Neonicotinoid Longevity in Potato Production Systems of the Northwest

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REPORTING PERIOD: March 1, 2017 – January 1, 2019 (2017 & 18 Growing Season)

ACCOMPLISHMENTS:
Potato cultivars differed in canopy weight early in the growing season as expected in 2017 but did not differ significantly in 2018. We detected a difference in plant foliar weight from season to season which impacted insecticide concentration in the leaves and therefore psyllid control. Tissue weights were lower in 2018, and insecticide concentration was higher resulting in improved psyllid control for longer into the season. Seed treatment with insecticide did reduce canopy weight in one cultivar in 2017 but not in 2018.

The slip cages were used in hopes to determine how long the at-plant neonicotinoids would be effective at controlling potato psyllids. The data from the cages were highly variable, making it difficult to confidently predict days of control of psyllids. Since the tissue weights and pesticide concentrations vary so much from year to year and one cultivar to another, it is highly unlikely that we could ever make that assessment. Rather, we can say that under conditions where plant canopy weights are high, psyllid control is likely to be much shorter than in conditions where plant foliar growth is reduced. For example, in 2017 and 2018, marginal psyllid control was only achieved for Alturas for up to 56 and 70 days after planting respectively for any of the three insecticide treatments. In Norkotah insecticide treated plots, adequate psyllid control was never achieved with any of the three insecticides. In some instances, the layby application of thiamethoxam appeared more effective than the at-plant treatments. Other data from this study suggest that aphid control is realistically achieved with the insecticides evaluated for 75 to 80 days. Colorado potato beetle was not evaluated as part of this study, but observations in the experimental area strongly indicate that the at-plant and layby treatments of neonicotinoids are highly effective at controlling the first generation of Colorado potato beetle.

This project demonstrates that neonicotinoid concentration in the potato plant, and therefore effectiveness in suppressing pest insects, varies by cultivar and growing season. In rapidly growing cultivars such as Norkotah, at-plant neonicotinoid treatments may not be effective for psyllid control. For practical purposes, prescriptive prophylactic use of at-plant neonicotinoid insecticides does not make sense for all cultivars and all growing conditions, especially in consideration for psyllid control. Neonicotinoids are an effective tool for managing early season aphid and Colorado potato beetle. These data call into question, however, how effectively systemic pesticides mobilize in different cultivars and different growing seasons. Scouting is still the best method to ensure that potato psyllids and other insect pests do not build up to numbers where they cannot be controlled.

PROCEDURES:
An experiment was conducted at the WSU research site in Pasco, WA and maintained mimicking commercial potato production in the Columbia Basin. All plots received a fungicide in-furrow treatment (Ridomil Gold at 6.5oz per acre and Quadris F at 8oz per acre), post-plant pre-emergence herbicides, applications of Coragen for Colorado potato beetle control, and foliar fungicides as needed to avoid disease outbreaks (Table 1a and 1b). The plots were arranged in a

randomized complete block design with four replications. Each plot was four rows wide and twenty-five feet in length.

Treatments included neonicotinoids applied in three ways: in-furrow with imidacloprid (Admire Pro 8.7 fl oz/A), seed piece with thiamethoxam (Cruiser Maxx 0.23 fl oz/100 lbs. seed), and a banded lay-by application with thiamethoxam (Platinum 8 fl oz/A). Cruiser Maxx and Platinum contain the same insecticide active ingredient, thiamethoxam, and with the rates that were used, were applied in equal amounts of active ingredient per acre. The in-furrow and seed piece treatments were made at planting (April 17, 2017 and April 20, 2018), and the lay-by treatments were made at the six to eight-inch rosette stage (May 22, 2017 and May 21, 2018). The in-furrow and layby treatments were applied with 5 and 10 gallons of water per acre, respectively. All the treatments were applied to two different cultivars. One cultivar was an abundant early-season foliage determinant cultivar (Norkotah), and the other of an indeterminant cultivar with typically sparse, early-season foliage (Alturas). Untreated check plots of both cultivars were also planted and evaluated.

Samples of the potato foliage were collected seven times during the growing season (43, 49, 56, 70, 84, 98, and 112 days after planting). Leaf samples consisted of one-gallon bags of foliage collected from at least twenty different plants per plot. On each plant, the most recent fully developed leaf was collected. Samples were collected at the same time of day for each sampling period, placed in a container with ice packs, and sent next day shipping to Pacific Agricultural Laboratories (PAL). PAL evaluated the samples for the amounts of thiamethoxam, its metabolite (clothianidin), and imidacloprid present utilizing liquid chromatography mass spectroscopy. At the designated dates as detailed above, we performed destructive plant sampling on three plants in each plot. Destructive whole plant sampling (a wet-weight measurement) provided a relative assessment of the canopy size of the two cultivars at the time the concentration of the pesticide was measured. The aboveground portion, roots, and tubers were all weighed separately for each three-plant sample.

Date	Pesticide	Rate	Unit
5/3/2017	Boundary	2	pt/A
5/3/2017	Eptam	3.5	pt/A
5/3/2017	Tricor	0.35	lbs/A
6/6/2017	Coragen	5	oz/A
6/10/2017	Luna	11	oz/A
6/10/2017	Equus	1.3	pt/A
6/20/2017	Bravo	1.5	pt/A
6/29/2017	Luna	11	oz/A
6/29/2017	Equus	1.3	pt/A
7/19/2017	Zing	34	oz/A
7/18/2017	Zing	34	oz/A
7/25/2017	Revus	7	oz/A
8/1/2017	Revus	7	oz/A
8/8/2017	Zing	34	oz/A
8/19/2017	Luna	11	oz/A
9/4/2017	Zing	34	oz/A
9/8/2017	Reglone	2	PT/A

Date	Pesticide	Rate	Unit
5/5/2018	Boundary	2	PT/A
5/5/2018	Eptam	3.5	PT/A
5/5/2018	Tricor	0.35	LB/A
5/15/2018	Boundary	2	PT/A
5/15/2018	Eptam	3.5	PT/A
5/15/2018	Tricor	2	LB/A
5/29/2018	Coragen	5	FL OZ/A
6/15/2018	Luna	11	FL OZ/A
6/15/2018	Bravo	1.5	PT/A
6/29/2018	Luna	11.5	FL OZ/A
7/5/2018	Coragen	7.5	FL OZ/A
7/9/2018	Zing	32	FL OZ/A
7/19/2018	Vertisan	24	FL OZ/A
7/23/2018	Zing	34	FL OZ/A
8/3/2018	Luna	4	FL OZ/A
8/13/2018	Revus Top	7	FL OZ/A
8/16/2018	Blackhawk	3	FL OZ/A
9/20/2018	Reglone	2	PT/A

Table 1a (2017) and 1b (2018): The maintenance pesticides applied to the Neonicotinoid Trial.

Additionally, we determined efficacy of the insecticides by enumerating key Columbia Basin region potato pests and beneficial insects. Insects were evaluated weekly from emergence to harvest using three different types of insect sampling methods: bucket samples, leaf samples, and vacuum samples with pest and beneficial insect counts performed at each assessment. Bucket samples are collected by shaking the tops of five potato plants over an 8.5-inch diameter, two-gallon plastic bucket and evaluating the contents. Leaf samples are taken by collecting ten of the newest fully developed leaves from the perimeter of the plots and placing them in a labeled zip top plastic bag to be quantified in the laboratory. Vacuum samples are collected by operating a Stihl leaf vacuum, with a mesh fabric affixed to the front of the vacuum, around the perimeter of each plot while brushing the plant tops with the apparatus. The mesh bag was then emptied into a labeled Ziploc bag for quantification in the laboratory.

In addition to evaluating the resident insect populations, slip cages with potato psyllids were utilized to assess the efficacy and residual effects of the insecticides. Each plot was infested with three second instar psyllid nymphs using a slip cage (6 x 9-inch mesh fabric) on a single potato leaf. They were placed on plants on the same seven dates that the foliage tissue samplings for the insecticide concentration levels were procured. The slip cage remained on the leaf for seven days. The cages were then removed, and mortality of the psyllids was assessed. At the end of the season, the potato tubers were dug from a ten-foot section of row from the middle of each plot and evaluated for yield and quality.

