Project/Proposal Title: N, Mg, and K guidelines to control disorders for Honeycrisp and WA 38

PI: Lee Kalcsits
Organization: Washington State University
Telephone: 509-293-8764
Email: lee.kalcsits@wsu.edu
Address: 1100 N Western Ave.
City/State/Zip: Wenatchee/WA/98801

Co-PI: Bernardita Sallato
Organization: Washington State University
Telephone: 509-786-9205
Email: b.sallato@wsu.edu
Address: 24106 N Bunn Rd
City/State/Zip: Prosser/WA/99350

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Budget 1
Primary PI: Lee Kalcsits
Organization Name: Washington State University
Contract Administrator: Darla Ewald
Telephone: 509-293-8800
Contract administrator email address: dewald@wsu.edu
Station Manager/Supervisor: Chad Kruger Email Address: cekruger@wsu.edu

Item	**2020**	**2021**	**2022**
Salaries	43,200[1]	44,928	46,726
Benefits	15,895[2]	16,530	17,192
Wages	7,800[3]	8,112	8,436
Benefits	1,735[4]	1,805	1,877
Equipment			
Supplies	6,900[5]	6,900	6,900
Travel	3,240	3,240	3,240
Miscellaneous			
Plot Fees	2,500	2,500	2,500
Total	$81,270	$84,015	$86,871

Footnotes:

OBJECTIVES

This project had three objectives aimed at improving fertilizer management and establishing thresholds on fertilizer applications for Honeycrisp and WA 38.

1. Test how varying rates of N, K, and Mg affects fruit quality traits, disorder incidence, return bloom and tree vigor in Honeycrisp and WA 38 orchards.
2. Identify the relation between shoot growth, crop load, and nutrient concentration with disorder incidence for commercial orchards in WA State.
3. Develop clear thresholds for N, K, and Mg fertilization based on fruit and leaf elemental concentrations for Honeycrisp and WA 38 orchards in WA State.

SIGNIFICANT FINDINGS

1. Crop load continues to be one of the main contributing factors for the development of both bitter pit and green spot. Nutrient analysis on fruitlets and fruit need crop load data to accompany them or they are impossible to estimate risk.
2. For commercial sampling, green spot in WA 38 demonstrated the same risk indicators (high vigor, low crop load, and high K: Ca ratios) as bitter pit in Honeycrisp.
3. Green spot decreased in incidence from 2020 to 2021 going from almost 12% in 2020 to 3.7% in 2021 and then 4.2% in 2022. Further evaluations in 2023 indicated minimal green spot again across most orchards.
4. N applications increased tree vigor and green spot incidence in 'WA 38' apple and increase bitter pit in Honeycrisp apple.
5. Rootstock can also contribute to green spot and bitter pit incidence through its effect on vigor and fruit set each year.

METHODS

1. **Test how varying rates of N, K, and Mg affects fruit quality traits, disorder incidence, return bloom and tree vigor in Honeycrisp and WA 38 orchards.**

The first objective is being conducted at Sunrise Research Orchard. In response to reviewer comments, in 2020, treatments were applied every two weeks over three applications in liquid form in May and June. For both cultivars, a second experiment was used to measure seasonal response of N, Mg, and K rates on growth, physiology, and fruit quality of both Honeycrisp and WA 38 trees. These experiments were conducted on untreated trees each year to determine seasonal responses of post-bloom applications of each of N, Mg, and K to WA 38 and Honeycrisp. For Honeycrisp, crop load was carefully regulated using the combination of bloom and fruitlet thinning strategies and hand clean-up to target crop loads by June 1. WA 38 was not thinned. Shoot growth was measured at harvest.

Table 1. Rates for nitrogen, potassium, and magnesium at low, medium, and high applications rates for controlled experiments.

lbs/acre applied	Nitrogen (N)	Potassium (K)	Magnesium (Mg)
Low	12	50	25
Medium	25	100	50
High	50	200	100

Fruit quality

At harvest (early September for Honeycrisp and early October for WA 38), all fruit was completely removed from each sample tree (two trees per replicate) and weighed to provide total yield. Then, 48 fruit was randomly selected from each tree. 16 fruit were used for fruit quality at harvest and the other fruit was stored in regular atmosphere for three months at 1° C and used for disorder evaluation after storage. Elemental analysis was performed using a pooled sample consisting of a peel sample collected from the calyx end of eight fruit from each replicate. Samples were dried, ground, and acid digested then analyzed using an Agilent 4200 MP-AES elemental analyzer. N was analyzed separately with a elemental analyzer. Then, after 3 months of storage, bitter pit and green spot incidence and severity along with fruit firmness will be assessed again for fruit from each replicate.

