FINAL PROJECT REPORT

Project Title: Calcium fertilization efficacy

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Total Project Request: **Year 1:** 13,000 **Year 2:** **Year 3:**

Other funding sources: **Awarded**
Root Growth Management to Reduce Ca Deficiency Disorders in Apples and Cherries. Washington State USDA- Specialty Crop Block Grant. $152,938. P.I. B. Sallato. Co-P.I.s; L. Kalcsits, M. Whiting.

Budget 1
Organization Name: Washington State University **Contract Administrator:** Katy Roberts
Telephone: (509) 335-2885 **Email address:** arcgrants@wsu.edu

Item	**2020**
Salaries	
Benefits	
Wages	4800
Benefits	480
Equipment	
Supplies	7312
Travel	653
Miscellaneous	
Plot Fees	
Total	13,100

Footnotes: Supply include Soil, Tissue and Fruit nutrient analyses; 328 x 18 USD for tissue (leaf, fruit, buds, flowers and fruitlets) and 64 x 22 USD for complete soil test (includes WSU discount) = 7312. Travel for two sites (10 times x 94 miles average x 0.54 = 508), Wages (320 hours at 15 USD/hour plus 10% benefits) for temporary support during sampling.

OBJECTIVES

Calcium (Ca^{+2}) nutrient has been recognized as one key element due to its many roles plant physiological processes and fruit development (Marschner, 2002). Several fruit disorders have been associated to Ca^{+2} deficiencies, being bitter pit (BP) the most important Ca deficiency disorder in apples in Washington (Kalcsits 2017). The application of Ca to reduce Ca related disorders have been widely used in apple production (Ferguson et al., 1979). In Washington, growers have reported an intensive Ca spray program with inconsistent results or no improvement at all. The objective of this project was to evaluate different calcium treatments in two different conditions, developing a thoughtful diagnostic process to determine:

1) Calcium fertilizer efficacy on nutrient uptake.

2) Calcium fertilizer efficacy on fruit quality in 'Honeycrisp' apples.

SIGNIFICANT FINDINGS

- The two sites had significant differences in BP incidence at harvest and after storage, with high incidence at Site 1 with average of 54% compared to 24% on Site 2.
- Among treatments, there were no statistical differences in controlling BP incidence. However, when compared with the control receiving no Ca, F_CaCO3 and F_ Ca+N where effective in reducing BP on Site 1 and Site 2, respectively.
- At Site 2, where sulfate (S) levels in the soil were deficient, S_CaSO4 improved fruit firmness when compared with the control, but there were no differences between the other Ca treatments.
- On both sites, Ca treatments had no effect on Ca uptake by the fruitlets, leaves of fruit flesh and peel, and none of these measurements correlated with BP incidence, thus should not be utilized as BP predictors.
- Possible causes for the higher BP incidence exhibited at Site 1 can be associated to: reduced root growth, excessive levels of soil K (above 250 mg/kg) and oversized fruit.
- Results from the treatments receiving 12 lbs of Ca/acre in this trial, did not differ from the results observed from the grower-managed areas, where total applied Ca was more than 200 lbs/acre and 400 lbs/acre on Site 1 and Site 2, respectively.
- From this one year trial, it appears that prophylactic applications of calcium are ineffective for reducing BP.

RESULTS AND DISCUSSION

This research was conducted in two 'Honeycrisp' orchards located near Pasco, WA. The application method, date and formulations for each orchard are indicated in table 1. The total amount of actual Ca applied was equal for all treatments at 12 lbs/acre, equivalent to 36 lbs of CaCl/acre. Dry products were dissolved in water and soluble products were diluted according to the label recommendations. Treatments were applied on 6 or 4 dates for foliar and soil, respectively, every 14 days starting at petal fall. Gyspum ($CaSO_4$) was applied in one application with the second irrigation. Foliar sprays were applied with a Flow-Zone FZSAAJ-2 4-Gallon Cyclone Multi-Use 18V Lithium-Ion Backpack Sprayer, with automatic PSI controller. The experimental unit consisted of 10 trees, replicated 4 times in a complete randomize design with one border rows on each side.

Table 1. Treatments: commercial name, method and total cost for 12 lbs of actual Ca/acre.

Treatment	Commercial name	Method	USD/acre[b]
Control	Control (No Calcium)	-	-
F_CaCl	Mora-Leaf® Calcium (Wilbur-Ellis Company LLC)	Foliar	$16
F_$CaCO_3$	Mainstay ™ Calcium (Redox Chemical LLC)	Foliar	$120
F_Ca+1%-N	ProNatural ® Calcium Plus (Wilbur-Ellis Company LLC)	Foliar	$444
S_CaCl	Mor-Calcium (Genesis Agri Products, Inc)	Soil	$16
S_$CaCO_3$	Mainstay ™ Calcium (Redox Chemical LLC)	Soil	$120
S_$CaSO_4$	Pro-Pell-it (Marion Ag Service Inc.)	Soil	$13

Note: 1. Soil CaCl was not applied to the soil in orchard 2 (Sagemore) as it is not labelled for organic production. b. Cost estimate for the 12 lbs/acre of actual Ca applied. Includes only the fertilizer at a standard rate for bulk purchase and does not include application cost.

