Report on the 2017 Apple Precision Agriculture Survey

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1. Introduction

Advances in sensor technology and data analytics have generated increasing interest in precision agriculture (PA) technologies to increase resource efficiency and sustainability in crop production. However, research and adoption in this area has lagged for perennial specialty crops, such as apples. Industry experts posit no doubt that sensors and data analytics will revolutionize U.S. apple production and perennial specialty crop production in general. However, the specific time frame for adoption is still unknown (Brown, 2017).

In 2016, U.S. production value of fresh apples was $3.5 billion, with $3.0 billion (85%) coming from MI, NY, and WA (USDA-NASS 2017). Nationally, apples rank behind only grapes in production value. However, the challenges of available labor, market quality demands, and efficient resource utilization confront apple producers at all operational scales and across production regions. Apple growers are adopting premium cultivars and high-density plantings, which requires a substantial initial investment and ongoing management expenses (Galinato et al., 2016) to improve human and natural resource efficiency and meet market demands. With this high risk: high reward scenario, there is tremendous potential for PA technologies to optimize horticultural practices for apple and related crops.

This report presents information on the most important crop production challenges and the current knowledge and utilization of PA technologies by U.S. apple growers in Washington, New York, and Michigan representing a wide range in scale of operations (<15 acres to >1,000 acres).

2. Methods

During October – December 2017, an online survey was of fresh market apple producers conducted using the survey resource Qualtrics. The survey link was disseminated with the support of University extension agents in Washington (Washington State University), Michigan (Michigan State University) and New York (Cornell University). We procured responses from the principal operator or the individual in charge of making capital investment decision in the apple agribusiness operation. The survey included questions on owner and operation demographics; respondents' awareness and implementation of PA technologies; number of years using PA technologies; perceived benefits and challenges associated with investment in PA technologies; trusted sources of information; and perceived degree of importance of consultant agents for transferring knowledge. The report presents total number and frequency of responses for each response category in each question. We also report number and frequency of responses by state and by size of operation.

3. Results

3.1 Responses by state

The most responses came from New York (49), followed by Washington (43), Michigan (27), Oregon (4), and Chihuahua, MX (1). For the remainder of this report we will only consider the responses from Washington, Michigan, and New York, N=119 (see Table 1).

Table 1. Number of responses by State

Region	Total responses by region	Percentage of total responses
Washington[1]	43	35
Michigan	27	22
New York	49	40
Oregon	4	3
Chihuahua, MX	1	<1
Total	124	

[1]Three growers with orchards in more than one state were classified as Washington growers, the site of their principal operation.

3.2 Size of operation

Of the 119 apple operations surveyed across three states, the largest in terms of acreage were in Washington (369 acres on average), followed by Michigan (255 acres), and New York (176 acres). Across all states, average size was 266 acres (see Table 2).

Table 2. Number and Frequency of Operation Size Category by State

	Size of Opperation (acres)						Weighted Average
State	< 15	15-99	100-249	250-499	500-999	>1000	(acres)
Washington	5 (12%)	16 (37%)	5 (12%)	4 (9%)	2 (4%)	11 (26%)	369
Michigan	2 (7%)	9 (33%)	7 (26%)	5 19%)	3 (11%)	1 (4%)	255
New York	8 (16%)	14 (29%)	14 (29%)	12 24%)	1 (2%)	0 (0%)	176
Total	15 (14%)	39 (33%)	26 (22%)	21 17%)	6 (5%)	12 (10%)	

3.3 Most important challenge faced by growers in fresh apple production in 2017

The availability/cost of labor for harvest activities was the highest ranked challenge, with 50 growers (42%) identifying it as their most important challenge. Weather (28 growers), and the availability/cost of labor for preharvest activities (10 growers) were identified as the most important challenge with the second and third highest frequency, respectively (see Table 3).

Table 3. Rank order of number and frequency (%) of the most important challenge faced by growers, by region

Most important challenge	Washington N=43	Michigan N=27	New York N=49	Average
Availability/cost of labor for harvest activities	28 (65%)	7 (26%)	15 (31%)	50 (42%)
Weather	2 (5%)	11 (41%)	15 (31%)	28 (24%)
Availability/cost of labor for other pre-harvest activities	3 (7%)	2 (7%)	5 (10%)	10 (8%)

Competing markets	3 (7%)	5 (19%)	2 (4%)	10 (8%)
Pests and diseases	2 (5%)	1 (4%)	6 (12%)	9 (8%)
Other[1]	3 (7%)	1 (4%)	2 (4%)	4 (5%)
Availability/cost of intermediate supervisory labor	2 (5%)	0 0%	2 (4%)	4 (3%)
Productivity/profitability of available scion/rootstock cultivars	0 (0%)	0 (0%)	2 (4%)	2 (2%)
Water	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Postharvest handling	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Food safety	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Total	43	27	49	119

[1]Examples: Regulatory demands, new marketable cultivars available to all growers not solely club members, inadequate information on performance of new scion cultivars on various rootstocks, fire blight, farm succession, government intervention, and lack of autonomous equipment.