RESULTS/DISCUSSION:

Potato cultivars did not differ in leaf tissue weights early in the season in 2018, but as the season progressed, Norkotah leaf tissue weights were significantly lower than Alturas leaf tissue weights (Figure 1). This trend is somewhat different than in 2017, where early in the growing season, Norkotah leaf tissue weights were higher than Alturas, which was what we expected with the determinant cultivar. The maximum foliar weights for both cultivars differed by season, with both cultivars containing significantly higher maximum foliar weights in 2017 compared to 2018 (Figure 1). During the 2018 growing season, potato growing degree days accumulated more rapidly in May compared to 2017 which may have had an impact on the foliar growth patterns of both cultivars (Figure 2). For most sample dates, insecticide treatment did not influence leaf tissue weights (Table 2a & 2b). In 2017, during two sample periods (June 12 and 26), plots treated with thiamethoxam as a seed treatment contained lower fresh canopy weights than the untreated check, but as the season progressed, that trend was no longer present (Table 2a). On the July 5, 2018 sample date, plots treated with CruiserMax and Platinum contained lower leaf tissue weights than the untreated check (Table 2b). These data suggest there is likely some inherent cost to the plant from metabolizing the insecticide treatment in terms of reduced tissue weight, but that impact is resolved once the material is reduced in concentration in the system and does not appear to adversely impact potato yield.

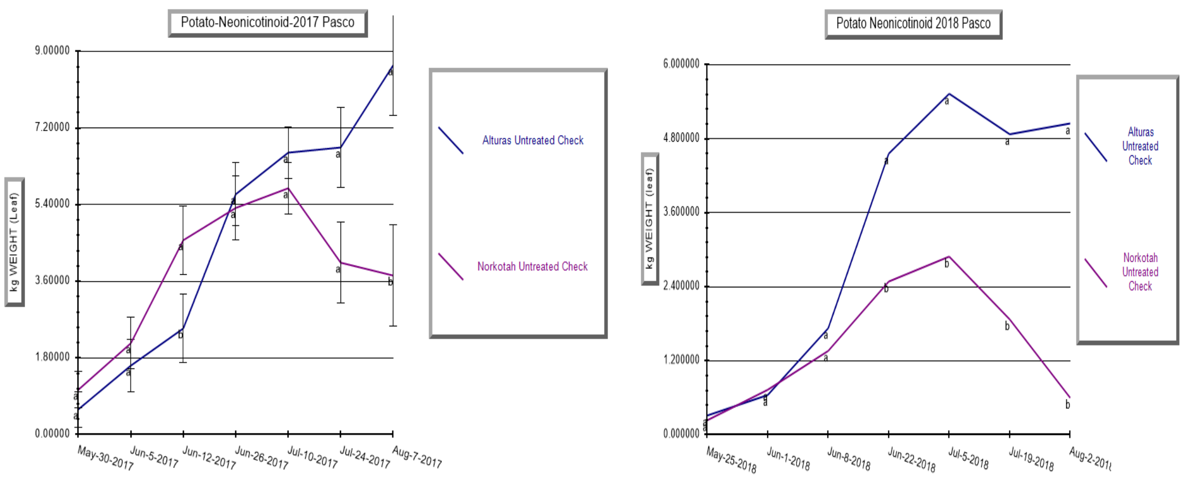

Figure 1. Fresh plant weights for three plants per plot by cultivar during the seven sample periods. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

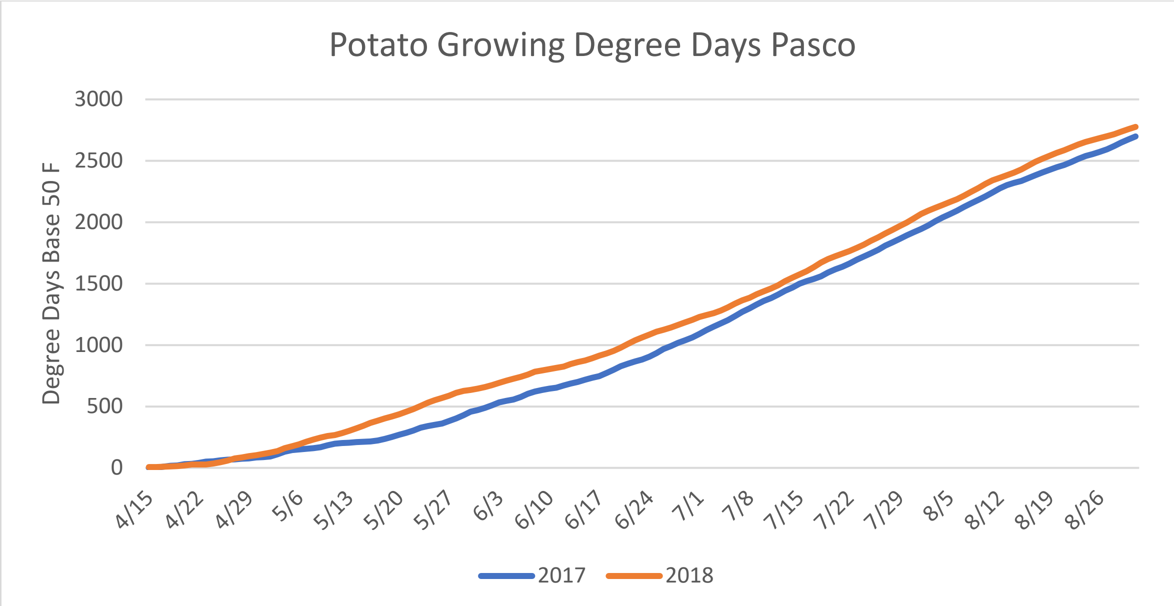

Figure 2. Potato growing degree days at the WSU AgWeatherNet weather station in Pasco, WA from when the plots were planted until harvest for 2017 and 2018.

Plant Weights	Weight in Kg						
Treatment	Date						
	30-May	5-Jun	12-Jun	26-Jun	10-Jul	24-Jul	7-Aug
Alturas	0.6801b	1.5809b	2.9238b	5.0875a	6.2778a	6.40298a	6.81135a
Norkotah	0.9789a	2.2560a	3.7333a	4.7109a	5.7154a	4.58389b	3.43961b
LSD	0.180	0.373	0.484	1.080	1.277	1.079	1.420-1.893
Untreated Check	0.8234a	1.8836a	3.5300a	5.4861a	6.2064a	5.66601a	5.57358a
Admire Pro	0.7535a	1.8595a	3.4054ab	5.0301ab	6.4460a	5.74412a	4.80971a
Cruiser Maxx	0.7645a	1.7823a	2.7644b	3.8909b	5.1873a	5.96010a	4.55911a
Platinum	0.9768a	2.1484a	3.6145a	5.1896ab	6.1466a	4.60349a	4.66473a
LSD	0.254	0.527	0.684	1.080	1.277	1.526	2.134-2.672
Alturas/Untreated Check	0.5930b	1.6208cd	2.4928c	5.6475a	6.6243a	6.74490ab	8.63111a
Norkotah/Untreated Check	1.0538a	2.1456abc	4.5673a	5.3248a	5.7885a	4.58712bcd	3.48670b
Alturas/Admire Pro	0.6403b	1.7165bcd	3.3303bc	4.9558a	6.7108a	7.02860a	6.56224ab
Norkotah/Admire Pro	0.8668ab	2.0025abc	3.4805b	5.1045a	6.1813a	4.45965cd	3.46333b
Alturas/Cruiser Maxx	0.6585b	1.1690d	2.4000c	3.9985a	5.4668a	6.56385abc	6.00997ab
Norkotah/Cruiser Maxx	0.8705ab	2.3955ab	3.1288bc	3.7833a	4.9078a	5.35635a-d	3.40853b
Alturas/Platinum	0.8288ab	1.8173a-d	3.4723b	5.7483a	6.3093a	5.27455a-d	6.29224ab
Norkotah/Platinum	1.1248a	2.4795a	3.7568ab	4.6310a	5.9840a	3.93243d	3.40046b
LSD	0.360	0.745	0.968	2.161	2.554	2.158	3.266-4.103