RESULTS AND DISCUSSION

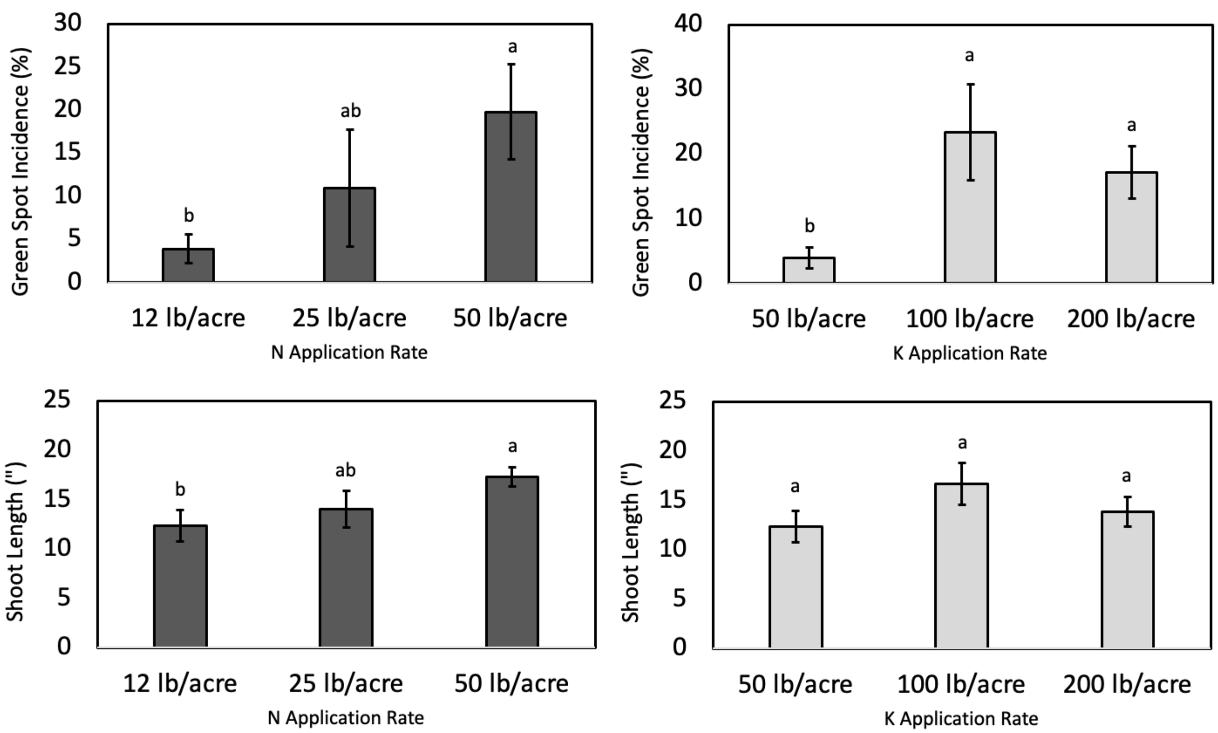

Figure 1. Green spot incidence (top) and mean shoot length (bottom) for WA 38 apple after three months of storage in regular atmosphere when treated with different soil-based application rates of N (left) and K (right). Error bars indicate standard error (N=3) and letters denote differences among treatment means.