While not included in the experimental design, additional sampling unit was included as the grower's managed area from three representative trees to compare with the standard grower's practice. The Ca program for each site is described below:

- Site 1: Two applications of 500 lbs/acre of CaSO4 (Gypsum) plus 30 lbs/acre of CaCl spread in 5 sprays and 8 gallons/acre of Ca+1%N spread in 20 dates during the growing season. The total Ca unit applied summed 210 lbs/acre by ground and 14 lbs/acre by foliar spray. Fertilizer cost was approximately 378 USD/acre.
- Site 2: One application of 2000 lbs/acre of CaSO4 (Gypsum) during spring plus 9 lbs/acre of CaCl spread in 5 sprays, one spray of 0.2 lbs/acre with Ca+1%N and 12.2 lbs/acre of $CaCO_3$ alone or in combination with Silicon (Si). The total Ca unit applied summed 430 lbs/acre via ground and 11.5 lbs/acre via spray. Fertilizer cost was approximately 650 USD/acre.

Complete details about the methods can be found in the proposal Sallato_Ca_New_2019.

Initial conditions

Both sites were mature 'Honeycrisp' orchard located in Franklin county, WA with mean annual precipitation between 6 to 12 inches.

Site 1: 'Honeycrisp' grafted onto Malling 9 (M9- Nic 29) rootstock on a spindle system at 12 ft x 1.5 ft spacing. The block is located near Pasco 46°20'35.8"N 119°08'57.8"W. The soil series at this site is associated to Quincy loamy fine sand, an Entisoil formed in sands on dunes and terraces. This soil series cover 714,600 acres of eastern Washington, representing a large portion of apple orchards located in Quincy, Mattawa, Basin City and Pasco area (Figure 1, left.) The soil profile had a surface layer ranging from 4 to 60 inches of loamy find sand and a second strata of fine sand, with excessive drainage in some areas.

Site 2: 'Honeycrisp' grafted onto EMLA (M26) rootstock on a V trellis system at 12 ft x 6 ft spacing. Each rootstock supports 4 leaders tied horizontally to the first wire plus 6 upright leaders (3 per side). The orchard is in Sagemoor 46°24'14.1"N 119°14'05.5"W. The soil type at this site can be associated to Warden silt loam series, and Aridisoil, silt loam soil, alkaline, well drained. Warden series cover 486,111 acres, representing a large proportion of orchards in the Yakima valley and the Basin (Figure 1, right).

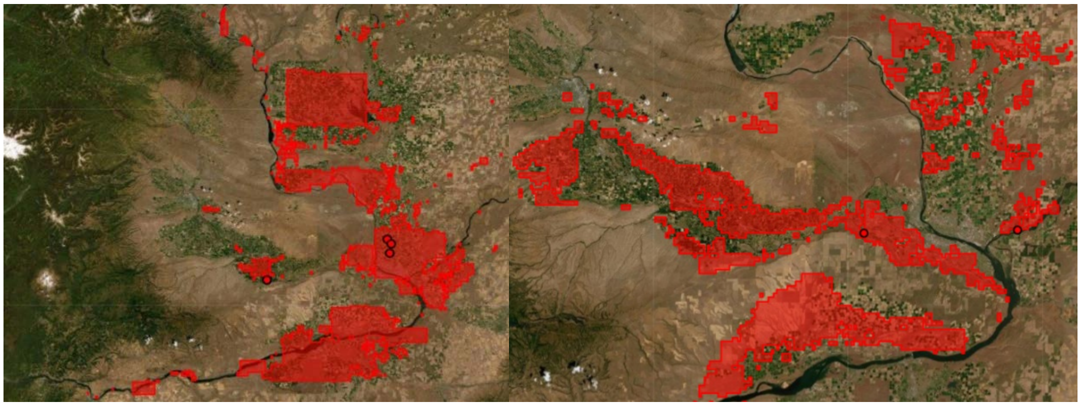

Figure 1. Map of soil series associated to Quincy (left) and Warden (right). (USDA-NRCS Web Soil Survey).

For Site 1, the first strata had nine inches of loamy sand (75% sand) followed by fine sand of at least 20 inches deep. Most fine roots were observed in the first strata with few roots observed in the second strata (Figure 2, left). Site 2 had 2 feet of effective soil depth with varying soil conditions, but predominantly silt loam soil with large volume of roots growing throughout the soil profile (Figure 2, right).

Figure 2. Soil profile for the top 3 foot. left: Site 1 (Quincy series) near Pasco, right: Site 2 (Warden series) in Sagemoor.