Table 2a. Fresh plant weights for three plants per plot by various factors during the seven sample periods 2017. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Plant Weights in Kg	Weight in Kg						
Treatment	Date						
	25-May	1-Jun	8-Jun	22-Jun	5-Jul	19-Jul	2-Aug
Alturas	0.3232a	0.6578a	1.6807a	4.0182a	4.1937a	4.9309a	5.3168a
Norkotah	0.2650a	0.6021a	1.4890a	2.9043b	2.7816a	1.9412b	0.6282b
LSD	0.099953	0.138679	0.245567	0.435806-0.503902	0.653244	0.702112	0.301723-0.746946
Untreated Check	0.2743a	0.6876a	1.5446a	3.4023a	4.2111a	3.3737a	2.2957a
Admire Pro	0.2554a	0.6408a	1.6908a	3.4200a	3.6073ab	3.0818a	2.4082a
Cruiser Maxx	0.2938a	0.5333a	1.5978a	3.6590a	2.9324b	3.5687a	2.5126a
Platinum	0.3528a	0.6582a	1.5061	3.2345a	3.1998b	3.7201a	2.4426a
LSD	0.141355	0.196122	0.347285	0.647563-0.683572	0.923826	0.992937	0.706451-0.786746
Alturas (Untreated)	0.3129a	0.6450a	1.7284a	4.5596a	5.5317a	4.8747a	5.0503a
Norkotah (Untreated)	0.2357a	0.7302a	1.3609a	2.4860a	2.8904a	1.8728a	0.6000a
Alturas (Admire Pro)	0.2307a	0.6291a	1.7914a	3.8714a	4.1518a	4.4645a	5.2482a
Norkotah (Admire Pro)	0.2802a	0.6525a	1.5903a	3.0103a	3.0629a	1.6992a	0.6463a
Alturas (Cruiser Maxx)	0.2787a	0.5709a	1.7433a	4.1559a	3.6660a	4.8329a	5.3680a
Norkotah Cruiser Maxx)	0.3089a	0.4957a	1.4524a	3.2099a	2.1990a	2.3044a	0.7132a
Alturas (Platinum)	0.4704a	0.7864a	1.4599a	3.5416a	3.4253a	5.5517a	5.6078a
Norkotah (Platinum)	0.2353a	0.5300a	1.5524a	2.9481a	2.9746a	1.8885a	0.5582a
LSD	0.199906	0.277359	0.491135	0.821659-1.060458	1.306487	1.404224	0.630936-1.479884

Table 2b. Fresh plant weights for three plants per plot by various factors during the seven sample periods 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

At the end of the 2017 growing season, in fact, yields did not differ between plots treated with Cruiser, Admire Pro, or the untreated check treatments (Table 3a). Plots treated with Platinum contained significantly lower overall yields in 2017. The overall yield did not differ between cultivars, but grades did where there were significantly more oversized Grade 1 tubers, fewer Grade 2 tubers, and fewer culls in the Norkotah than Alturas. Despite the differences in plant foliage weights during the growing season, yield and quality were not impacted directly by, or through interaction within, any of the main experimental factors.

In 2018, yield and quality were lower for Norkotah than Alturas, except with more culls reported in Alturas (Table 3b). Norkotah is a determinant early maturing cultivar, so this result of lower yield and specific gravity is expected. Insecticide treatment did not influence potato yield or quality factors that were evaluated in 2018 (Table 3b). There were not interaction effects of the two main factors evaluated, cultivar and insecticide treatment. When comparing 2017 and 2018, Alturas performed better in 2018 than 2017 while the opposite was true for Norkotah. This is probably a result of the growing degree day accumulation patterns of the two seasons.

Treatment	Grade 1		Grade 2							
	4 oz to >	6+ oz	4 oz	4 oz to>	6+ oz	Culls	Marketable Yield(T/A)	Specific Gravity	Solids	Total Yield
Alturas	4.834a	8.223b	2.853a	0.199a	0.420a	1.333a	19.173a	1.06753a	17.980a	32.5a
Norkotah	3.146b	13.803a	1.608b	0.002b	0.016b	0.660b	18.780a	1.06549a	17.549a	31.9a
LSD	0.6324- 0.7721	2.3578	0.3903	0.0696- 0.1485	0.189688- 0.31696	0.569431- 0.59577	3.2464	0.002212	0.4742- 0.4753	5.51
Untreated Check	3.937a	11.688a	2.214a	0.048a	0.091a	0.734a	19.195ab	1.06731a	17.921a	32.6ab
Admire Pro	4.368a	12.538a	2.421a	0.120a	0.208a	1.207a	21.761a	1.06705a	17.881a	36.9a
Cruiser Maxx	4.024a	10.098a	2.311a	0.039a	0.114a	1.014a	18.320ab	1.06536a	17.516a	31.1ab
Platinum	3.394a	9.728a	0.051a	0.051a	0.205a	0.946a	16.630b	1.06633a	17.739a	28.2b
LSD	0.9764- 0.9769	3.3344	0.5519	0.1189- 0.2205	0.493944- 99999.217629	0.752524- 0.89743	4.5911	0.003129	0.6650- 0.6745	7.79
Alturas/Untreated Check	4.885ab	8.723bcd	3.023a	0.118ab	0.365ab	0.843a	19.093a	1.07038a	18.589a	32.4a
Norkotah/Untreated Check	3.142d	14.653a	1.405c	0.009b	0.000b	0.631a	19.298a	1.06425c	17.276c	32.7a
Alturas/Admire Pro	5.863a	9.185bcd	3.033a	0.480a	0.517a	1.717a	22.425a	1.06925ab	18.360a	38.0a
Norkotah/Admire Pro	3.199d	15.890a	1.810c	0.000b	0.037ab	0.792a	21.098a	1.06485bc	17.414b	35.8a
Alturas/Cruiser Maxx	4.710abc	7.668cd	2.683ab	0.154ab	0.437a	1.397a	18.720a	1.06455c	17.336c	31.8a
Norkotah/Cruiser Maxx	3.421cd	12.528ab	1.940bc	0.000b	0.000b	0.694a	17.920a	1.06618ab	17.697a	30.4a
Alturas/Platinum	4.023bcd	7.315d	2.673ab	0.127ab	0.127ab	1.470a	16.455a	1.06595bc	17.662a	27.9a
Norkotah/Platinum	2.843d	12.140abc	1.278c	0.009b	0.009b	0.533a	16.805a	1.06670ab	17.816a	28.5a
LSD	1.2618- 1.6963	4.7155	0.7806	0.4167- 99999.2056	0.512819- 99999.438965	1.210710- 1.232171	6.4928	0.004425	0.9486- 0.9665	11.02

Table 3a: The yield and grade data for both the Norkotah and Alturas varieties 2017. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test). Yield and grade data expressed in kg per plot and ton per acre in total yield.

Treatment	Grade 1		Grade 2							
	4 oz to >	6+ oz	4 oz	4 oz to>	6+ oz	Culls	Marketable Yield(T/A)	Specific Gravity	Solids	Total Yield
Alturas	5.778a	15.136a	1.803a	0.184a	0.669a	2.489a	23.570a	1.07750 a	20.178 a	39.9a
Norkotah	1.842b	9.511b	1.100b	0.015b	0.147a	0.569b	12.643b	1.07064 b	18.676 b	21.4a
LSD	0.8154	2.3821	0.3614	0.137	0.5163	0.8872	2.4116	0.002766	0.6022	4.08
Untreated Check	3.757a	11.919a	1.358a	0.086a	0.599a	1.576a	17.740a	1.07505 a	19.641 a	30.0a
Admire Pro	3.772a	11.323a	1.550a	0.081a	0.260a	1.384a	16.984a	1.07250 a	19.084 a	28.8a
Cruiser Maxx	3.728a	14.104a	1.401a	0.068a	0.329a	1.804a	19.664a	1.07548 a	19.736 a	33.3a
Platinum	3.984a	11.946a	1.498a	0.164a	0.445a	1.352a	18.038a	1.07325 a	19.246 a	30.6a
LSD	1.1531	3.3688	0.511	0.1937	0.7301	1.2546	3.4106	0.003911	0.8517	5.78
Alturas/Untreated Check	5.636a	15.218a	1.474a	0.148a	0.885a	2.699a	23.360a	1.07880 a	20.463 a	39.6a
Norkotah/Untreated Check	1.878a	8.621a	1.242a	0.025a	0.313a	0.454a	12.120a	1.07130 a	18.820 a	20.5a
Alturas/Admire Pro	5.851a	13.846a	2.109a	0.125a	0.306a	2.211a	22.238a	1.07603 a	19.855 a	37.7a
Norkotah/Admire Pro	1.692a	8.800a	0.990a	0.036a	0.213a	0.556a	11.731a	1.06898 a	18.313 a	19.9a
Alturas/Cruiser Maxx	5.398a	17.497a	1.815a	0.136a	0.658a	2.767a	25.503a	1.07910 a	20.530 a	43.2a
Norkotah/Cruiser Maxx	2.058a	10.711a	0.988a	0.000a	0.000a	0.840a	13.825a	1.07185 a	18.943 a	23.4a
Alturas/Platinum	6.226a	13.982a	1.814a	0.329a	0.828a	2.279a	23.179a	1.07608 a	19.863 a	39.3a
Norkotah/Platinum	1.742a	9.911a	1.182a	0.000a	0.062a	0.425a	12.897a	1.07043 a	18.630 a	21.8a
LSD	1.6309	4.7642	0.7228	0.274	1.0326	1.7743	4.8232	0.005532	1.2045	8.17

Table 3b: The yield and grade data for both the Norkotah and Alturas varieties 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test). Yield and grade data expressed in kg per plot and ton per acre in total yield.