For Washington growers the most important challenge was the availability/cost of labor for harvest activities across all scales of operation, followed by availability/cost of labor for pre-harvest activities and competing markets (see Table 4).

Table 4. Ranking of most important challenge by operation size – Washington

Most important challenge	Number and frequency (%) of respondents selecting a category as its most important challenge						
	<15	15-99	100-249	250-499	500-999	>1000	Total/Avg.
Availability/cost of labor for harvest activities	2 (40%)	11 (69%)	1 (20%)	3 (75%)	2 (100%)	9 (82%)	28 (65%)
Availability/cost of labor for other pre-harvest activities	0 (0%)	1 (6%)	1 (20%)	1 (25%)	0 (0%)	0 (0%)	3 (7%)
Competing markets	1 (20%)	1 (6%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	3 (7%)
Other	1 (20%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (18%)	3 (7%)
Availability/cost of intermediate supervisory labor	0 (0%)	1 (6%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	2 (5%)
Weather	0 (0%)	1 (6%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	2 (5%)
Pests and diseases	1 (20%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (5%)
Water	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Postharvest handling	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Food safety	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Productivity/profitability of available scion/rootstock cultivars	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
N	5	16	5	4	2	11	43

For Michigan growers the most important challenge was weather, followed by the availability/cost of labor for harvest activities and postharvest handling (see Table 5).

Table 5. Ranking of most important challenge by operation size – Michigan

Most important challenge	Number and frequency (%) of respondents selecting a category as its most important challenge						
	<15	15-99	100-249	250-499	500-999	>1000	Total/Avg.
Weather	0 (0%)	5 (56%)	3 (43%)	3 (60%)	0 (0%)	0 (0%)	11 (41%)
Availability/cost of labor for harvest activities	0 (0%)	3 (33%)	2 (29%)	1 (20%)	1 (33%)	0 (0%)	7 (26%)
Postharvest handling	0 (0%)	1 (11%)	1 (14%)	1 (20 %)	2 (67%)	1 (100%)	5 (19%)
Availability/cost of labor for other pre-harvest activities	0 (0%)	0 (0%)	1 (14%)	0 (0%)	0 (0%)	0 (0%)	2 (7%)
Availability/cost of intermediate supervisory labor	1 (50%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (4%)
Water	1 (50%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (4%)
Pests and diseases	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Food safety	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Productivity/profitability of available scion/ rootstock cultivars	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Competing markets	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Other	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
N	2	9	7	5	3	1	27

For New York growers the two most important challenges were availability/cost of labor for harvest activities and weather, followed by pests and diseases (see Table 6).

Table 6. Ranking of most important challenge by operation size – New York

Most important challenge	Number and frequency (%) of respondents selecting a category as its most important challenge						
	<15	15-99	100-249	250-499	500-999	>1000	Total/Avg.
Availability/cost of labor for harvest activities	3 (38%)	3 (21%)	5 (36%)	4 (33%)	0 (0%)	0 (0%)	15 (31%)
Weather	1 (13%)	5 (36%)	4 (29%)	4 (33%)	1 (100%)	0 (0%)	15 (31%)
Pests & Diseases	3 (38%)	2 (14%)	0 (0%)	1 (8%)	0 (0%)	0 (0%)	6 (12%)
Availability/cost of labor for other pre-harvest activities	1 (13%)	2 (14%)	0 (0%)	2 (17%)	0 (0%)	0 (0%)	5 (10%)
Availability/cost of intermediate supervisory labor	0 (0%)	0 (0%)	1 (7%)	1 (8%)	0 (0%)	0 (0%)	2 (4%)
Productivity/profitability of available scion/rootstock cultivars	0 (0%)	1 (7%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	2 (4%)
Competing markets	0 (0%)	1 (7%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	2 (4%)
Other	0 (0%)	0 (0%)	2 (14%)	0 (0%)	0 (0%)	0 (0%)	2 (4%)
Water	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Postharvest handling	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Food safety	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
N	8	14	14	12	1	0	49

3.4 Familiarity with precision agriculture technologies

Across regions, growers are most familiar with precision soil mapping and nutrient management (94 growers (26%), followed by sensor-based irrigation management (74 growers (21%), and remote sensing for canopy mapping (53 growers (15%) (see Table 7).