For each site, soil samples were collected from the strata where most fine roots were observed. Soil chemistry for Site 1 was representative of a Quincy series with neutral pH, cation exchange capacity (CEC) of 8 meq/100g and within the low range of Ca and Mg. However, it had elevated levels of P and K (42 and 325 mg/kg respectively), uncommon on sandy soils. High levels of P and K in sandy textured soil are indicative of drainage impediments in the soil profile, which can be attributed to the texture differences within the soil profile. Site 2 had alkaline pH and higher CEC (10 meq/100g), representative of Warden silt loam series. Cation levels were adequate, while P, S and B levels were low.

To evaluate inherent nutrient variability of each orchard, dormant buds and blooms were collected from spurs on 2 year old wood, from 20 random trees, prior to the application of treatments. Both sites had consistent nutrient levels within the orchard, reflecting low initial variability between trees (data not shown). Between orchards, nutrient levels were equivalent, except for Ca and B were Site 1 had 30% more Ca and almost half the amount of B.

Table 2. Soil nutrient and physical initial conditions for Site 1 (Quincy soil series) and Site 2 (Warden soil series). Average of four randomly collected samples.

Soil test	**Unit**	**Optimal**	**Site 1 (Pasco)**	**Site 2 (Sagemoor)**
pH	-	5.0 – 7.0	6.9	**7.9**
O.M	%	> 1	1.1	1.3
E.C paste	mmhos/cm	< 2.5	0.4	0.4
Nitrate _(NO_3_N)	mg/kg	-	3.4	2.3
Ammonium _(NH^4_N)	mg/kg	-	2.6	2.5
Phosphorus (P)	mg/kg	15 - 40	**42**	**8**
Potassium (K)	mg/kg	150 - 250	**325**	217
Potassium (K)	meq/100g	0.4 - 0.6	0.8	0.6
Calcium (Ca)	meq/100g	4.1 - 20	5.8	7.4
Magnesium (Mg)	meq/100g	0.5 – 2.5	2.8	3.9
Sodium (Na)	meq/100g	< 0.5	0.2	0.2
Total Base	meq/100g	-	9.6	12.0
CEC	meq/100g	11 - 40	9.6	12.0
Boron (B)	mg/kg	1.0 – 1.5	**0.2**	**0.3**
Sulfur (S)[b]	mg/kg	9 - 20	12.3	**5.0**
Zinc (Zn)	mg/kg	> 1.0	2.6	4.0
Copper (Cu)	mg/kg	> 1.0	4.6	3.2
Manganese (Mn)	mg/kg	1 - 4	3.9	1.3
Iron (Fe)[c]	mg/kg	-	26.3	8.8
Sand	%	-	75.0	40.0
Clay	%	-	1.0	5.0
Silt	%	-	24.0	55.0

Methods: Methods: Plant, Soil and Water Reference Methods for the Western Region. 2005. R. G. Gavlak, D. A. Horneck, and R. O. Miller. http://www.naptprogram.org

1. Treatment effect on nutrient uptake

Treatment effect on nutrient concentration was determined for each replicated unit on fruitlets at 10 mm size (of golf ball), leaves during late July (when middle shoot leaves were mature) and in fruit peel and flesh during harvest (more details about the methodology can be found in the proposal).

Fruitlet nutrient analyses

Fruitlet nutrient concentration was not affected by treatments on either site except for B levels on Site 1 (Table 3 and 4). Despite the higher amount of initial Ca in blooms on Site 1, fruitlet Ca levels were equivalent in both sites (0.12 – 0.14 %) with no difference among treatments. There were significant differences between nutrient levels when comparing between orchards ($p < 0.001$) except for Ca fruitlet levels that were equivalent (0.12 %). Site 1 had higher levels of N, P and K and lower levels of B. Based on the fruitlet concentration recommendation from the pomological fruit center of Universidad de Talca in Chile (Centro de Pomaceas, 2011), Site 1 was above adequate concentration on N, P, K and Mg, while Site 2 was within range except of P and Mg slightly above the recommended levels.

Table 3. Effect of calcium treatments on 'Honeycrisp' fruitlet mineral concentration (dry weight) in Pasco orchard (Site 1).

Treatments	%					mg/kg
	N	P	K	Ca	Mg	B
Control	0.95	0.17	1.46	0.12	0.1	23 a
F_CaCl	0.92	0.17	1.39	0.12	0.1	16 bc
F_CaCO	0.95	0.17	1.44	0.13	0.11	15 c
F_Ca+N	0.97	0.17	1.45	0.14	0.1	22 ab
S_CaCl	0.87	0.15	1.3	0.12	0.1	20 abc
S_CaCO	0.94	0.16	1.34	0.12	0.1	19 abc
S_CaSO	0.94	0.16	1.38	0.12	0.1	16 bc
Pr > F(Model)	ns	ns	ns	ns	ns	0.006

Different letters within column indicate significant difference determined by Tukey mean separation test (a = 0.05).