In 2017, the neonicotinoid concentration differed between cultivars with the lay-by application of thiamethoxam and imidacloprid, but not with seed treatment of thiamethoxam for a majority of the sample periods (Table 4a). The imidacloprid concentration was higher in the Norkotah plots than in Alturas for the second sample period, then lower on the third and fourth sample periods (Table 4a). This trend was opposite of what we hypothesized, where the faster growing Norkotah cultivar contained higher concentrations of insecticide than the slower growing Alturas cultivar early in the growing season. If you compare these data with the plant tissue weights during the same time period, the tissue weights did not differ significantly until June 12 (Figure 1a). Perhaps the plant began to grow rapidly prior to the sample weights being obtained and therefore the imidacloprid had systemically moved into the rapidly growing leaf tissue. The same trend is not observed with the other insecticides. All the insecticides evaluated are moderate to highly soluble (340, 610 and 4100 mg/kg for clothianidin, imidacloprid, and thiamethoxam respectively), so if the plant is growing quickly and requiring more water, the neonicotinoid is more likely to be drawn up into the leaf tissue through the xylem. Thiamethoxam by the lay-by application contained significantly higher concentrations of active ingredient in the plant tissue than the application by seed treatment (Table 4a). The Norkotah plots had a lower concentration of thiamethoxam when applied by seed treatment as compared to the Alturas plots (Table 4a). The treatment of thiamethoxam by lay-by application did not differ by cultivar (Table 4a). Clothianidin is a biologically active (as an insecticide) metabolite of thiamethoxam and was, therefore, analyzed in the tissue tests. Clothianidin followed the same trend of lower concentrations in the faster growing Norkotah cultivar, but results were not statistically significant (Table 4a). The clothianidin concentration did differ in the lay-by application where there was a higher concentration of the compound in the faster growing Norkotah plots, following the same unexpected trend realized on the plots treated with imidacloprid (Table 4a).

In 2018, the concentration of imidacloprid did not differ significantly between the two cultivars, except for one sample date (July 20) where there was no detectible level in the Norkotah plots (Table 4b). The level of imidacloprid was numerically lower for the entire sample season in Norkotah for 2018, but varied more in 2017. The overall level of imidacloprid started at a much higher concentration early in 2018 compared to 2017 but reduced more dramatically (Table 4a and 4b). Leaf tissue weights were much higher in 2017 compared to 2018 and likely explain the initial higher titer level of imidacloprid in 2018 since there was less leaf tissue for the product to be diluted in. This supports the hypothesis that under conditions conducive for more foliar growth that the pesticide concentration would be reduced due to dilution. A similar trend occurs in relation to clothianidin and thiamethoxam, whereby concentrations were higher in 2018 than 2017 (Table 4a & 4b). The concentration of thiamethoxam and clothianidin remained at a higher concentration consistently over time in 2018 than in 2017 (Table 4a & 4b). This demonstrates that neonicotinoid concentrations can fluctuate significantly from one season to the next and from one cultivar to another but is largely impacted by plant foliar growth as larger canopies tended to have reduced pesticide concentrations. In 2018, the level of clothianidin differed by cultivar on June 22 where Alturas plots contained higher concentrations of the compound than Norkotah (Table 4b). For the other sample periods there was no significant difference in the concentration of clothianidin. The concentration of thiamethoxam was generally higher in plots treated by lay-by application, but not significantly different.

A great amount of variability occurs with consideration to titer level of the pesticides in the leaf of the plant at the same dose at the same number of days after planting. Regularly, individual plants in fields are detected with enormous populations of Colorado potato beetles while adjacent plants contain no beetles. This is likely due to the differences in titer level and could be attributed to pesticide application inaccuracies or plants that were inadvertently not treated.

Treatment		5/30/2017	6/5/2017	6/12/2017	6/26/2017	7/10/2017	7/24/2017	8/7/2017
Alturas (Admire Pro)	Imidacloprid (mg/kg)	0.2891a	0.1350a	0.2173a	0.1365a	0.0563a	0.0360a	0.0165a
Norkotah (Admire Pro)	Imidacloprid (mg/kg)	0.2000a	0.3473a	0.0623ab	0.0768ab	0.0615a	0.0368a	0.0215a
Alturas (Platinum)	Clothianidin (mg/kg)	0.0218bc	0.0338b	0.0616b	0.0768a	0.1297a	0.0303a	0.0220a
Norkotah (Platinum)	Clothianidin (mg/kg)	0.0445a	0.0725a	0.1284a	0.1008a	0.0945a	0.0354a	0.0215a
Alturas (Platinum)	Thiamethoxam (mg/kg)	0.1010b	0.1162a	0.1151a	0.1230a	0.1028a	0.0435ab	0.0338a
Norkotah (Platinum)	Thiamethoxam (mg/kg)	0.1352ab	0.0808ab	0.1024a	0.1415a	0.1122a	0.0753a	0.0595a
Alturas (Cruiser Maxx)	Clothianidin (mg/kg)	0.0415ab	0.0470b	0.0366bc	0.0295b	0.0217b	0.0029b	0.0000b
Norkotah (Cruiser Maxx)	Clothianidin (mg/kg)	0.0433a	0.0403b	0.0254c	0.0220b	0.0122bc	0.0033b	0.0025b
Alturas (Cruiser Maxx)	Thiamethoxam (mg/kg)	0.2475a	0.0888a	0.0677b	0.0473b	0.0008b	0.0186bc	0.0064b
Norkotah (Cruiser Maxx)	Thiamethoxam (mg/kg)	0.0847b	0.0479a	0.0270c	0.0299b	0.0000b	0.0074bcd	0.0079b
Alturas (Platinum)	Combined (mg/kg)	0.0338bc	0.1393a	0.1053bc	0.2028a	0.2445a	0.0843a	0.0563a
Norkotah (Platinum)	Combined (mg/kg)	0.0725a	0.0895a	0.0528c	0.2545a	0.2300a	0.1233a	0.0858a
Alturas (Cruiser Maxx)	Combined (mg/kg)	0.0470b	0.1508a	0.1805ab	0.0773a	0.0253a	0.0250a	0.0085a
Norkotah (Cruiser Maxx)	Combined (mg/kg)	0.0403b	0.1590a	0.2395a	0.0528a	0.0123a	0.0215a	0.0130a
LSD Value p=0.05	Imidacloprid	0.02026-0.10503	0.19212	0.15689	0.10177	0.0115	0.00935	0.00862
	Clothianidin	0.02011	0.02178	0.00689-0.03567	0.01615-0.06767	0.01212-0.05476	0.00806-0.02101	0.00912
	Thiamethoxam	0.04651-0.12074	0.0141-0.05486	0.01085-0.04938	0.03986	0.01950-0.06375	0.02404-0.05476	0.01375-0.02641
	Combined	0.07305	0.08269	0.07878	0.12975	0.11418	0.06888	0.03788

