducing crop load (yield) sufficiently to achieve optimum fruit size and adequate return bloom without reducing yield excessively (Francescatto et al. 2019).

There are 3 management practices that have a large effect on crop load: 1) pruning, 2) chemical thinning and 3) hand thinning (Robinson et al., 2021). Precision crop load management utilizes all three management approaches to adjust crop load. It begins with precision pruning to leave on the tree a preset bud load, followed by precision chemical thinning to reduce initial flower number per tree to a preset fruit number per tree and ends with precision hand thinning to leave a precise final number of fruits per tree.

USA NATIONAL PROJECT ON PRECISION CROP LOAD MANAGEMENT

In September of 2020 we began a 4-year national USA project on precision crop load management of apples that includes university researchers, extension educators and commercial company engineers that will bring digital solutions to managing crop load in apples. The project is funded by the federal US government through the USDA-NIFA Specialty Crops Research Initiative (SCRI). The project has both horticultural objectives, engineering objectives and economic objectives. Among the horticultural objectives are to: 1) assess the optimum crop load for two important apple cultivars ('Gala' and 'Honeycrisp') in different growing regions of the USA and 2) improve the three models used in chemical thinning (carbohydrate balance model, pollen tube growth model and the fruit growth rate model) to provide more precision and greater ease of use. The engineering objectives are to: 1) develop computer vision approaches and machines to count dormant fruit buds, flowers, and then fruitlets per tree and 2) process the information and communicate actionable information to human workers. The economic objectives are to: 1) assess the economic effects of thinning and 2) determine the economic feasibility of automated methods of assessing crop load and managing crop load. The project also seeks to extend to growers and tech companies the results of the research project to guide grower adoption of digital technology to manage crop load.

In this paper we report on a few of the early findings from the precision pruning objective and also give a brief overview of the progress of other aspects of the project.

MATERIALS AND METHODS

In 2021 we conducted a pruning severity study in 4 locations: Wenatchee, Washington (WA); Lansing, Michigan (MI); Geneva, New York (NY); and Ashville, North Carolina (NC). These four locations represent the Western, Midwestern, Eastern and Southern apple growing regions of the USA. At each location 'Gala' and 'Honeycrisp' trees on M.9 rootstock were pruned to 75, 150, 225 and 300 flowering spurs at bloom. Trees were then hand thinned to single fruitlets at 10mm fruit size. At harvest the final number of fruits and yield per tree were recorded and the circumference of the trunk at 30 cm above the ground. Crop load was calculated by first calculating trunk cross-sectional area (TCSA) and then dividing the number of fruits per tree by the TCSA. A sample of 20 fruits per tree was collected at harvest and fruit color and size were measured with commercial electronic color and sizing machines. Crop value was calculated from the yield, fruit size and fruit color data by calculating a commercial pack out and assigning commercial prices to each size and color grade.

A second study at each location compared trees of 'Gala' and 'Honeycrisp' which were pruned to a uniform flower bud number (150) and then hand thinned to different fruit number per tree when fruitlets were 10mm in size. Data collected at harvest and the calculation of crop value were the same as the pruning severity study.

Data from both experiments were analyzed by regression analysis.

RESULTS

Pruning Severity Experiment. When Gala trees were pruned to different number of flower bud in different climates, fruits grown in WA had the largest fruit size at any crop load

(Figure 1). Gala fruits from NY had the smallest fruit size at any crop load. Gala fruits from MI was similar in size to those from NY at lower crop loads but similar to fruits from WA at high crop loads. No data was recorded from NC due to spring frost damage which compromised the experiment.

With Honeycrisp trees, fruits from the NY, WA and MI climates had larger fruit size at any crop load (pruning severity) than those from NC (Figure2). Fruits from the WA and MI climates gave similar fruit size to NY at lower crop loads but NY grown Honeycrisp were larger at high crop loads.