Table 4. Effect of calcium treatments on 'Honeycrisp' fruitlet mineral concentration in Sagemoor orchard (Site 2).

Treatments	%					mg/kg
	N	P	K	Ca	Mg	B
Control	0.65	0.13	1.17	0.13	0.09	22.2
F_CaCl	0.59	0.13	1.1	0.12	0.08	21.3
F_CaCO	0.64	0.12	1.05	0.13	0.09	21.5
F_Ca+N	0.58	0.13	1.09	0.13	0.09	21.1
S_CaCO	0.57	0.12	1.04	0.12	0.09	22.3
S_CaSO	0.62	0.12	1.07	0.12	0.09	22.4
Pr > F(Model)	ns	ns	ns	ns	ns	ns

ns: no significance determined by ANOVA test ($p < 0.05$).

Leaf nutrient analyses

Leaf nutrient levels have been utilized for more than 50 years as an indicator for nutrient uptake by the plant and yield. For leaves tissue analyses, there are validated standards that can be utilized as reference to determine overall nutrient status, health of the trees, deficiencies, or toxicities.

Treatment effect on nutrient concentration varied between orchards. At Site 1, soil treatment S_CaCO had the highest amount of N in leaves followed by S_CaSO and F_Ca+N with no significant differences (Table 5). The lowest concentration was observed in the control and all foliar sprays. However, all treatments were within adequate range for N concentration (Shear and Faust. 1980, Riguetti et al 1990). The improved N uptake with the soil Ca treatments might be a consequence of the removal of weeds around the trunk done on the soil treatments. Thus, improving the root zone environment. Leaf treatments had higher K levels, however, only F_Ca+N was higher than the control (Table 5). The F_Ca+N impact on K uptake was not determined. Despite the differences between treatments in N and K, all nutrient levels were within the adequate ranges (Shear and Faust. 1980, Riguetti et al 1990).

Table 5. Effect of calcium treatments on ‘Honeycrisp’ leaves mineral concentration in Pasco orchard (Site 1).

Treatments	%					mg/kg
	N	P	K	Ca	Mg	B
Control	2.2 c	0.21	1.4 bcd	1.68	0.40	33
F_CaCl	2.3 bc	0.23	1.6 ab	1.64	0.42	39
F_CaCO	2.3 bc	0.23	1.5 abc	1.90	0.42	37
F_Ca+N	2.2 c	0.23	1.6 a	1.72	0.40	35
S_CaCl	2.4 abc	0.22	1.3 d	1.71	0.42	30
S_CaCO	2.5 a	0.22	1.3 cd	1.65	0.41	40
S_CaSO	2.4 ab	0.23	1.4 bcd	1.78	0.44	35
Pr > F(Model)	0.037	ns	0.018	ns	ns	ns
Grower*	2.1	0.18	1.1	2.2	0.49	25

ns: no significance determined by ANOVA test ($p < 0.05$). Different letters within column indicate significant difference determined by Tukey mean separation test (a = 0.05). *grower managed area not included in the statistical analyses.

Although not included in the statistical analyses, samples from the grower managed area, outside the trial site but within the same block, were also collected to utilize as a reference added at the bottom of each table. Here, nutrient levels were slightly lower on N, P and K, but higher on Ca and Mg.

Leaf tissue analyses of P and K did not correlate with soil elevated nutrient levels of these two elements, which suggest that there is a limiting factor at the uptake level: poor root growth, physical impediment or bad drainage. In this condition, while the demand of the trees remains the same, the efficiency is reduced, and the supply should be increased until cause of the limited uptake is resolved.

At Site 2, the treatments did not affect nutrient uptake (Table 6). Only B levels were different between treatments, being slightly lower on F_CaCl, and in both soil treatments (S_CaSO and S_CaCO) when compared with the control. However, in this site all samples were within adequate levels (Shear and Faust. 1980, Riguetti et al 1990). The grower managed sample were also within adequate range and equivalent to those obtained in all treatments.

Table 6. Effect of calcium treatments on ‘Honeycrisp’ leaves mineral concentration in Sagemoor orchard (Site 2).

Treatments	%					mg/kg
	N	P	K	Ca	Mg	B
Control	1.8	0.40	1.9	2.1	0.51	36 bc
F_CaCl	2.0	0.44	2.0	2.4	0.56	43 ab
F_CaCO	2.1	0.38	1.5	2.4	0.57	32 c
F_Ca+N	2.2	0.32	1.4	2.2	0.53	46 a
S_CaCO	2.1	0.40	1.6	2.1	0.57	33 c
S_CaSO	2.0	0.35	1.5	2.0	0.54	32 c
Pr > F(Model)	ns	ns	ns	ns	ns	0.006
Grower*	2.0	0.29	1.3	2.3	0.59	37

ns: no significance determined by ANOVA test ($p < 0.05$). Different letters within column indicate significant difference determined by Tukey mean separation test (a = 0.05). *grower managed area not included in the statistical analyses.