Table 4a. Residue values by treatment. Values expressed in milligrams of pesticide per kilogram of plant fresh weight. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Treatment		5/25/2018	6/1/2018	6/8/2018	6/22/2018	7/5/2018	7/20/2018	8/2/2018
Alturas (Admire Pro)	Imidacloprid (mg/kg)	0.5570a	0.2375a	0.0800a	0.0864a	0.0205a	0.0115a	0.0030a
Norkotah (Admire Pro)	Imidacloprid (mg/kg)	0.3139a	0.0763a	0.0319a	0.0628a	0.0070a	0.0000b	0.0000a
Alturas (Platinum)	Clothianidin (mg/kg)	0.2568a	0.1330a	0.1675a	0.0900a	0.0338a	0.0483a	0.0315a
Norkotah (Platinum)	Clothianidin (mg/kg)	0.0850a	0.1468a	0.1425a	0.0610b	0.0218a	0.0263a	0.0298a
Alturas (Platinum)	Thiamethoxam (mg/kg)	0.4020a	0.2250a	0.3395a	0.0723a	0.0365a	0.0208ab	0.0155b
Norkotah (Platinum)	Thiamethoxam (mg/kg)	0.1825a	0.2480a	0.1861a	0.0675a	0.1570a	0.0143bc	0.0438a
Alturas (Cruiser Maxx)	Clothianidin (mg/kg)	0.5125a	0.1175a	0.0865a	0.0809ab	0.0248a	0.0340a	0.0210a
Norkotah (Cruiser Maxx)	Clothianidin (mg/kg)	0.2925a	0.1025a	0.0873a	0.0363c	0.0228a	0.0213a	0.0155a
Alturas (Cruiser Maxx)	Thiamethoxam (mg/kg)	1.4500a	0.4950a	0.1201a	0.0588a	0.0238a	0.0290a	0.0090b
Norkotah (Cruiser Maxx)	Thiamethoxam (mg/kg)	1.0300a	0.1980a	0.0561a	0.0483a	0.0203a	0.0108c	0.0085b
Alturas (Platinum)	Combined (mg/kg)	0.6588a	0.3580a	0.5200a	0.1623a	0.0703a	0.0690a	0.0470a
Norkotah (Platinum)	Combined (mg/kg)	0.2675a	0.3943a	0.3325a	0.1285a	0.1788a	0.0405a	0.0735a
Alturas (Cruiser Maxx)	Combined (mg/kg)	1.9625a	0.6125a	0.2083a	0.1083a	0.0485a	0.0630a	0.0300a
Norkotah (Cruiser Maxx)	Combined (mg/kg)	1.3225a	0.3000a	0.1438a	0.0845a	0.04300a	0.0320a	0.0240a
LSD Value p=0.05	Imidacloprid	0.43263-99999.0882	0.17686	0.04504-99999.01812	0.04157-99999.01426	0.00934	0.00491	0.0031
	Clothianidin	0.12601	0.12208	0.04125	0.02122	0.01543	0.01196	0.01215
	Thiamethoxam	0.2399	0.1907	0.11084-99999.01988	0.02171	0.16611	0.00889	0.01561
	Combined	0.48244	0.38292	0.15522	0.05697	0.22035	0.02015	0.03011

Table 4b. Residue values by treatment. Values expressed in milligrams of pesticide per kilogram of plant fresh weight. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

The potato psyllid slip cage assays are difficult to interpret due to the high mortality rates in the untreated check plots during some assay periods. Cages were placed too high in the canopy during one sample period in 2017, leading to high mortality in the untreated check plots (June 19th). Psyllids were reared in a laboratory, and then transferred to the field. This did not appear to impact survivorship during the cooler days but appeared to be problematic during warmer weather. The raw percent mortality was subjected to a correction formula to account for natural mortality attributed to the insects being caged on the plants. The raw data was subjected to the following formula: Schneider-Orelli Formula (the mortality % in treated plot minus the mortality % in the control plot, all of that divided by 100 minus the mortality % in the control plot. The result of that equation is then multiplied by 100). For all sample periods in 2017 except the last one, cultivar did not impact psyllid survivorship significantly (Table 5a). In 2017 there was a strong numeric trend for mortality rates being higher in Alturas plots, and if you look at the interaction of the two main factors, Alturas plots treated with either thiamethoxam application (Cruiser Maxx and Platinum) routinely recorded higher mortality rates for psyllids. Insecticide treatment did impact psyllid survivorship, where during all but one sample period in 2017, plots treated with lay-by thiamethoxam (Platinum) had higher mortality rates for psyllids than the untreated check plots and were more often numerically higher than the other insecticide treatments (Table 5a).

Alturas plots tended to have higher psyllid mortality rates in slip cages in 2018, similar to what was observed in 2017 and in fact were significantly higher on June 8, July 26, and August 9

(Table 5b). This once again is likely attributed to the different growth patterns of the two cultivars. Norkotah is a determinant cultivar and it is likely, especially toward the end of the sample period, that most of the plants' resources were being directed toward the tubers, resulting in generally reduced insecticide concentration in the leaves and subsequently lower mortality rates to potato psyllids. For efficacy against potato psyllids, based on the slip cages, adequate control was never achieved in Norkotah plots irrespective of insecticide treatment or insecticide titer level. In both seasons, control of potato psyllids in slip cages in Norkotah plots was only above 33% twice, both instances in 2018 with lower canopy weights. In Alturas plots, control was achieved (75% and above) on numerous occasions, but more-so in 2018 than 2017 and in plots treated with Cruiser Maxx or Platinum than with Admire Pro. Insecticide treatment influenced mortality rates in psyllid cages in 2018, but the insecticides did not differ between one another (Table 5b). Mortality rates of psyllids in slip cages in 2018 were greater than in 2017 (Tables 5a & 5b). The lower tissue weights recorded in 2018 resulted in higher insecticide titer levels which resulted in the increased mortality. This supports the overall hypothesis that under fast growing conditions, potato plant canopies are larger, and the concentration of the pesticide is reduced leading to lower psyllid mortality compared to seasons where canopy growth is reduced.

How long are at plant neonicotinoid treatments effective for insect control? This project supports the idea that the control period is dependent upon foliar growth of the crop, whereby when foliar growth is greater, neonicotinoid concentration is diluted and therefore control is less. The slip cages were used in hopes to determine how long the at-plant neonicotinoids would be effective at controlling potato psyllids. The data from the cages were highly variable, making it difficult to confidently predict days of control of psyllids. Since the tissue weights and pesticide concentrations vary so much from year to year and one cultivar to another, it is highly unlikely that we could ever make that assessment. Rather, we can say that under conditions where plant canopy weights are high, psyllid control is likely to be much shorter than in conditions where plant foliar growth is reduced. For example, in 2017 and 2018, adequate psyllid control was only achieved for Alturas for up to 56 and 70 days after planting respectively for any of the three insecticide treatments. In Norkotah insecticide treated plots, adequate psyllid control was never achieved with any of the three insecticides. In rapidly growing cultivars such as Norkotah, at plant neonicotinoid treatments may not be effective for psyllid control. Scouting is still the best method to ensure that potato psyllids and other insect pests do not build up to numbers where they cannot be controlled.

Treatment	Date						
	6-Jun	12-Jun	19-Jun	3-Jul	17-Jul	31-Jul	7-Aug
Alturas	55.92a	43.45a	31.70a	40.60a	26.80a	23.90a	41.83a
Norkotah	33.75a	19.82a	33.30a	24.60a	19.60a	21.90a	15.55b
LSD	24.53	24.23	27.91	30.05	27.46	24.15	24.99
Untreated Check	0.00c	0.00c	0.00b	0.00b	0.00b	0.00b	0.00b
Admire Pro	52.00ab	26.13bc	46.90a	29.0ab	18.40ab	37.50a	45.13a
Cruiser Maxx	45.88b	39.52ab	29.00ab	55.30a	52.50a	10.30ab	18.69ab
Platinum	81.46a	60.88a	54.00a	46.30a	22.00ab	43.80a	50.94a
LSD	34.68	34.26	39.47	42.5	38.84	34.16	35.34
Alturas/Untreated Check	0.00c	0.00c	0.00b	0.00b	0.00b	0.00b	0.00c
Norkotah/Untreated Check	0.00c	0.00c	0.00b	0.00b	0.00b	0.00b	0.00c
Alturas/Admire Pro	62.50ab	27.27bc	43.80ab	25.00ab	8.30ab	25.00ab	71.50a
Norkotah/Admire Pro	41.50bc	25.00bc	50.00ab	33.00ab	28.50ab	50.00a	18.75bc
Alturas/Cruiser Maxx	68.42ab	54.05ab	33.00ab	75.00a	55.00a	20.50ab	33.33abc
Norkotah/Cruiser Maxx	23.35bc	25.00bc	25.00ab	35.50ab	50.00ab	0.00b	4.06c
Alturas/Platinum	92.75a	92.50a	50.00ab	62.50a	44.00ab	50.00a	62.50ab
Norkotah/Platinum	70.17ab	29.27bc	58.00a	30.00ab	0.00b	37.50ab	39.38abc
LSD	49.05	48.46	55.82	60.11	54.92	48.3	49.98