Hand Thinning Experiment. When Gala trees were pruned to the same number of flower buds (150) and then hand thinned to different number of fruitlets when fruits were 10mm in diameter in different climates, fruits grown in WA and NY had the largest fruit size at any crop load (Figure 3) while Gala fruits from MI were smaller at any crop loads. No data was recorded from NC due to spring frost damage which compromised this experiment.
With the same pruning severity (150 buds) but different crop loads:

With Honeycrisp trees, fruits from the WA climate had largest fruit size at any crop load while those from NC had the smallest fruit size (Figure4). Fruit size from the NY and MI climates was smaller than fruit size from WA at lower crop loads but fruit size was similar at high crop loads.

Economic calculations of crop value from this experiment showed that with Gala, crop value from WA was higher than from NY or MI which were similar (Figure 5). The optimum crop load in WA was 6.9 fruits/cm^2 TCSA while the optimum crop load for NY was 8.9 and for MI was 10.1 fruits/cm^2 TCSA. With Honeycrisp the greatest crop value was from WA, followed by MI, NC and lastly NY (Figure 6). The optimum crop load at WA was 7.7, at MI it was 11.8, at NC it was 7.6 and at NY it was 11.2 fruits/cm^2 TCSA.

DISCUSSION

The results of the pruning severity study and the hand thinning study showed that location (climate) has a large influence on the relationship between crop load established by pruning severity or by hand thinning and fruit size. Within each location there was an optimum economic crop load when considering fruit size, yield and fruit quality. The WA climate appears to produce larger fruits at any given crop load for 'Gala' and similar fruit size with 'Honeycrisp'. This advantage resulted in a substantially greater crop value for 'Gala' and 'Honeycrisp' trees in WA than from the other 3 locations.

The precision pruning study also showed that pruning too little (leaving too many floral buds) resulted in a lower crop value than pruning to the optimum bud load. We have shown in a 17-year study that a high number of floral buds results in a high number of final fruits despite later chemical thinning (Lordan et al, 2019). The exact number of buds to leave has been unclear. We recently published results with 'Gala' that indicate leaving 1.5-2.0 buds per final fruit number, maximized crop value over 4 years (Francescatto, et al, 2019).

Our previous studies and the current studies across 4 different climates have shown that pruning to a precise bud number has large economic benefits. This information will establish targets for pruning severity in each location.

OTHER ADVANCES FROM THE SCRI PROJECT

Improvements in precision chemical thinning. Precision chemical thinning utilizes sequential sprays of chemical thinner beginning at bloom and continuing until sufficient thinning is achieved or fruit size exceeds 20mm (Robinson et. al, 2021) The process is aided by the use of 3 computer models (pollen tube growth model, PTGM; carbohydrate balance model, MaluSim; and the fruit growth rate model FGRM) (Robinson et al, 2021). Through this project we are working to improve each of these models to provide greater accuracy and ease of use. First, a team is working to develop a universal pollen tube growth model that would allow the PTGM to guide blossom thinning sprays of all varieties. Second, another team is working to improve the MaluSim model to provide greater accuracy of predicting thinning efficacy from post bloom thinning sprays. Third, a team is working to develop alternative and simpler approaches to the fruit growth rate model. In this effort we highlight 3 advances. Einhorn and his team have developed a size distribution model (SDM) which accurately predicts fruit set after a chemical thinning spray (Hillman et al, 2022). The SDM is simpler to use than the FGR model and will likely induce many more growers to use this model to assess thinning efficacy after each of the sequential thinning sprays used in the precision thinning program. A second approach was developed by Kon and his team which uses near infrared light (NIR) to determine if a fruit will abscise or persist after a thinning spray. A third approach was developed by a commercial company (Fruit Scout) which uses sequential pictures of fruitlets taken every 3-4 days with a cell phone camera to measure fruit growth. The pictures are uploaded to the company website and their algorithm determines predicted fruit set. Lastly another company (Farm Vision) has developed a method of using video recorded from a cell phone camera every 3-4 days to assess fruit growth rate. Each of these 4 methods are simpler to use than the original FGR model which required manual fruit diameter measurements every 4 days to estimate fruit set. Our team is working with the commercial companies to validate and evaluate their systems of determining fruit set.