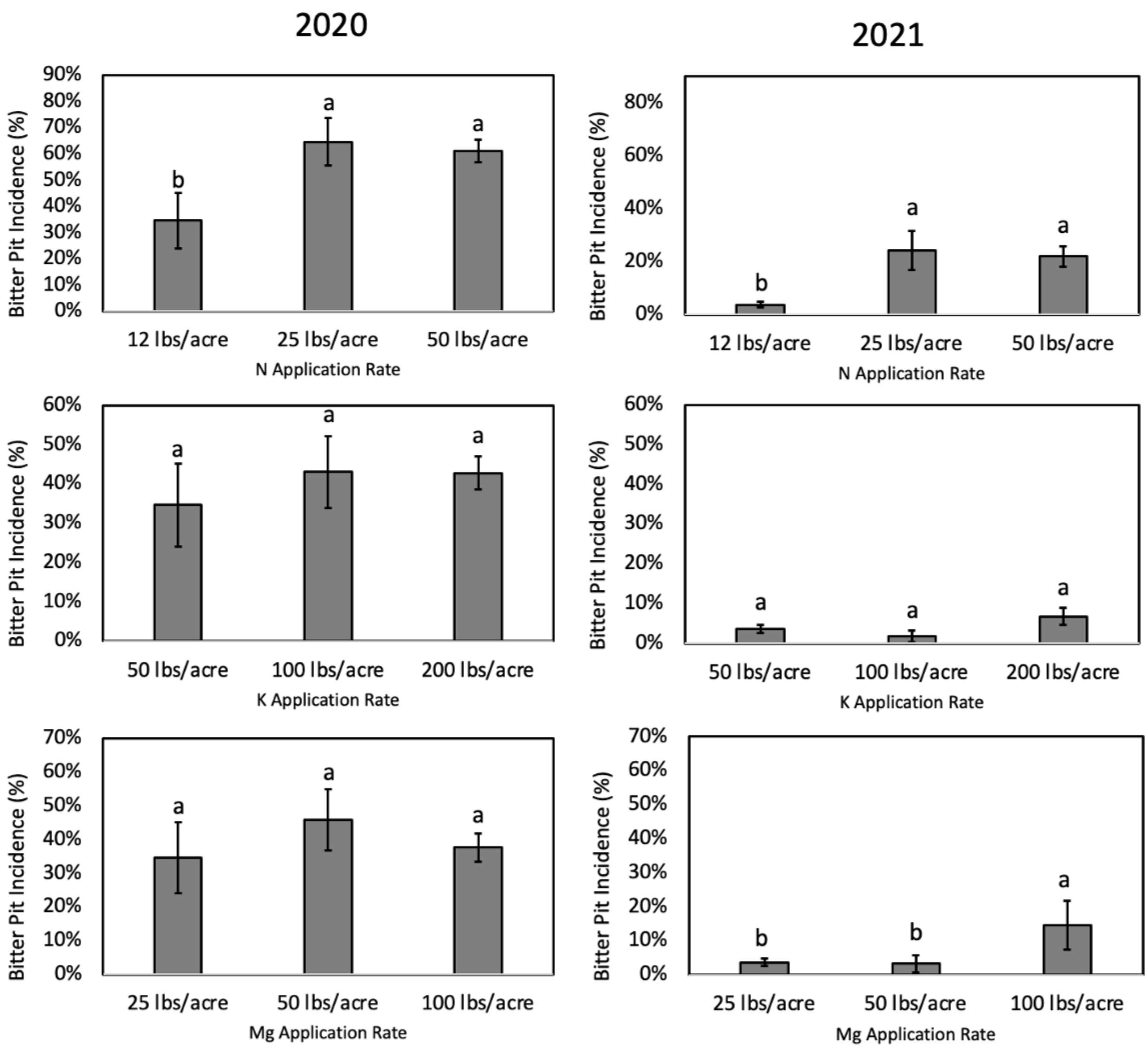

Figure 2. Bitter pit incidence in Honeycrisp apple in 2020 (left) and 2021 (right) after three months of storage in regular atmosphere when treated with different soil-based application rates of N (top), K (middle) and Mg (bottom). Error bars indicate standard error (N=3) and letters denote differences among treatment means.