When comparing between the two orchards, all nutrients were significantly different except for B. Site 1 had higher levels of N, while, while Site 2 had higher levels of P (despite the low P-Olsen observed in the soils), K, Ca and Mg. The greater amount of P and K on Site 2, despite the reduced level of soil supply can be associated to the greater volume of roots observed in the soil pit, which is particularly important for P uptake. Higher levels of Ca and Mg in Site 2 can also be attributed to the increased levels of these nutrients in the soil.

Fruit nutrient analyses

Fruit nutrient analyses were determined in a sub sample of 20 fruit per replicated unit. Each fruit was weighed and a ring of 1 inch from the center of the fruit was then obtained and separated into peel and flesh for elemental analyses. Each tissue component was weighed and dried at 60 °C (140 °F). Once there was no more weight loss, samples were removed from the oven, ground to powder, and sent to Soiltest Lab for chemical analyses.

At Site 1, the treatments had no effect on nutrient concentration in the fruit peel nor the flesh (Table 7). Similarly, in Site 2, only N and Mg concentration of the peel was affected by the spray treatments.

In the peel, N concentration was higher on all soil treatments and with F_Ca+N (between 0.25 and 0.27 %), compared to the control (0.23%). Levels of Mg in the peel were also higher in both soil treatments, but with no different from the control (Table 8). Regarding fruit nutrient concentration, values obtained in this study were equivalent to those obtained by Cheng and Raba (2009), however N levels were below the reported values for ‘Honeycrisp’, while Ca were higher.

Overall, the treatments did not affect Ca concentration on fruitlets, leaf tissue or in the fruit (peel and flesh). The response to nutrient uptake was different for each orchard, which might be due to their specific limiting factors. Initial diagnostics at Site 1 reflected root growth limitations: shallower root growth and reduced effective soil depth, with high accumulation of P and K in the upper layer. And while Ca uptake was not impacted by any of the treatments, soil treatments CaCO and CaSO improved N uptake. This effect could be attributed to modifying the environment around the root zone (weed removal, temperature) which relate to the site limiting condition. On Site 2, where there were no evident limiting factors, nutrient application of Ca treatment had no significant effect on nutrient uptake.

Correlations between nutrient levels from blooms, fruitlets, leaves and fruit peel and flesh were weak, though some were statistically significant ($p < 0.001$). The strongest relations were within tissue tissue (with correlation above 60%) (data not shown). The lack of correlation between nutrient levels and tissue suggest that nutrient analyses of fruitlets and leaves are not a good predictor for fruit nutrient concentration, which has been indicated previously by numerous authors (Manganaris et.al, 2005, Torres et al, 2015). The lack of prediction within nutrient levels is that trees are able to regulate their demand and needs when nutrient are sufficiently supplied.

2. Effect of treatments on fruit quality

At harvest, overall vigor assessment was determined on each site by measuring 20 shoot, trunk diameter and total fruit count from 3 representative trees on each site. Crop load was calculated as the number of fruit per square centimeter of trunk cross sectional area (fruit/cm^2 of TCSA). Site 1 had an average of 5 inches of shoot growth, 91.33 fruit per tree and 11.6 cm^2 TCSA, leading to a crop load of 8 fruit/cm^2 TCSA. Site 2, with grafted trees had an average of 3 inches of shoot growth, 216 fruit per

Table 7. Effect of calcium treatments on 'Honeycrisp' flesh and peel mineral concentration in Pasco orchard (Site 1).

Treatments	Flesh (% dry weight)					Peel (% dry weight)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Control	0.20	0.06	0.70	0.04	0.04	0.38	0.13	0.92	0.12	0.12
F_CaCl	0.19	0.06	0.71	0.05	0.04	0.36	0.13	1.00	0.12	0.11
F_CaCO	0.20	0.06	0.66	0.04	0.04	0.38	0.12	0.92	0.11	0.11
F_Ca+N	0.22	0.07	0.73	0.05	0.04	0.42	0.15	1.05	0.12	0.12
S_CaCl	0.19	0.05	0.64	0.04	0.04	0.38	0.12	0.92	0.10	0.11
S_CaCO	0.20	0.05	0.69	0.04	0.04	0.36	0.14	1.05	0.10	0.13
S_CaSO	0.21	0.06	0.71	0.05	0.04	0.39	0.13	0.94	0.12	0.12
Pr > F(Model)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns: no significance determined by ANOVA test ($p < 0.05$). Different letters within column indicate significant difference determined by Tukey mean separation test ($a = 0.05$).

Table 8. Effect of calcium treatments on 'Honeycrisp' flesh and peel mineral concentration in Sagemoor orchard (Site 2).