Advances in bud, flower and fruit counting. We are working with four companies which use rovers or drones and computer vision to count fruit numbers per tree on a whole orchard basis. To precisely manage crop load, manual counting of the number of floral buds or flowers or fruitlets for each tree is required. However, this process is tedious and growers soon tire of the effort. However, with computer vision and machines to do the counting the process of precision pruning and precision thinning will be more widely adopted. First, we are working with MOOG corporation from East Aurora, New York, USA to evaluate a rover with cameras and lights to measure each tree's trunk diameter and number of floral buds at bud break or flower numbers at bloom or fruitlets from petal fall until harvest. Their system keeps data from each tree separate and calculates the number of buds, flowers or fruits the tree should carry to guide pruning and thinning. The geo-referenced data for each tree is uploaded to the cloud and then can be communicated to workers on a work platform to guide their actions relative to each geo-referenced tree.

Second, we are working with a Canadian company, Vivid, who have developed their own multi-spectral camera which can be mounted on an ATV to measure fruitlet number. Their system allows estimates of crop load before and after thinning and produces maps of crop load which can be used by managers to focus thinning efforts where most needed.

Third, we are working with and Australian company, Green Atlas, to evaluate and improve their rover which counts fruitlets per linear meter or row from 20mm fruit size until harvest. Their system also estimates of crop load before and after thinning and produces maps of crop load. This system is now commercial and is adopted by some growers to help in their crop load management efforts.

Fourth we are working with a British company, Outfield, to evaluate their system of counting fruitlets using drone flights.

All of the four computer vision systems whether by rover or drone cannot detect all fruitlets due to occlusion. Thus, they all require a correction factor that is obtained by manual counting of some representative trees or row sections. Our team of engineers are working on approaches to eliminate the manual counting of trees for this correction factor.

SUMMARY

We have assembled a large team of researchers, extension educators and company engineers to develop automated approaches to crop load management to implement more precise crop load management under a nationally funded SCRI project. We are conducting physiological experiments coupled with economic analyses to define the optimum crop load in different climates of the USA. We are also developing improvements to existing models used in chemical thinning to allow simpler and more efficient prediction of fruit set before and after application of chemical thinners. Lastly, we are developing machines which use computer vision to automate the counting of floral buds, flowers and fruitlets to guide precision pruning and precision chemical and hand thinning.