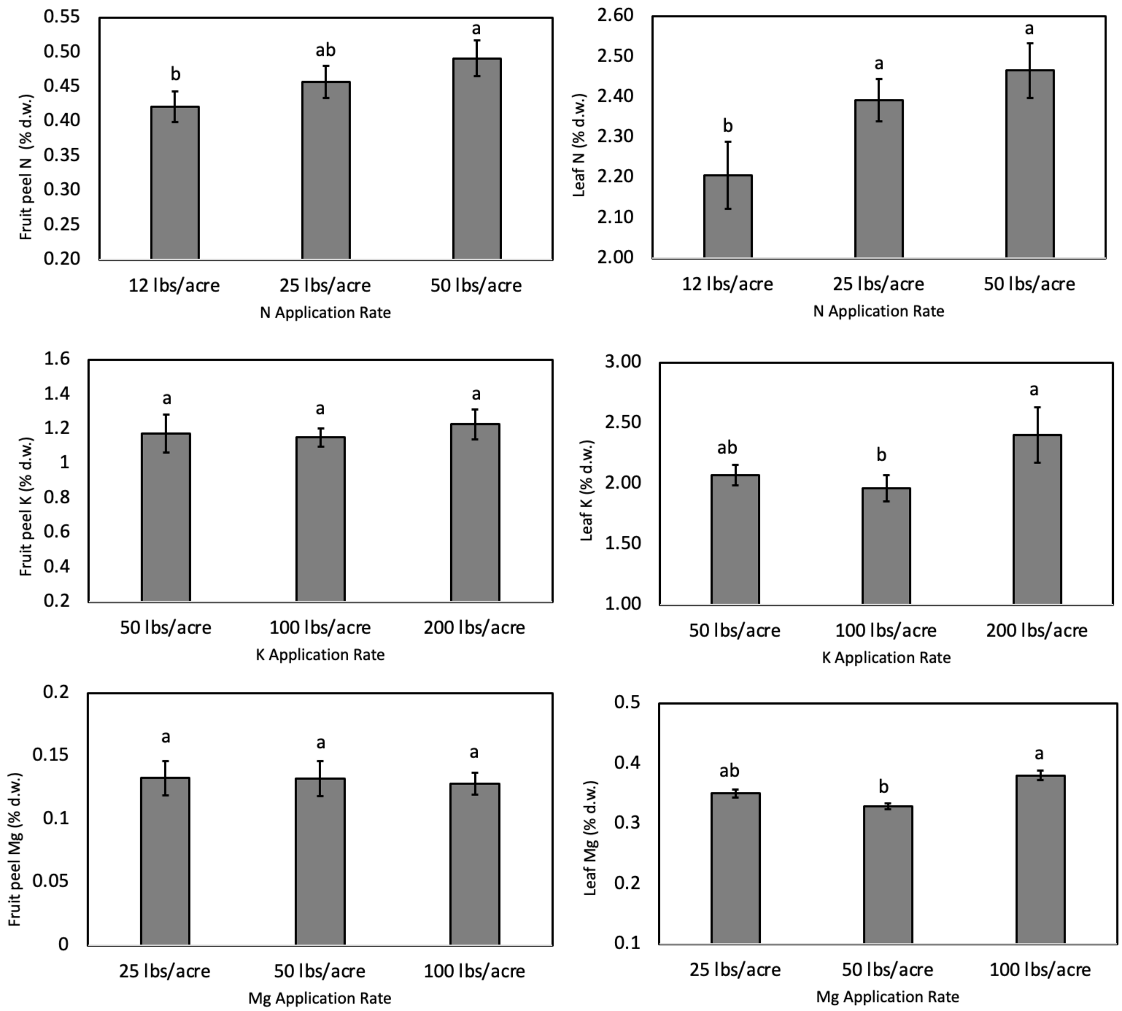

Figure 3. Fruit peel (right) and leaf (left) N (top), K (middle), and Mg (bottom) concentrations for Honeycrisp in 2020 after being treated with different rates of early-season N, K, and Mg soil applications. Error bars indicate standard error (N=3). Different letters denote significant differences among means.

2. Identify the relationship between shoot growth, crop load, and nutrient concentration with disorder incidence at harvest and after storage for commercial orchards.

Experiments conducted in objective 1 were valuable for determining thresholds and impacts of fertilization on fruit and tree physiology along with disorder incidence. However, commercial orchards span a larger range of environments, soil types, ages, training system, management strategies, and rootstocks that underscore the importance of including a thorough sampling approach to capture the range in factors that affect disorder incidence for both Honeycrisp and WA 38.

In 2020, there were a total of 42 orchards sampled for Honeycrisp and WA 38 in total. In 2021, there were 56 orchards sampled. Management information will also be collected that will include soil type, physical and chemical conditions, location and management practices to better help understand key factors on the disorder development.

In all sampled commercial orchards, three representative trees were chosen and diameter measured. Fruitlet and leaf samples were collected at this time for nutrient analysis. We added a component using fruitlet sap analysis in collaboration with Dr. Lailiang Cheng from Cornell University and are working to compile the results from that study. Fruit was harvested within three days of commercial harvest for all sites. At harvest, fruit counts were determined for selected trees and a subsample of 32-48 fruit per tree was collected. Half were placed in cold storage for three months and fruit quality will be measured using the parameters described in objective 1. Shoot growth will also be measured on 20 terminal shoots per tree. Fruit peel elemental analysis was performed as described in objective 1 including N, Ca, Mg, and K concentrations along with $\delta^{13}C$ analysis as an indicator of irrigation management relative to soil type. Elemental analysis was completed for 2020 and is in the process of being completed for 2021. Data for elemental composition will be presented for 2020 and disorder incidence, yield, etc. will be presented for both year.

3. **Develop clear thresholds for N, K, and Mg fertilization based on fruit and leaf elemental concentrations for Honeycrisp and WA 38 orchards in WA State.**

This work started in 2021 and will continue after the end of the project as regular Extension material. This will include Extension deliverables prepared by both Lee Kalcsits and Bernardita Sallato. Peer-reviewed publications are being written in 2024 that will be communicated and summarized for the industry like this existing report.

RESULTS AND DISCUSSION

For all WA 38 orchards that were sampled in all three years, 88%, 82%, and 82% of target crop load was achieved in 2020, 2021, and 2022, respectively. These targets were based on 5 fruit cm^{-2} TCSA in 2020 and 6 fruit cm^{-2} TCSA in 2021 and 2022. For Honeycrisp, crop load targets were 5 fruit cm^{-2} TCSA for all three years. Honeycrisp orchards achieved a higher % target in 2020 at 95% then fell lower again at 82% and 81% of target crop load for 2021 and 2022, respectively. Lower harvested yields compared to optimum is indicative of the hot period and wind events that led to fruit loss in 2021 and then the cold spring in 2022 that may have caused freezing damage and/or poor pollination. For Honeycrisp, orchards that had higher than optimum crop loads in 2020 averaged 7.6 fruit cm^{-2} TCSA and as a result, yields averaged 40% lower the following year in 2021. These same orchards had only 13.5% bitter pit in 2020 compared to an increase to 33.3% in 2021. Off years drive bitter pit risk. Orchards that were able to maintain crop load within 1 fruit cm^{-2} TCSA target in 2020, were able to maintain consistent crop in 2021 averaging 5.24 fruit cm^{-2} TCSA and then 4.56 fruit cm^{-2} TCSA in 2022. Bitter pit in those orchards with an optimum crop load averaged 5.4% and 17.8% in 2020 and 2021, respectively.