Table 7. Number and frequency of growers familiar with three precision agriculture technologies, by region

State	Number and frequency (%) of respondents familiar with the following technologies						
	Remote sensing for canopy mapping		Precision soil mapping and nutrient management		Sensor-based irrigation management		% in each region
	Yes	No	Yes	No	Yes	No	
Washington N=43	27 (63%)	16 (37%)	30 (70%)	13 (30%)	38 (88%)	5 (12%)	36%
Michigan N=27	5 (19%)	22 (81%)	22 (81%)	5 (18%)	13 (48%)	14 (52%)	23%
New York N=49	21 (43%)	28 (57%)	42 (856	7 (14%)	23 (47%)	26 (53%)	41%

Growers in Washington and New York are more familiar than Michigan growers with remote sensing for canopy mapping (63% and 43% respectively vs, 19%). Scale of operation was not related to familiarity (see Table 8).

Table 8. Grower familiarity with remote sensing for canopy mapping by region and operation size

State	Frequency (%) of respondents familiar with remote sensing for canopy mapping						
	<15	15-99	100-249	250-499	500-999	>1000	Total
				Washington			
Yes	2 (40%)	9 (56%)	2 (40%)	4 (100%)	2 (100%)	8 (73%)	27 (63%)
No	3 (60%)	7 (44%)	3 (60%)	0 (0%)	0 (0%)	3 (27%)	16 (37%)
				Michigan			
Yes	1 (50%)	0 (0%)	2 (29%)	1 (20%)	1 (33%)	0 (0%)	5 (19%)
No	1 (50%)	9 (100%)	5 (71%)	4 (80%)	2 (67%)	1 (100%)	22 (81%)
				New York			
Yes	4 (50%)	6 (43%)	5 (36%)	6 (50%)	0 (0%)	0 (0%)	21 (43%)
No	4 (50%)	8 (57%)	9 (64%)	6 (50%)	1 (100%)	0 (0%)	28 (57%)

Growers in New York and Michigan were more familiar with precision soil mapping and nutrient management (86% and 81%, respectively) than Washington growers (70%). No obvious relation to scale of op operation was observed (see Table 9).

Table 9. Grower familiarity with precision soil mapping and nutrient management by region and operation size

State	Frequency (%) of respondents familiar with precision soil mapping and nutrient management						
	<15	15-99	100-249	250-499	500-999	>1000	Total
				Washington			
Yes	3 (60%)	11 (69%)	2 (40%)	4 (100%)	2 (100%)	8 (73%)	30 (70%)
No	2 (40%)	5 (31%)	3 (60%)	0 (0%)	0 (0%)	3 (27%)	13 (30%)
				Michigan			
Yes	1 (50%)	8 (89%)	4 (57%)	5 (100%)	3 (100%)	1 (100%)	22 (81%)
No	1 (50%)	1 (11%)	3 (43%)	0 (0%)	0 (0%)	0 (0%)	5 (19%)
				New York			
Yes	4 (50%)	13 (93%)	13 (93%)	11 (92%)	1 (100%)	0 (0%)	42 (86%)
No	4 (50%)	1 (7%)	1 (7%)	1 (8%)	0 (0%)	0 (0%)	7 (14%)

Washington growers more familiar with sensor-based irrigation management (88%) than growers in Michigan (48%) and New York (47%) (see Table 10). No obvious relation to scale of operation was observed.

Table 10. Grower familiarity with sensor-based irrigation management by region and operation size

State	Frequency (%) of respondents indicating familiar with sensor-based irrigation management						
	<15	15-99	100-249	250-499	500-999	>1000	Total
				Washington			
Yes	4 (80%)	13 (81%)	4 (80%)	4 (100%)	2 (100%)	11 (100%)	38 (88%)
No	1 (20%)	3 (19%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	5 (12%)
				Michigan			
Yes	1 (50%)	2 (22%)	3 (43%)	3 (60%)	3 (100%)	1 (100%)	13 (48%)
No	1 (50%)	7 (78%)	4 (57%)	2 (40%)	0 (0%)	0 (0%)	14 (52%)
				New York			
Yes	4 (50%)	7 (50%)	6 (43%)	5 (42%)	1 (100%)	0 (0%)	23 (47%)
No	4 (50%)	7 (50%)	8 (57%)	7 (58%)	0 (0%)	0 (0%)	26 (53%)

3.5 Use of precision agriculture technologies

Across all regions, growers currently use precision soil mapping and nutrient management technologies the most often (11%), followed by sensor-based irrigation management (7%), and remote sensing for canopy mapping (1%) (see Table 11).