ACKNOWLEDGEMENTS

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Figures

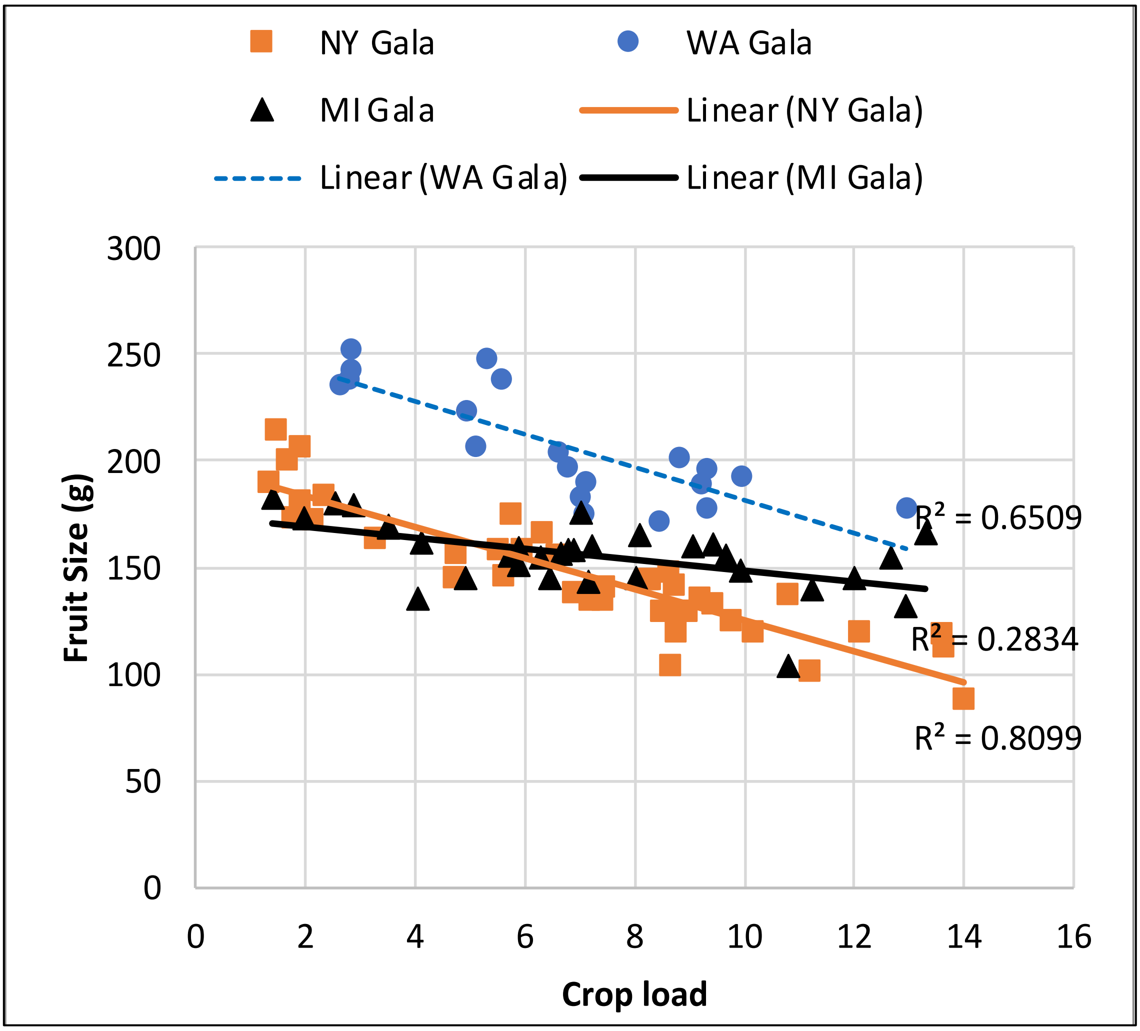

Figure 1. Relationship of fruit size and crop load of 'Gala' apple trees pruned to different flower bud loads at 3 geographic locations in the USA.