Bitter pit incidence was not different between the two years reported here (2020 and 2021) and averaged approximately 15% across both years. Fruit weight was significantly higher for WA 38 than Honeycrisp most likely because they were younger trees than Honeycrisp. There were significant differences in fruit peel nutrient concentrations for WA 38 and Honeycrisp. Fruit potassium concentrations were higher for Honeycrisp (Tables 4). Magnesium concentrations were not different between the two cultivars. Calcium and nitrogen concentrations were higher for WA 38 than

Honeycrisp. When a statistical clustering approach was used to cluster outcomes for groups of orchards into five different categories, there were significant differences in bitter pit and green spot among the clusters (Tables 6 and 7). Orchard years that clustered low for bitter pit in Honeycrisp had low vigor and optimum crop load. Although vigor was higher for WA 38 in general, vigor didn't cluster with green spot for commercial orchards. However, crop load clustered closely to green spot where orchard years with low crop load had clear elevated incidence of green spot. Rapid fruit growth associated with high carbohydrate loading during fruit expansion may be responsible for cracks and green spot developing on the peel of WA 38.

There have been significant discussions about the use of fruitlet and leaf testing for predicting bitter pit at harvest. Our results show that there are significant relationships between fruitlet and leaf concentrations in June compared to fruit peel concentrations at harvest. However, fruitlet (K+Mg)/Ca ratios were related to bitter pit incidence in Honeycrisp. The variability around these ratios limits the predictive power. There are many factors that happen following June sampling that can affect final bitter pit risk. Examples of this include rapid fruit growth, post sampling thinning, summer pruning, irrigation management. All of these can change the nutrient ratios and limit the usefulness of those June fruitlet samples. These samples might indicate if there are some potential problems emerging, but crop load and vigor assessments will probably catch the same issues without needing the nutrient analysis unless the grower is trying a new fertility program or product. Fruitlet and leaf N and K concentrations clustered with bitter pit and green spot risk in Honeycrisp and WA 38 (Tables 8 and 9). Both nutrients are associated with rapid fruit growth and larger fruit sizes. These appear to be targets for early season monitoring and have the potential to be remobilized and accumulate later in the season in developing fruit. N and K also were the most closely correlated with final fruit nutrient concentrations (Figures 4 and 5). We also had the opportunity to test the peel sap method with traditional fruitlet sampling. Ratios in sap were significantly positively related to bulk nutrient ratios in the fruitlets. (K+Mg)/Ca ratios for both methods were significantly correlated with bitter pit risk for Honeycrisp for commercial orchards. However the predictive power of these ratios in fruitlets was relatively low compared to near harvest. Fruit peel N/Ca ratios remain a good indicator of green spot and bitter pit. These results were supported by findings from our controlled experiments presented in 2021 where elevated N and K applications contributed to elevated green spot risk in WA 38.

Table 2. Commercial orchard sampling for WA 38 and Honeycrisp used for objective 2

	'WA 38'	**'Honeycrisp'**
2020	23	28
2021	19	22
2022	17	22
Total 'Orchard Years'	**59**	**72**

Table 3. Descriptive statistics and range in agronomic variables among commercial orchards for 'Honeycrisp'.

	Bitter pit (%)	Shoot length (inches)	Crop load (fruit cm^{-2} TCSA)	Fruit weight (g)
		2020		
Average	16.6	6.5	5.4	231
Minimum	0	1.0	1.1	156
Maximum	94.6	13.3	14.2	325
		2021		
Average	14.4	4.5	4.0	214
Minimum	0	1.8	0.95	111
Maximum	71.9	7.6	9.5	317
		2022		
Average	*	6.6	4.2	253
Minimum	*	3.8	0.85	205
Maximum	*	18.1	11.9	275

Table 4. Descriptive statistics and range in agronomic variables among commercial orchards for 'WA 38'.

	Green spot (%)	Shoot length (inches)	Crop load (fruit cm^{-2} TCSA)	Fruit weight (g)
		2020		
Average	13.47	7.9	4.4	286
Minimum	0	3.0	0.8	186
Maximum	72.2	14.4	11.4	385
		2021		
Average	3.91	8.5	5.3	272
Minimum	0	2.7	1.1	184
Maximum	18.75	13.6	10.9	327
		2022		
Average	4.1	8.0	5.5	277
Minimum	0	5.0	1.8	225
Maximum	19.1	12.6	12.1	306

Table 5. Descriptive statistics and ranges in fruit peel nutrient concentrations among commercial orchards for ‘WA 38’ and ‘Honeycrisp’.