Treatments	Flesh (% dry weight)					Peel (% dry weight)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Control	0.12	0.05	0.67	0.04	0.03	0.23 c	0.10	0.80	0.07	0.07 ab
F_CaCl	0.13	0.05	0.66	0.04	0.04	0.25 bc	0.10	0.71	0.07	0.07 ab
F_CaCO	0.12	0.05	0.63	0.04	0.03	0.25 b	0.08	0.68	0.07	0.07 ab
F_Ca+N	0.13	0.05	0.63	0.04	0.03	0.25 ab	0.09	0.68	0.07	0.07 b
S_CaCO	0.13	0.05	0.63	0.04	0.04	0.26 ab	0.10	0.72	0.07	0.08 a
S_CaSO	0.14	0.05	0.62	0.04	0.04	0.27 a	0.09	0.75	0.07	0.08 a
Pr > F(Model)	ns	ns	ns	ns	ns	0.009	ns	ns	ns	0.041

ns: no significance determined by ANOVA test ($p < 0.05$). Different letters within column indicate significant difference determined by Tukey mean separation test ($a = 0.05$).

tree (with 4 leaders per tree) and 19.9 cm^2 of TCSA, leading to a crop load of 10 fruit/ cm^2 TCSA. A crop load above 8 had no negative impact on nutrient concentration (Serra et al. 2016) or bitter pit (BP) incidence (Robinson, et al., 2009), so this factor was not a limiting condition on either location.

The treatments had no impact on fruit firmness, weight, or diameter on Site 1. On Site 2, fruit was firmer with S_CaSO4 (Gypsum) compared to the control that had the softest fruit (Table 9). However, there was no statistical difference among treatments. On both sites, the grower managed condition had similar values to the ones obtained in this trial. When comparing values between orchards (data not shown), fruit firmness in Site 1 had significantly lower (17 lbs) and fruit was significantly bigger. Fruit weight in Site 1 ranged from 248 to 345 g, compared to 211 to 323 g on Site 2.

Table 9. Treatment effect on fruit quality indicators at harvest on 'Honeycrisp' apples on Site 1 and Site 2.

Treatments	Site 1- Pasco			Site 2- Sagemoor		
	Firmness (lbs)	Weight (g)	Diameter (mm)	Firmness (lbs)	Weight (g)	Diameter (mm)
Control	17.1	321	97	18.9 a	290	88
F_CaCl	16.8	299	89	21.2 ab	278	87
F_CaCO	15.6	289	88	20.9 ab	245	84
F_Ca+N	17.7	308	90	19.9 ab	262	85
S_CaCl	16.3	303	90	-	-	-
S_CaCO	16.6	298	89	19.3 ab	256	84
S_CaSO	17.7	292	89	22.0 b	262	86
Pr > F(Model)	0.134	0.738	0.293	**0.027**	0.339	0.399
Grower*	17	298	88	19	271	86

*Grower site was not included in the statistical analyses. Different letters within column indicate significant difference determined by Tukey mean separation test (a = 0.05).

Treatment effect on bitter pit (BP) development

To evaluate harvest BP, 40 fruit per replicated unit were randomly harvested and taken to the laboratory for fruit quality assessment and bitter pit incidence. For storage BP, half the fruit was stored at 39 F (the other half was utilized for the nutrient analyses). After 4 weeks of storage, fruit were removed from the cold room and kept at room temperature for 12 hours prior to BP evaluation.

Bitter pit incidence varied significantly between the orchard sites. Fruit from Site 1 exhibited very high levels of BP at harvest, ranging from 53% to 74% (data not shown), however there were no differences among treatments. After four weeks of storage, significant differences were observed between the control, with 54% BP and the F_$CaCO_3$ treatment with 5% BP. There were no statistical differences among the other treatments (Figure 3). The grower managed sample developed 60% BP after storage.

At Site 2, BP incidence at harvest and after storage was lower than at Site 1. At harvest, BP incidence ranged from 0 to 14% with no statistical differences ($p<0.05$). The grower managed sample exhibited only 4% BP incidence (data not shown). After storage, BP increased, though with no statistical differences at 95% probability. However, when considering 86% probability ($p = 0.136$), the F_Ca+N treatment had lower BP incidence (3%) compared to the control (24%), with no differences among the other treatments (Figure 4).