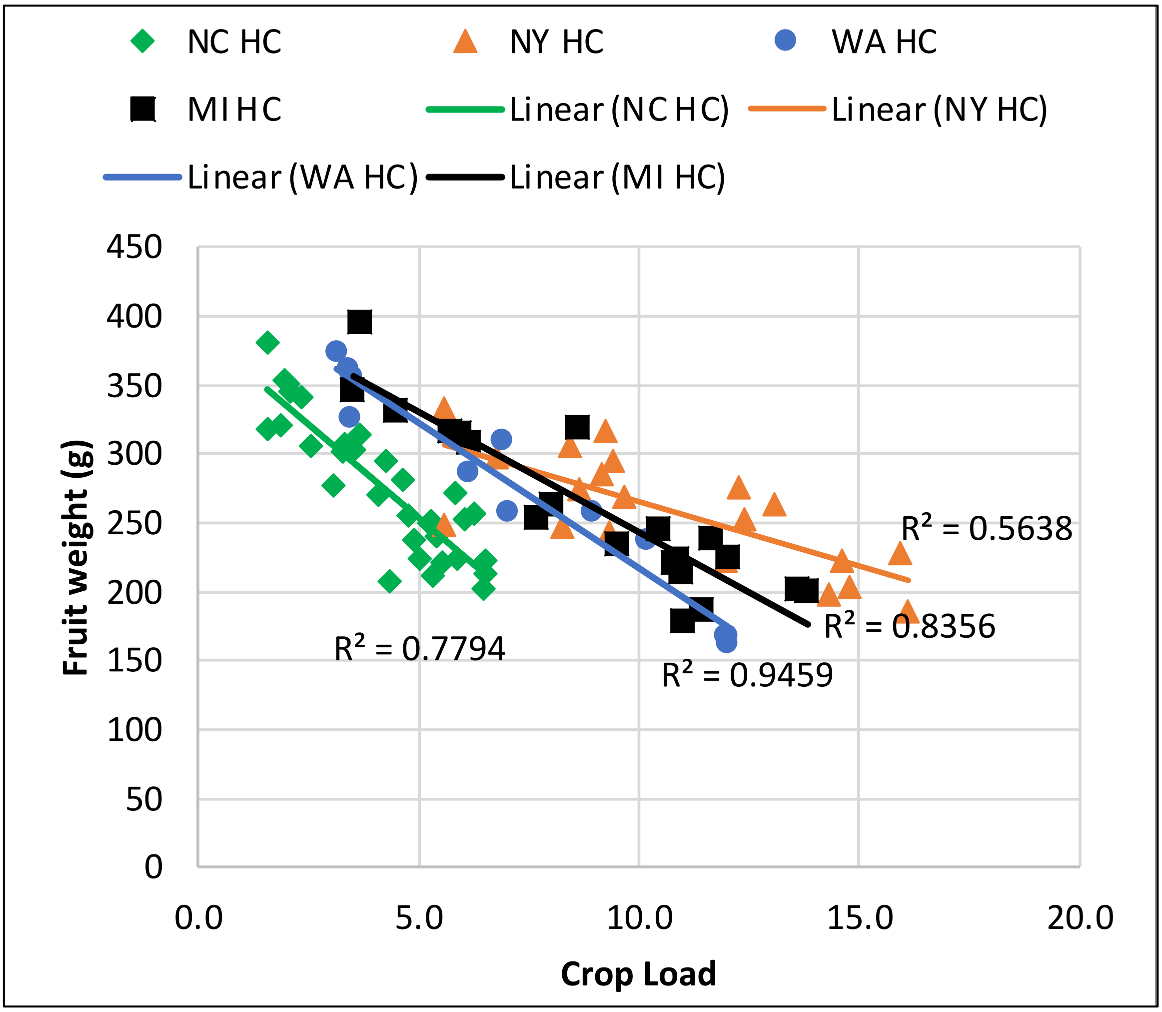

Figure 2. Relationship of fruit size and crop load of 'Honeycrisp' apple trees pruned to different flower bud loads at 4 geographic locations in the USA.