Table 5a. Percent mortality of psyllids in slip cages 2017. Mortality corrected using the Schneider-Orelli Formula. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Treatment	Date						
	1-Jun	8-Jun	15-Jun	29-Jun	12-Jul	26-Jul	9-Aug
Alturas	64.10a	70.80a	18.70a	63.20a	50.00a	45.30a	50.00a
Norkotah	45.30a	13.90b	37.50a	59.40a	32.70a	0.00b	0.00b
LSD	24.42	19.88	24.54	19.76	30.28	20.61	18.27
Untreated Check	0.00b	0.00b	0.00a	0.00b	0.00b	0.00a	0.00b
Admire Pro	68.80a	46.50a	43.70a	87.50a	46.70a	31.30a	34.40a
Cruiser Maxx	78.10a	60.40a	29.10a	81.30a	62.50a	25.00a	31.30a
Platinum	71.90a	62.50a	39.60a	76.50a	56.30a	34.40a	34.40a
LSD	34.53	28.12	34.7	27.95	42.82	29.15	25.84
Alturas/Untreated Check	0.00a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00b
Norkotah/Untreated Check	0.00a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00b
Alturas/Admire Pro	75.00a	87.50a	31.10a	87.50a	62.50a	62.50a	68.80a
Norkotah/Admire Pro	62.50a	5.60b	56.30a	87.50a	31.00a	0.00a	0.00b
Alturas/Cruiser Maxx	93.80a	95.80a	8.30a	100.00a	75.00a	50.00a	62.50a
Norkotah/Cruiser Maxx	62.50a	25.00b	50.00a	62.50a	50.00a	0.00a	0.00b
Alturas/Platinum	87.50a	100.00a	35.40a	65.50a	62.50a	68.80a	68.80a
Norkotah/Platinum	56.30a	25.00b	43.80a	87.50a	50.00a	0.00a	0.00b
LSD	48.83	39.76	49.07	39.53	60.56 a	41.22	36.54

Table 5b. Percent mortality of psyllids in slip cages 2018. Mortality corrected using the Schneider-Orelli Formula. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Pest and beneficial insects were also enumerated in the test plots. In 2017 insects were not as abundant in potatoes compared to previous seasons. Lygus counts were significantly impacted by cultivar, where early in the season, more were captured in Norkotah plots, but as the season progressed, significantly more Lygus were captured in Alturas plots (Figure 3). It can be assumed that this difference is a result of the overall plant health and vigor. Norkotah is a determinant cultivar, and as the crop reached its maturity, leaves began to senesce, and fewer Lygus were captured in those plots. Lygus counts were not impacted by the neonicotinoid insecticides used in this study.

Psyllid counts were extremely low during 2017 and rarely encountered in these experimental plots. Aphid counts were also relatively low in 2017. During one sample period at the beginning of July, wingless aphid counts increased in untreated check plots, but remained low in treated plots (data not shown) indicating that the neonicotinoids were still impacting aphid counts nearly 80 days after planting.

Insect were more abundant in plots in 2018 than in 2017. Beneficial insects were not adversely impacted by insecticide applications at planting or lay-by. In fact, minute pirate, damsel, and big-eyed bugs were abundant in all treatments for the first four sampling periods, and sometimes more abundant in treated plots (Figures 4, 5 & 6). Big-eyed bugs were the most common beneficial insect encountered; both damsel and minute pirate bugs were encountered ten times less frequently. Beneficial insects tended to occur more frequently in Alturas than Norkotah (Figures 4, 5 & 6).

Beet leafhoppers were not impacted by insecticide treatment at the dates they appeared in the plots in significant numbers (74 DAP) (Figure 7a & 7b). Beet leafhoppers were more abundant in Norkotah plots than in Alturas. This trend could be attributed to the relative location of the experimental blocks whereby the Norkotah plots were closer to the adjacent upland vegetation that is oftentimes attributed to hosting large populations of beet leafhopper.

During 2018, Lygus were not impacted by insecticide treatment, but were more abundant in Alturas plots than Norkotah plots (Figure 8). During most sample periods, nearly twice as many were detected in Alturas plots. This trend differs slightly from 2017 where initially more lygus were found in Norkotah plots. The number of Lygus was higher overall in 2018, except during the peak Lygus flight during 2017 where more were recorded. Lygus have been noted to exhibit preference for some cultivars over others on farms, and these data seem to corroborate that trend. This information, while not impactful in terms of insecticide efficacy of this study, could be useful in understanding cultivars to utilize in future studies.

The occurrence of potato psyllids outside of the slip cages was rare in 2018 and did not present an opportunity to determine efficacy. Colorado potato beetle was abundant, but in order to preserve potato foliage and not confound other data collection for the experiment, they were controlled with a narrow spectrum insecticide (Coragen, chlorantraniliprole). Aphid numbers were also relatively low and only appeared in untreated check plots until around 75 days after planting, when numbers were not impacted by treatment (Figure 9).

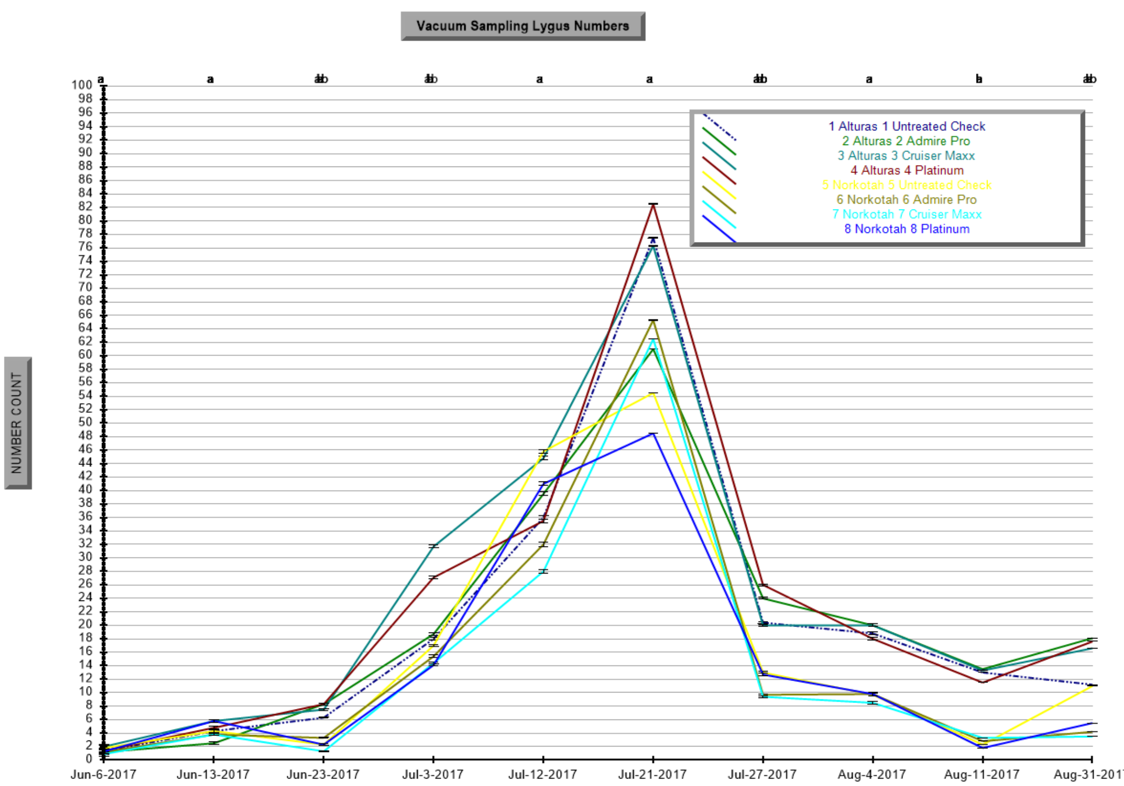

Figure 3. Lygus per vacuum sample by treatment 2017. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

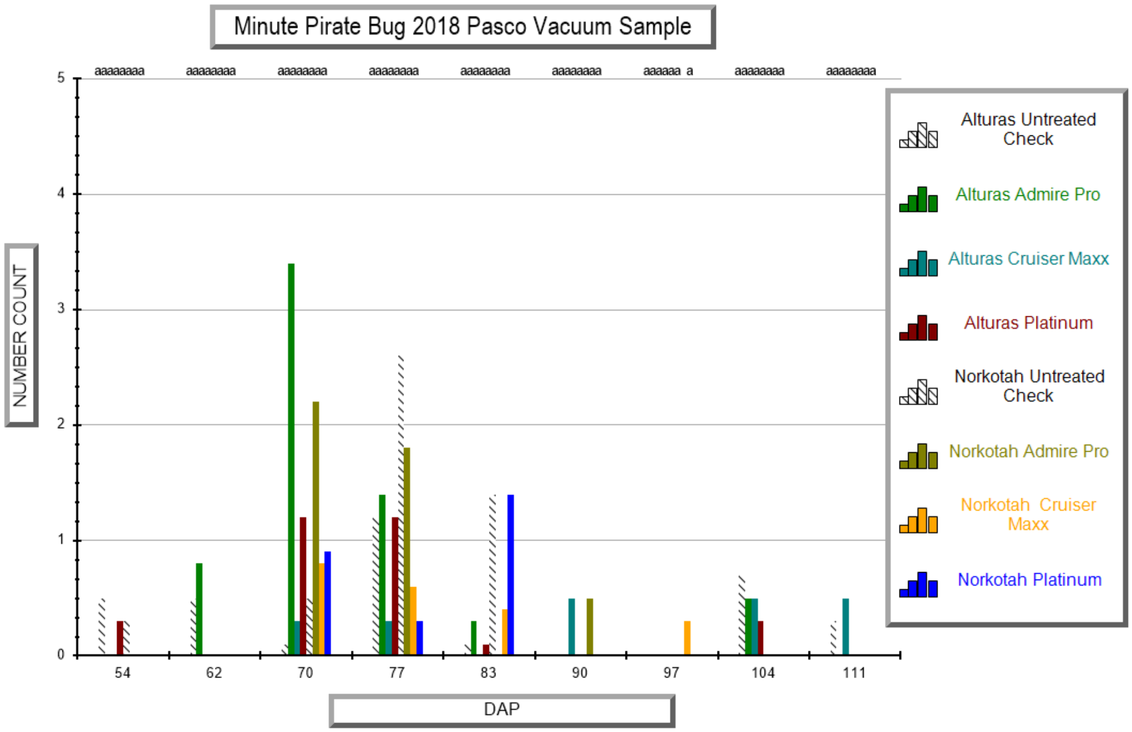

Figure 4. Minute pirate bugs per vacuum sample by treatment 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