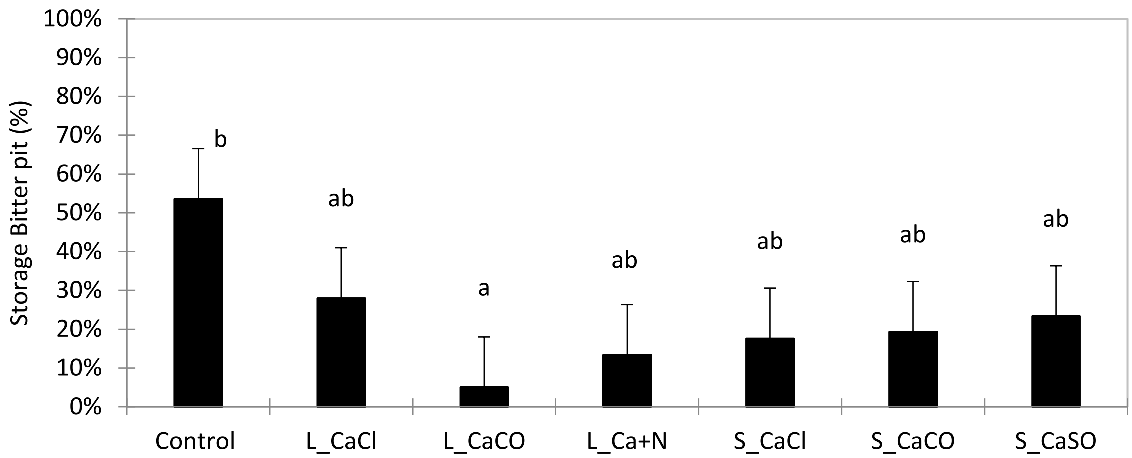

Figure 3. Effect of Ca treatments on Bitter pit development after 4 weeks of storage (bottom) on Site 1. Different letters indicate significant difference determined by Tukey mean separation test (a = 0.05).

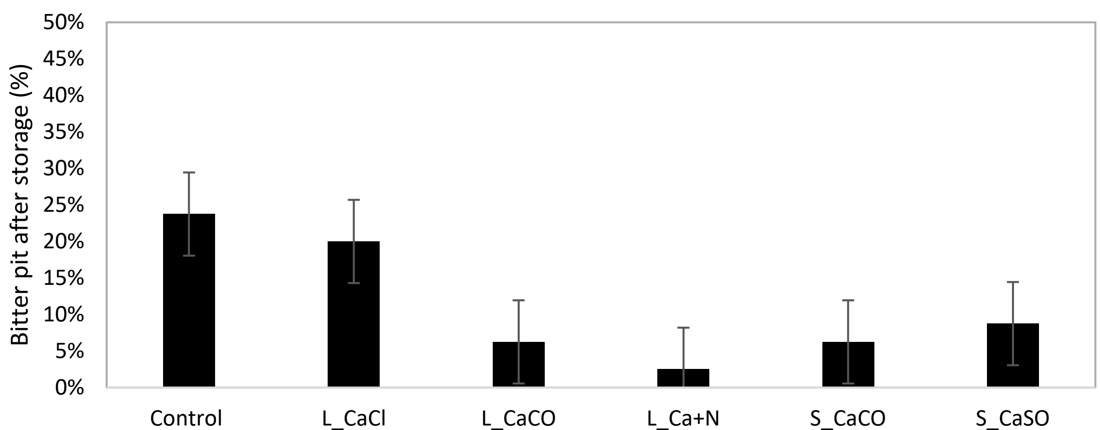

Figure 4. Effect of Ca treatments on Bitter pit development after 4 weeks of storage on Site 2. Treatment were not significantly different ($p > 0.05$)

The relation between parameters and bitter pit incidence vary between sites. Site 1, had a strong relation between fruit weight and BP incidence. The linear regression linear regression $y = 0.0069x - 1.4643$ had a correlation value *r* of 0.8, and coefficient of determination R2 of 0.64 (Figure 5). If the *r* value is close to 1 or -1, the relation is very strong, while the R2 value reflects how much of the variation on BP incidence can be explained by the fruit weight, in this case 64% of BP at harvest can be explained by the fruit weight. However, Site 2 had a weak relation between BP and fruit weight (r = 0.33) and the relation only explained 10% of the variation (Figure 5)