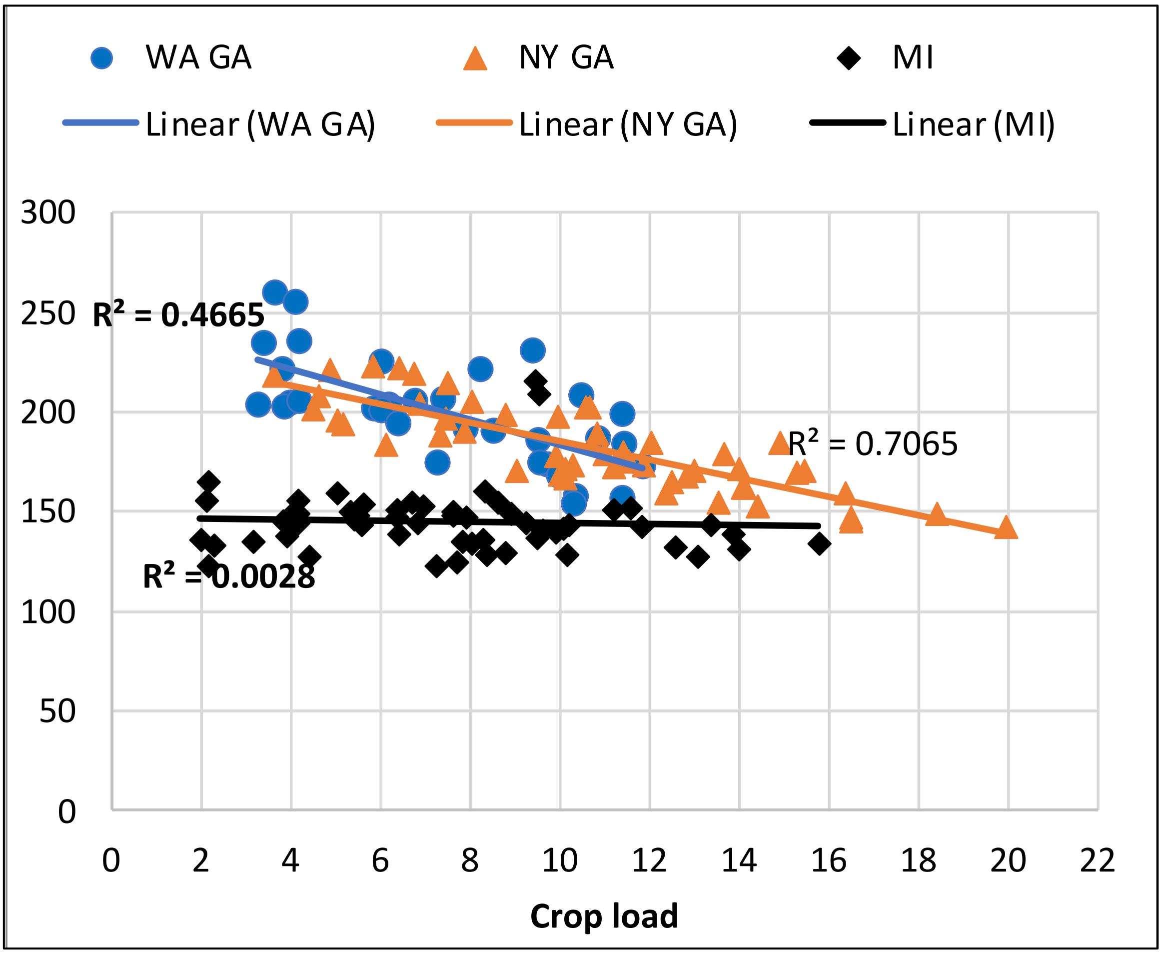

Figure 3. Relationship of fruit size and crop load of 'Gala' apple trees hand thinned to different fruitlet numbers at 3 geographic locations in the USA.