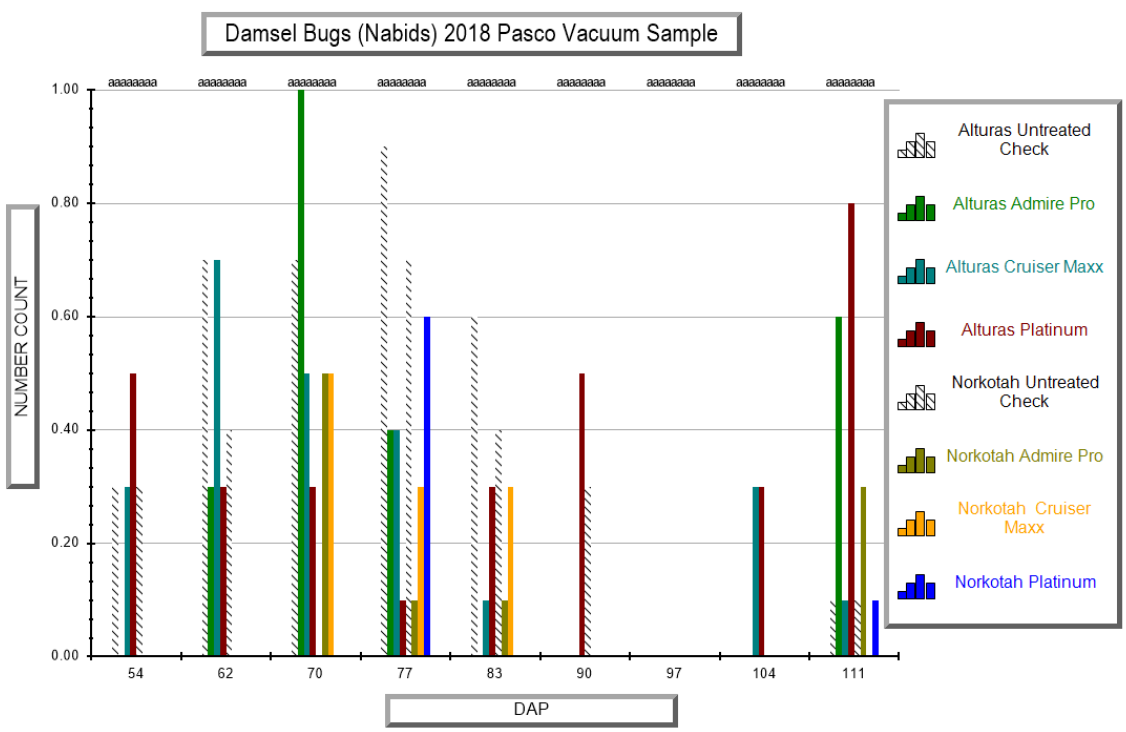

Figure 5. Damsel bugs per vacuum sample by treatment 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

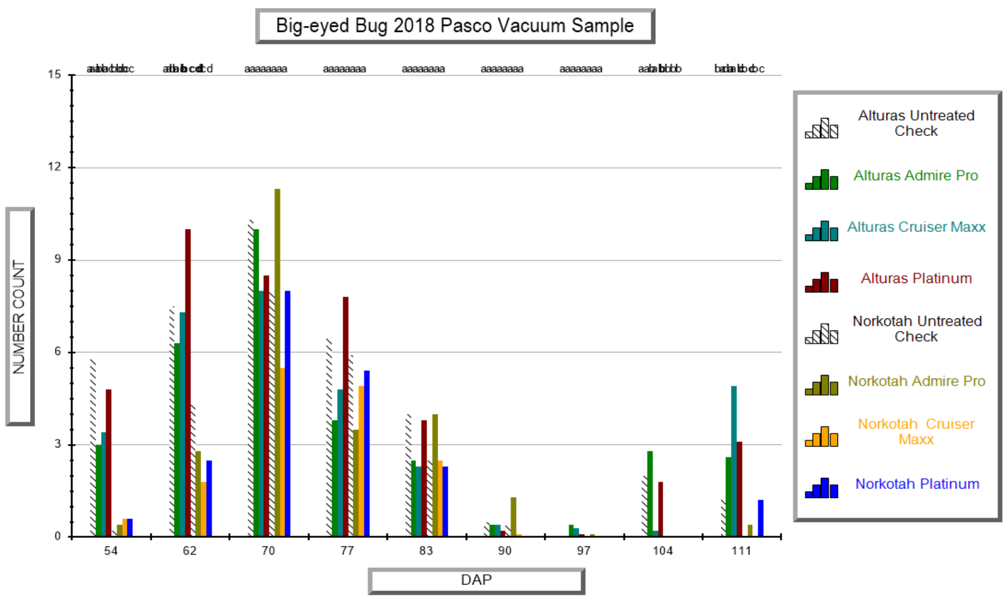

Figure 6. Big-eyed bugs per vacuum sample by treatment 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

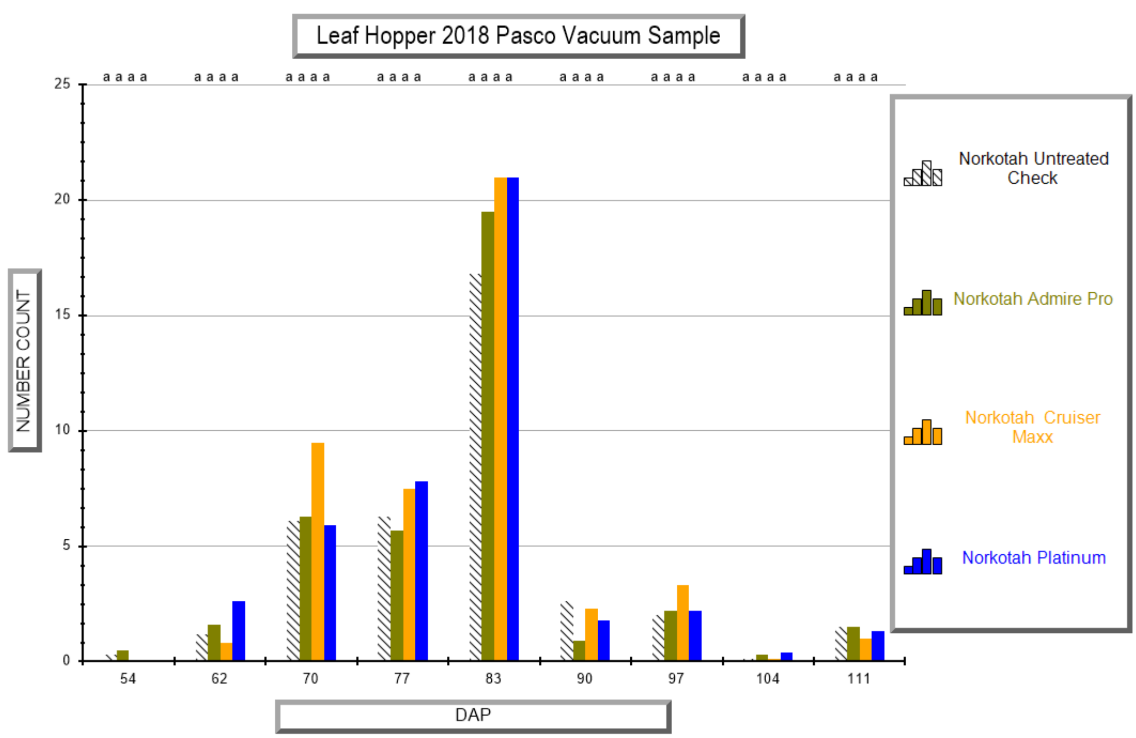

Figure 7a. Beet leafhoppers per vacuum sample by treatment, Norkotah plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