Table 11. Use of three precision agriculture technologies, by region

State	Frequency (%) of respondents indicating use of the following technologies						
	Remote sensing for canopy mapping		Precision soil mapping and nutrient management		Sensor based irrigation management		% in each region
	Yes	No	Yes	No	Yes	No	
Washington N=43	3 (7%)	40 (93%)	10 (23%)	33 (77%)	22 (52%)	21 (49%)	36%
Michigan N=27	0 (0%)	27 (100%)	11 (41%)	16 (59%)	2 (7%)	25 (93%)	23%
New York N=49	2 (4%)	47 (96%)	18 (37%)	31 (63%)	2 (4%)	47 (96%)	41%
Total	5 1%	114 32%	39 11%	80 22%	26 7%	93 26%	357 100%

Very few growers currently use remote sensing for canopy mapping. Washington growers use it more than New York growers (4%). Michigan growers do not use this technology yet (see Table 12).

Table 12. Use of remote sensing for canopy mapping by region and operation size

State	Frequency (%) of respondents using remote sensing for canopy mapping						
	<15	15-99	100-249	250-499	500-999	>1000	Total
				Washington			
Yes	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (27%)	3 (7%)
No	5 (100%)	16 (100%)	5 (100%)	4 (100%)	2 (100%)	8 (73%)	40 (93%)
				Michigan			
Yes	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
No	2 (100%)	9 (100%)	7 (100%)	5 (100%)	3 (100%)	1 (100%)	27 (100%)
				New York			
Yes	0 (0%)	0 (0%)	1 (7%)	1 (8%)	0 (0%)	0 (0%)	2 (4%)
No	8 (100%)	14 (100%)	13 (93%)	11 (92%)	1 (100%)	0 (0%)	47 (96%)

Growers in Michigan use precision soil mapping and nutrient management more than New York growers (41% and 37%) respectively), followed by Washington growers (23%) (see Table 13).

Table 13. Grower use of precision soil mapping and nutrient management by region and operation size

State	Frequency (%) of respondents indicating use of precision soil mapping and nutrient management						
	<15	15-99	100-249	250-499	500-999	>1000	Total
				Washington			
Yes	1 (20%)	3 (19%)	1 (20%)	2 (50%)	0 (0%)	3 (27%)	10 (23%)
No	4 (80%)	13 (81%)	4 (80%)	2 (50%)	2 (100%)	8 (73%)	33 (73%)
				Michigan			
Yes	0 (0%)	2 (22%)	2 (29%)	3 (60%)	3 (100%)	1 (100%)	11 (41%)
No	2 (100%)	7 (78%)	5 (71%)	2 (40%)	0 (0%)	0 (0%)	16 (59%)
				New York			
Yes	0 (0%)	6 (43%)	8 (57%)	4 (33%)	0 (0%)	0 (0%)	18 (37%)
No	8 (100%)	8 (57%)	6 (43%)	8 (67%)	1 (100%)	0 (0%)	31 (63%)

In terms of the % of growers in a region that use sensor-based irrigation management, growers in Washington use it the most (51%), followed by growers in Michigan (7%), and New York growers (4%) (see Table 14).

Table 14. Grower use of sensor-based irrigation management by region and operation size

State	Frequency (%) of respondents indicating use of sensor-based irrigation management						
	<15	15-99	100-249	250-499	500-999	>1000	Total
				Washington			
Yes	1 (20%)	2 (12%)	5 (100%)	2 (50%)	1 (50%)	11 (100%)	22 (51%)
No	4 (80%)	14 (88%)	0 (0%)	2 (50%)	1 (50%)	0 (0%)	21 (49%)
				Michigan			
Yes	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (67%)	0 (0%)	2 (7%)
No	2 (100%)	9 (100%)	7 (100%)	5 (100%)	1 (33%)	1 (100%)	25 (93%)
				New York			
Yes	0 (0%)	1 (7%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	2 (4%)
No	8 (100%)	13 (93%)	13 (93%)	12 (100%)	1 (100%)	0 (0%)	47 (96%)

3.6 Benefits perceived from adopting precision agriculture technologies

Across regions, improvement in the effectiveness of green fruitlet thinning was the identified by 35% of growers as the most beneficial result of adoption of precision ag, followed by nutrient application based on real-time needs of each plant (24%), improvement in the effectiveness of dormant pruning (17%), and better targeted irrigation programs (17%). A range of other benefits was identified by 8% of growers (see Table 15).