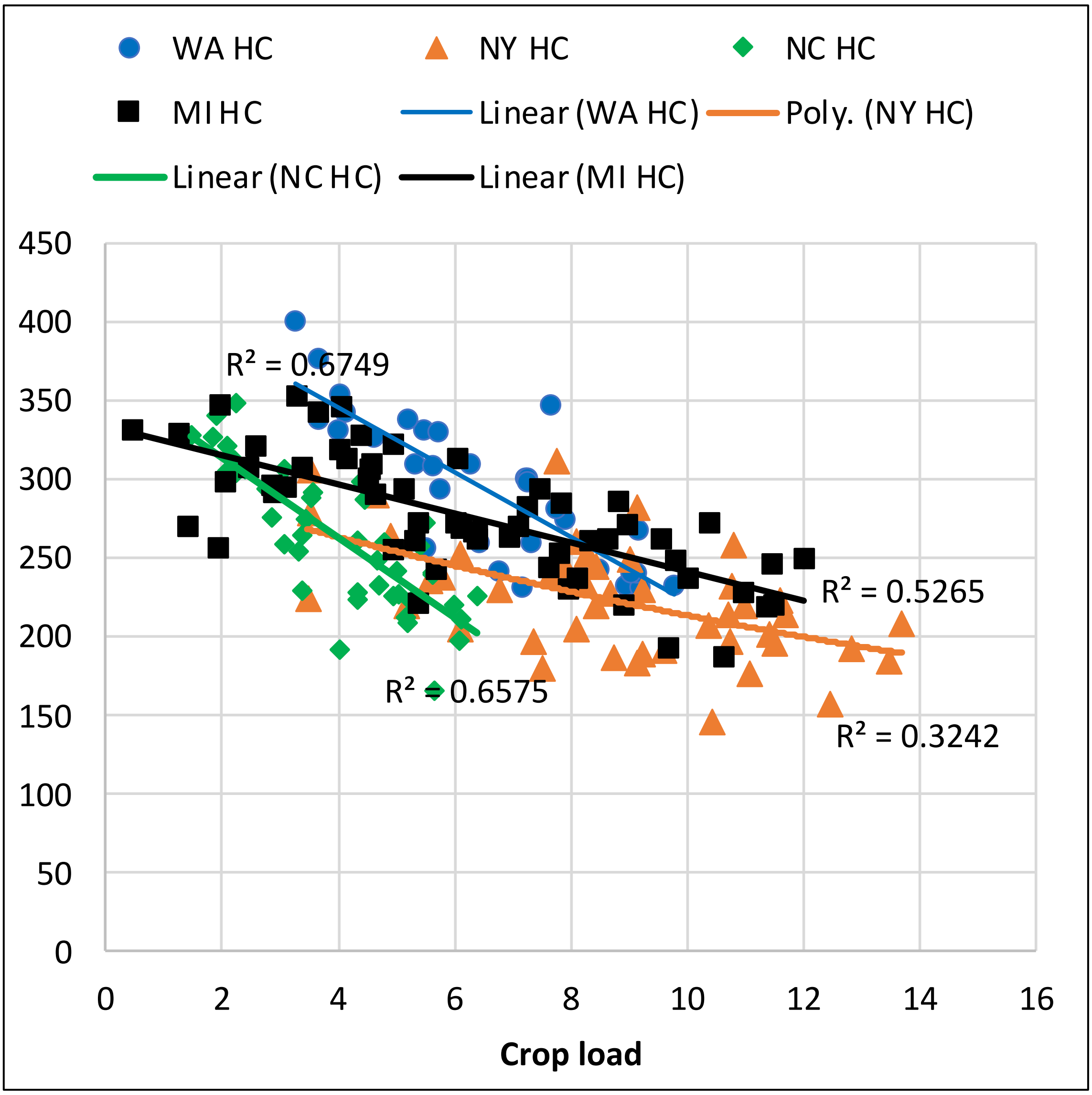

Figure 4. Relationship of fruit size and crop load of 'Honeycrisp' apple trees hand thinned to different fruitlet numbers at 4 geographic locations in the USA.