	Calcium (mg g^{-1} dw)	Potassium (mg g^{-1} dw)	Magnesium (mg g^{-1} dw)	Nitrogen (mg g^{-1} dw)
		WA 38		
Average	0.9	7.2	1.0	4.5
Minimum	0.2	5.5	0.7	2.7
Maximum	1.9	13.8	1.9	5.8
		Honeycrisp		
Average	0.7	9.6	1.1	3.9
Minimum	0.1	6.2	0.7	2.5
Maximum	2.7	15.6	1.6	5.9

Table 6. Clustering of variability in bitter pit among 72 commercial orchard years for ‘Honeycrisp’. These are statistically clustered orchards with centered values for each variable.

Risk	Bitter pit (%)	Shoot length (inches)	Crop load (fruit cm^{-2} TCSA)	Fruit weight (g)	Fruit Ca (mg g^{-1} dw)	Fruit K (mg g^{-1} dw)	Fruit Mg (mg g^{-1} dw)	Fruit N (mg g^{-1} dw
Low	8.2	6.5	4.9	226	0.72	9.8	1.02	3.8
Low	11.6	4.9	4.9	179	0.74	9.1	0.98	3.8
Moderate	20.0	8.8	4.6	284	0.64	9.2	1.03	3.8
High	69.2	11.2	3.7	247	0.52	9.2	1.07	3.7
Very High	83.5	17.1	2.8	339	0.27	7.5	1.03	4.0

Table 7. Clustering of variability in green spot among 59 commercial orchard years for ‘WA 38’. These are statistically clustered orchards with centered values for each variable.

Risk	Bitter pit (%)	Shoot length (inches)	Crop load (fruit cm^{-2} TCSA)	Fruit weight (g)	Fruit Ca (mg g^{-1} dw)	Fruit K (mg g^{-1} dw)	Fruit Mg (mg g^{-1} dw)	Fruit N (mg g^{-1} dw
Low	3.1	8.1	6.0	258	0.97	7.1	0.97	4.4
Low	4.1	9.6	7.5	210	1.09	6.5	0.94	4.6
Moderate	8.5	8.3	4.7	301	0.81	7.4	1.00	4.4
Mod-High	17.7	7.3	3.0	356	0.65	8.5	1.11	4.6
Very High	51.9	8.1	1.7	314	0.32	8.0	0.99	4.9

Table 8. Clustering of variability in bitter pit associated with fruitlet and leaf nutrient concentrations that were sampled in late June. These are statistically clustered orchards with centered values for each variable.

Risk	Bitter pit (%)	Fruitlet Ca (mg g^{-1} dw)	Fruitlet K (mg g^{-1} dw)	Fruitlet Mg (mg g^{-1} dw)	Fruitlet N (mg g^{-1} dw	Leaf Ca (mg g^{-1} dw)	Leaf K (mg g^{-1} dw)	Leaf Mg (mg g^{-1} dw)	Leaf N (mg g^{-1} dw
Low	0.8	0.87	11.9	0.78	6.3	21.6	15.5	4.6	26.1
Moderate	10.6	0.81	13.8	0.88	10.7	21.6	16.5	4.1	27.8
Mod-High	23.0	0.83	13.1	0.73	7.1	25.7	16.8	5.2	28.8
High	57.1	0.95	13.7	0.81	10.1	29.5	15.5	5.9	27.5
Very High	77.3	1.05	15.5	1.04	11.5	21.9	17.5	5.4	30.1

Table 9. Clustering of variability in green spot associate with fruitlet and leaf nutrient concentrations that were sampled in late June. These are statistically clustered orchards with centered values for each variable.

Risk	Green spot (%)	Fruitlet Ca (mg g^{-1} dw)	Fruitlet K (mg g^{-1} dw)	Fruitlet Mg (mg g^{-1} dw)	Fruitlet N (mg g^{-1} dw	Leaf Ca (mg g^{-1} dw)	Leaf K (mg g^{-1} dw)	Leaf Mg (mg g^{-1} dw)	Leaf N (mg g^{-1} dw
Low	3.6	1.86	17.4	1.31	10.2	20.4	22.3	4.3	25.8
Moderate	2.5	1.83	17.9	1.36	11.2	21.2	22.9	3.9	28.0
Mod-High	30.5	1.47	19.0	1.26	11.5	15.3	19.7	3.4	24.9
High	38.9	1.92	19.3	1.60	17.6	23.6	21.8	4.6	29.4
Very High	59.3	1.89	20.5	1.64	15.4	24.4	28.9	4.2	29.8