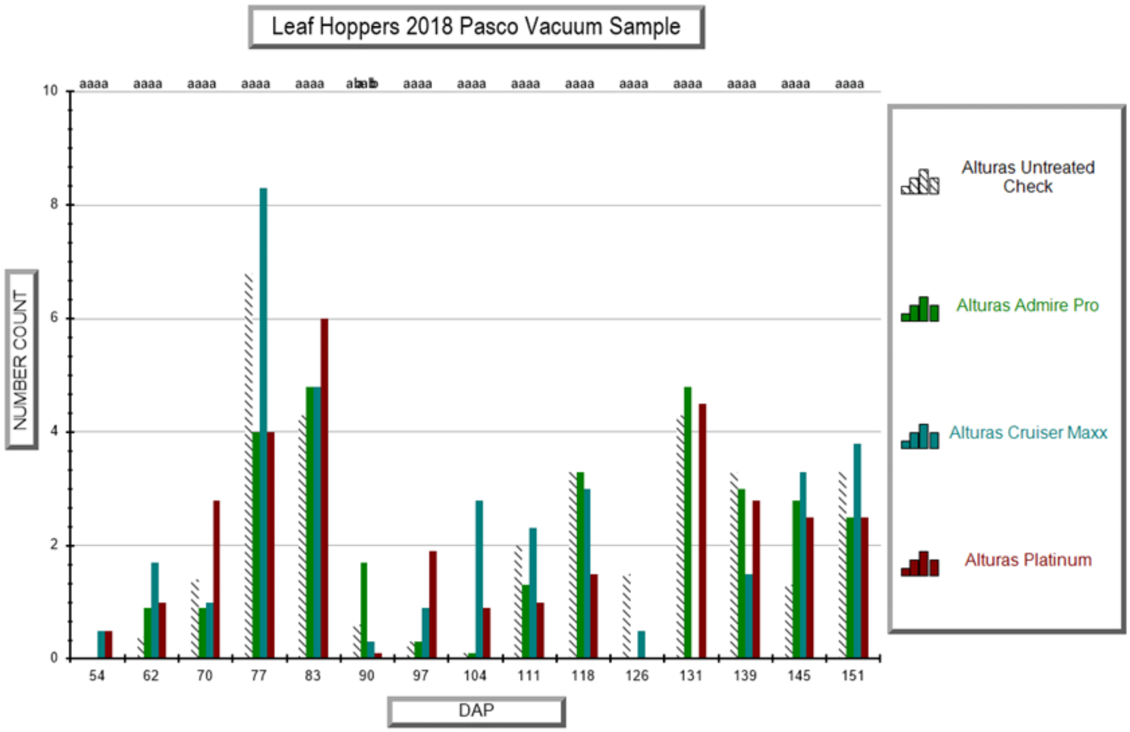

Figure 7b. Beet leafhoppers per vacuum sample by treatment, Alturas plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

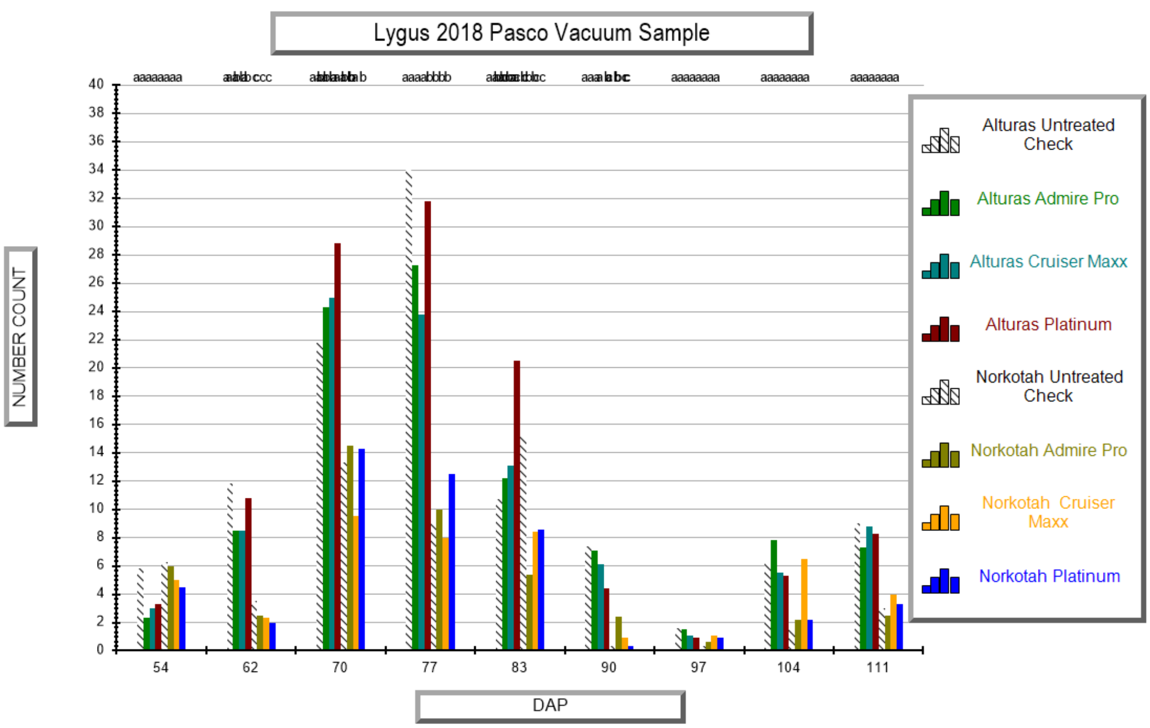

Figure 8. Lygus per vacuum sample by treatment, Alturas plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

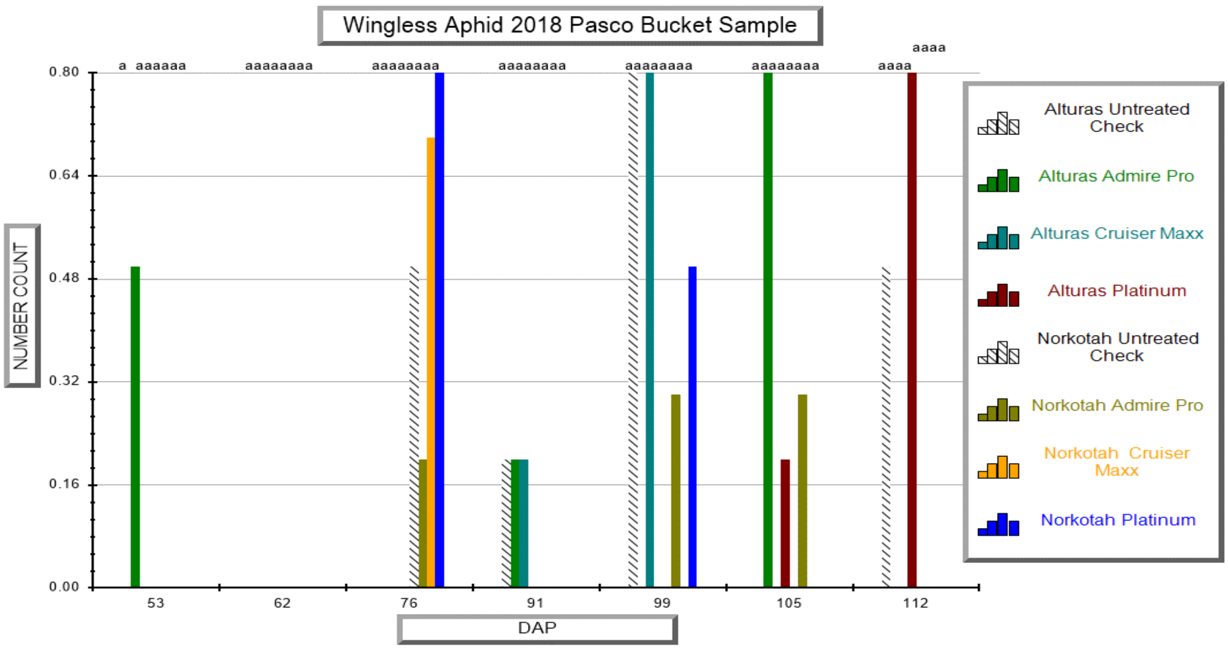

Figure 9. Wingless aphids by bucket sample by treatment, Alturas plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

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