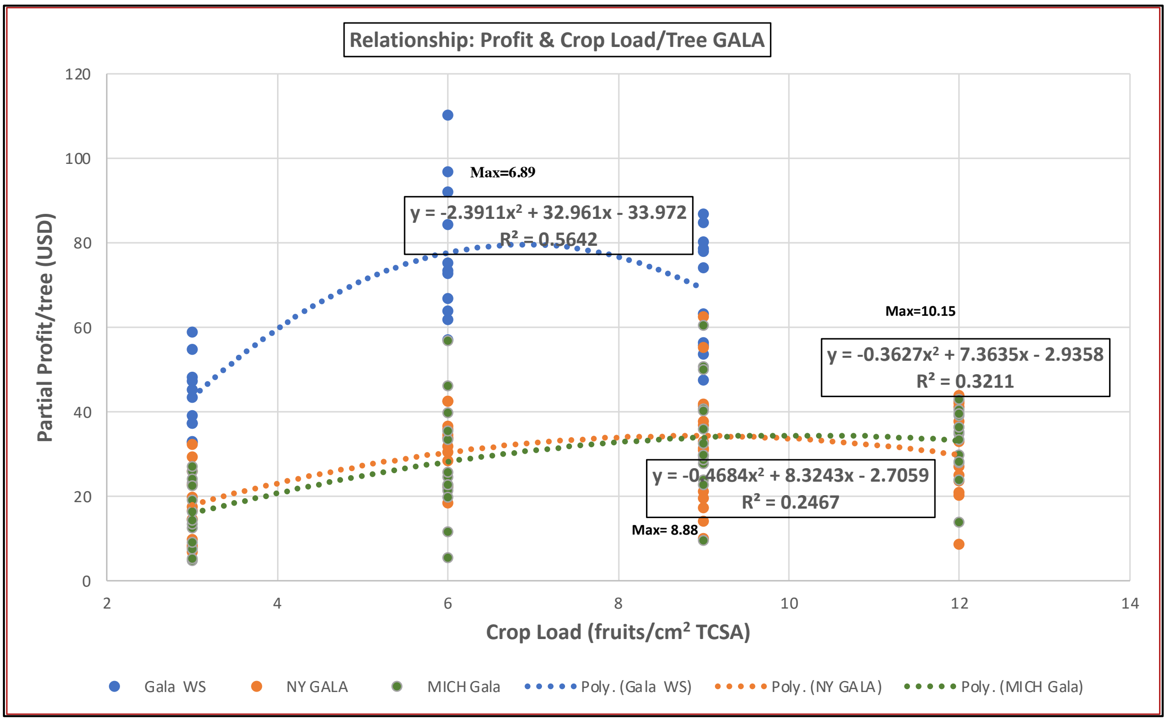

Figure 5. Relationship of crop value and crop load of 'Gala' apple trees pruned to different flower bud numbers at 3 geographic locations in the USA.

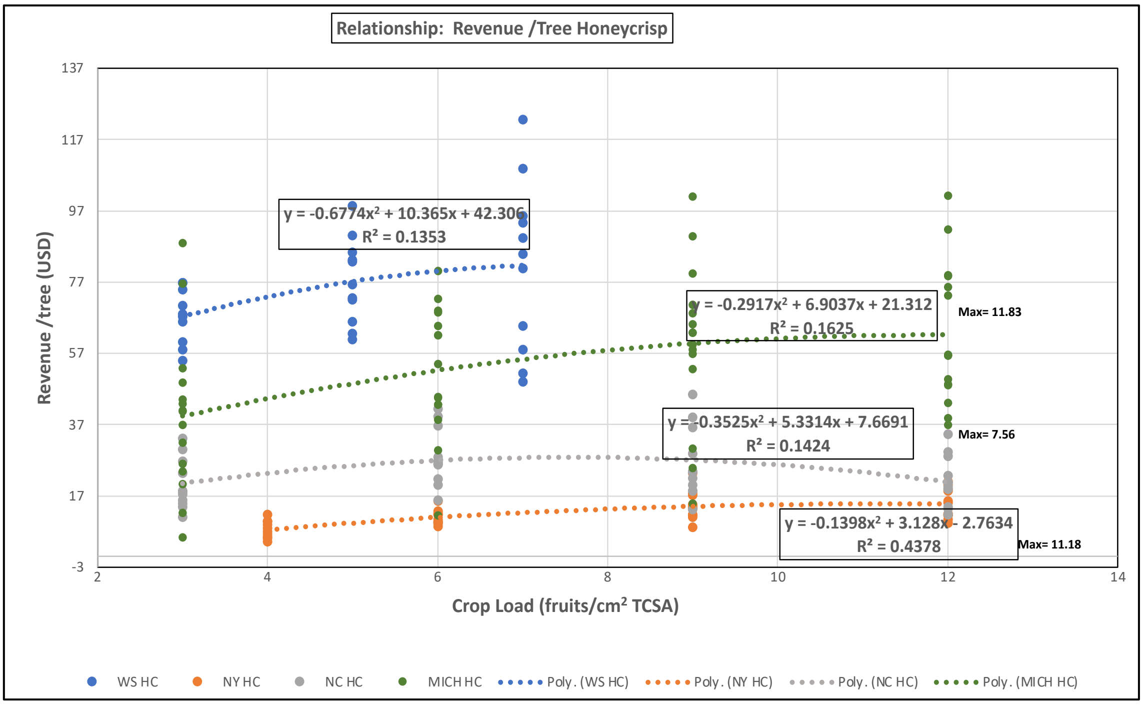

Figure 6. Relationship of crop value and crop load of 'Honeycrisp' apple trees pruned to different flower bud numbers at 4 geographic locations in the USA.