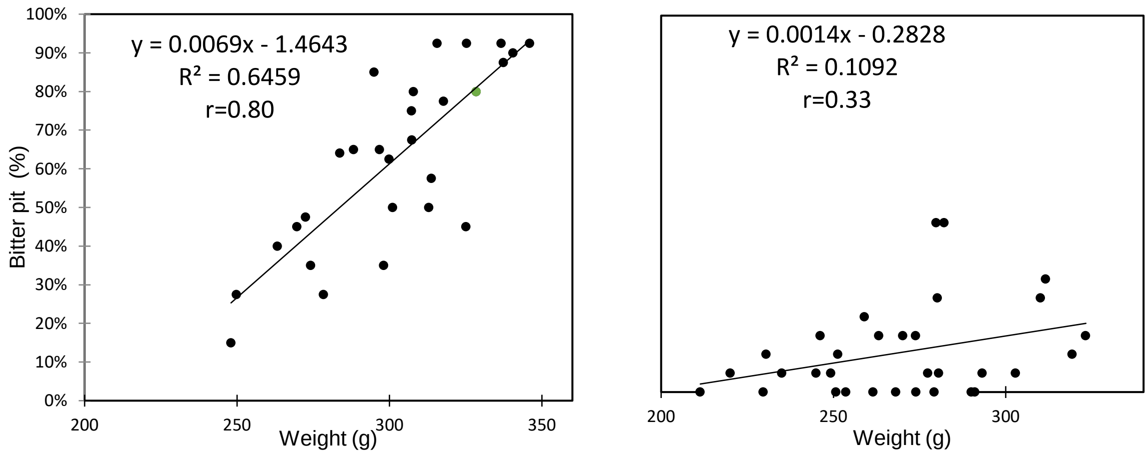

Figure 5. Relation between Bitter pit and fruit weight on Site 1 (left) and Site 2 (right) ($p < 0.001$).

Overall, the different treatments of Ca applications at a fixed rate of 12 lbs of actual Ca/acre had no statistical differences in controlling BP incidence after storage on 'Honeycrisp' apples. The two sites had significant differences in BP incidence at harvest and after storage, with high incidence at Site 1 with average of 54% compared to 24% on Site 2. Among treatments, there were no statistical differences in controlling BP incidence. However, when compared with the control receiving no Ca, F_$CaCO_3$ and F_ Ca+N where effective in reducing BP on Site 1 and Site 2, respectively. At Site 2, where sulfate (S) levels in the soil were deficient, S_$CaSO_4$ improved fruit firmness when compared with the control, but there were no differences between the other Ca treatments. On both sites, Ca treatments had no effect on Ca uptake by the fruitlets, leaves of fruit flesh and peel, and none of these measurements correlated with BP incidence, thus should not be utilized as BP predictors. Only at Site 1, where fruit was oversized (above 300 g), fruit weight had a strong relation with BP development. However, under adequate fruit weight and size (below 300 g), there were no strong predictors of BP development.

Possible causes for the higher BP incidence exhibited at Site 1 can be associated to: reduced root growth due to soil stratification, excessive levels of soil K (above 250 mg/kg) and oversized fruit (above 300g). Interestingly, results from the treatments receiving 12 lbs of Ca/acre in this trial, did not differ from the results observed from the grower-managed areas, where total applied Ca was more than 200 lbs/acre and 400 lbs/acre on Site 1 and Site 2, respectively. Therefore, from this one year trial, it appears that prophylactic applications of calcium are ineffective for reducing BP.

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EXECUTIVE SUMMARY

Project title: Calcium fertilization efficacy

Key words: Calcium, Bitter pit, Honeycrisp.

Abstract: Calcium (Ca^{2+}) has been recognized as one key element due to its many roles in plant physiological processes and fruit development. Several fruit disorders have been associated to Ca^{2+} deficiencies, including bitter pit (BP), the most important for apple growers in Washington. The application of Ca to reduce Ca-related disorders has been widely used in apple production with inconsistent results or no improvement at all. The objective of this research was to evaluate Ca fertilizer efficacy on nutrient uptake and fruit quality, including BP development at harvest and after storage in two orchards. The treatments included a control with no Ca, three foliar sprays (F): F_CaCl, F_$CaCO_3$ and F_Ca + N (Calcium plus 1% N), and three soil applications (S): S_CaCl (only in the conventional site), S_$CaCO_3$ and $CaSO_4$ (Gypsum). The total amount of actual Ca applied was equal for all treatments at 12 lbs/acre. Treatments were applied on 6 or 4 dates for foliar and soil, respectively, every 14 days starting at petal fall. Gyspum ($CaSO_4$) was applied in one application with the second irrigation. The two sites had significant differences in BP incidence at harvest and after storage, with high incidence at Site 1 with average of 54% compared to 24% on Site 2. Among treatments, there were no statistical differences in controlling BP incidence. However, when compared with the control receiving no Ca, F_$CaCO_3$ and F_ Ca+N where effective in reducing BP on Site 1 and Site 2, respectively. At Site 2, where sulfate (S) levels in the soil were deficient, S_$CaSO_4$ improved fruit firmness when compared with the control, but there were no differences between the other Ca treatments. On both sites, Ca treatments had no effect on Ca uptake by the fruitlets, leaves of fruit flesh and peel, and none of these measurements correlated with BP incidence, thus should not be utilized as BP predictors. Possible causes for the higher BP incidence exhibited at Site 1 can be associated to: reduced root growth, excessive levels of soil K (above 250 mg/kg) and oversized fruit. Interestingly, results from the treatments receiving 12 lbs of Ca/acre in this trial, did not differ from the results observed from the grower-managed areas, where total applied Ca was more than 200 lbs/acre and 400 lbs/acre on Site 1 and Site 2, respectively. Therefore, from this one year trial, it appears that prophylactic applications of calcium are ineffective for reducing BP.