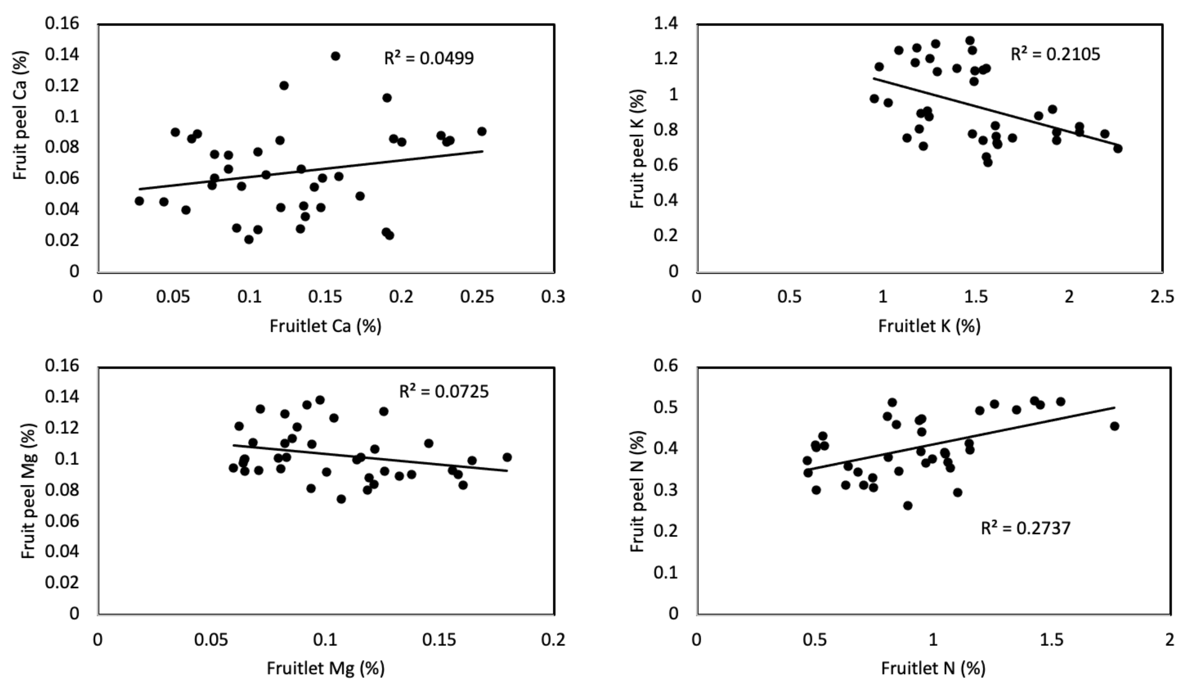

Figure 4. Relationships between fruitlet and leaf and fruit nutrient concentrations for WA 38 and Honeycrisp.

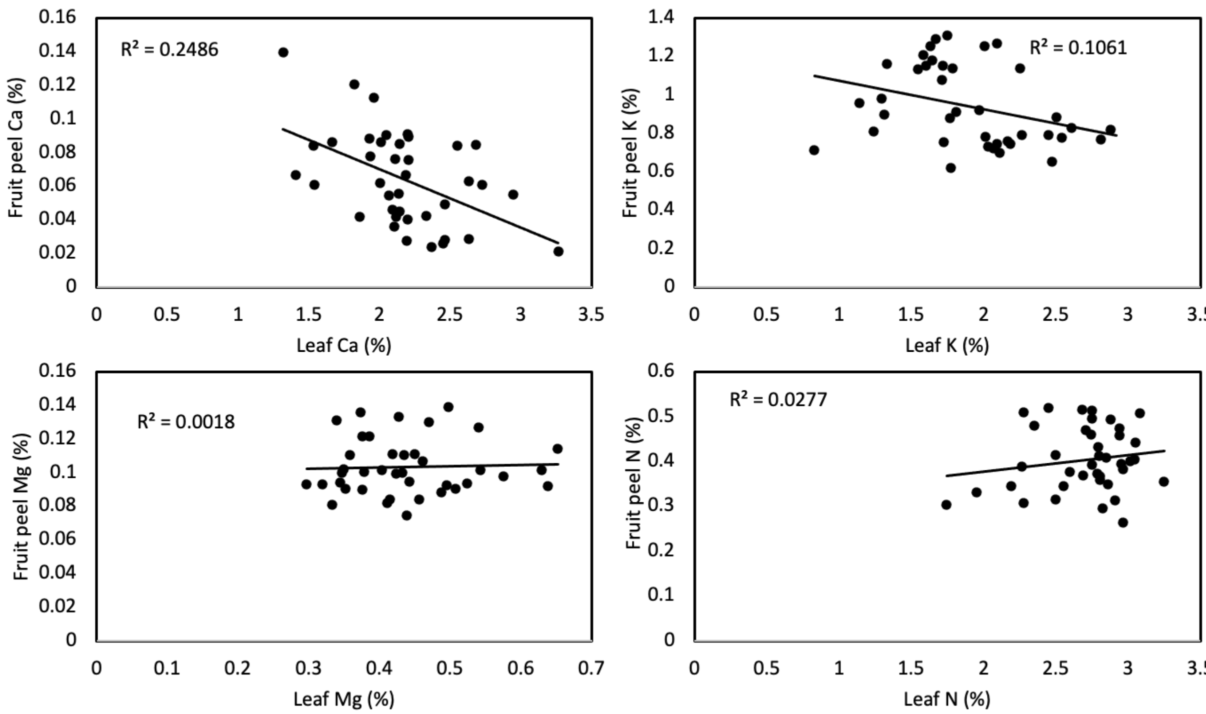

Figure 5. Relationships between fruitlet and leaf and fruit nutrient concentrations for WA 38 and Honeycrisp.

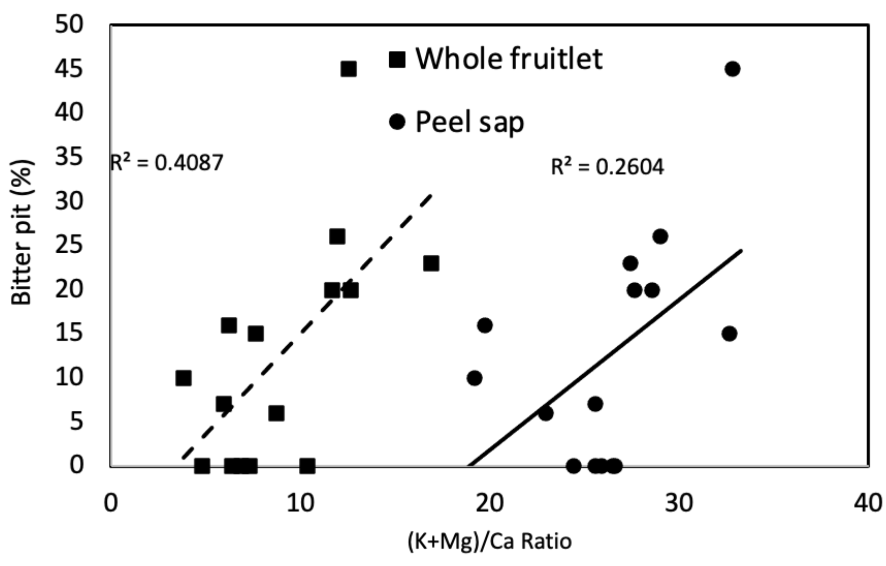

Figure 6. Relationship between peel sap and traditional whole fruitlet analysis and bitter pit in Honeycrisp

EXECUTIVE SUMMARY

Project title: N, Mg, and K guidelines to control disorders for Honeycrisp and WA 38

Keywords: Fertilizer management, bitter pit, green spot, physiological disorders

Abstract: For Honeycrisp, nutrient management is critical for limiting bitter pit. In this project, we used experimental and commercial orchard sampling approaches to better understand the roles of antagonistic nutrient contents in leaves, fruitlets, and fruit peel at harvest on bitter pit and green spot development for Honeycrisp and WA 38, respectively. For experimental approaches, we altered the application of potassium, magnesium, and nitrogen in a non-limiting orchard environment that span the normal range of application rates advised for WA state apple producers. N applications increased tree vigor and green spot incidence in 'WA 38' apple and increase bitter pit in Honeycrisp apple. For commercial orchards, bitter pit ranged from near 0 in some orchards to nearly 100% in other orchards. Green spot decreased in incidence from 2020 to 2021 going from almost 12% in 2020 to 3.7% in 2021 and then 4.2% in 2022. Further evaluations in 2023 indicated minimal green spot again across most orchards. For commercial sampling, green spot in WA 38 demonstrated the same risk indicators (high vigor, low crop load, and high K: Ca ratios) as bitter pit in Honeycrisp. Crop load was one of the main contributing factors for the development of both bitter pit and green spot. Rootstock can also contribute to green spot and bitter pit incidence through their effects on vigor, nutrient uptake, and fruit set each year. However, even rootstocks like G.41 can continue to produce high yields of green spot free fruit if crop loads are sufficient every year. Nutrient analysis on fruitlets and fruit need crop load data to accompany them or they are impossible to estimate risk. Leaf analysis was not a useful indicator of final fruit nutrient status. Fruitlet analysis gives early indications of problems, but other factors can lead to divergence from fruitlet values and final fruit nutrient content. Fruitlet sap analysis developed at Cornell corresponded to fruit nutrient concentrations at harvest and may also be an option for early risk identification. However, risk assessment can be as simple as evaluating vigor and crop load including identifying areas of the orchard which may be light in crop load.