Table 15. Most important benefit of adopting precision agriculture technologies by region

Most important benefit	Frequency (%) of respondents identifying a PA category as its most important benefit			
	Washington N=43	Michigan N=27	New York N=49	Total N=119
Improvement in effectiveness of green fruitlet thinning	10 (23%)	15 (56%)	17 (35%)	42 (35%)
Nutrient application based on real-time needs of each plant	8 (19%)	8 (30%)	13 (27%)	29 (24%)
Improvement in effectiveness of dormant pruning	5 (12%)	3 (11%)	12 (24%)	20 (17%)
Better targeted irrigation programs	16 (37%)	0 (0%)	3 (6%)	19 (16%)
Other[1]	4 (9%)	1 (4%)	4 (8%)	9 (8%)
Total in each region	43	27	49	119

[1]Examples: Robotic harvest, improved database for decision management, lack of autonomous equipment, directed accurate spraying, improve returns, more reliable pest and disease management information, stress detection from mite/aphid feeding, platform assisted horticulture activities, terminate buds for return bloom.

Across scale of operations, 37% of Washington growers identified better targeted irrigation programs as the most important benefit of adopting PA technologies, followed by improvement in the effectiveness of green fruitlet thinning (23%), nutrient application based on real-time needs of each plant (19%), improvement in the effectiveness of dormant pruning (12%), and other (9%) (see Table 16).

Table 16. Most important benefit of adopting precision agriculture technologies by operation size – Washington.

Most important benefit	Frequency (%) of respondents identifying a PA category as its most important benefit						
	<15 N=5	15-99 N=16	100-249 N=5	250-499 N=4	500-999 N=2	>1000 N=11	Total N=43
Better targeted irrigation programs	2 (40%)	3 (19%)	4 (80%)	1 (25%)	1 (50%)	5 (45%)	16 (37%)
Improvement in effectiveness of green fruitlet thinning	0 (0 %)	3 (19%)	0 (0%)	2 (50%)	1 (50%)	4 (36%)	10 (23%)
Nutrient application based on real-time needs of each plant	1 (20%)	5 (31%)	0 (0%)	1 (25%)	0 (0%)	1 (9%)	8 (19%)
Improvement in effectiveness of dormant pruning	1 (20%)	3 (19%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	5 (12%)
Other	1 (20%)	2 (13%)	0 (0%)	0 (0%)	0 (0%)	1 (9%)	4 (9%)

Across scale of operations, 56% of Michigan growers identified improvement in the effectiveness of green fruitlet thinning as the most important benefit of adopting PA technologies, followed by nutrient application based on real-time needs of each plant (30%), improvement in the effectiveness of dormant pruning (11%), and other (4%). None identified better targeted irrigation programs (see Table 17).

Table 17. Most important benefit of adopting precision agriculture technologies by operation size – Michigan.

Most important benefit	Frequency (%) of respondents identifying a PA category as its most important benefit						
	<15 N=2	15-99 N=9	100-249 N=7	250-499 N=5	500-999 N=3	>1000 N=1	Total N=27
Improvement in effectiveness of green fruitlet thinning	0 (0%)	4 (44%)	5 (71%)	4 (80%)	1 (33%)	1 (100%)	15 (56%)
Nutrient application based on real-time needs of each plant	2 (100%)	3 (33%)	1 (14%)	1 (20%)	1 (33%)	0 (0%)	8 (30%)
Improvement in effectiveness of dormant pruning	0 (0%)	2 (22%)	1 (14%)	0 (0%)	0 (0%)	0 (0%)	3 (11%)
Other	0 (0%)	0 (0 %)	0 (0 %)	0 (0 %)	1 (33%)	0 (0%)	1 (4%)
Better targeted irrigation programs	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Across scale of operations, 35% of Michigan growers identified improvement in the effectiveness of green fruitlet thinning as the most important benefit of adopting PA technologies, followed by nutrient application based on real-time needs of each plant (27%), improvement in the effectiveness of dormant pruning (24%), other (8%) and better targeted irrigation programs (6%) (see Table 18).

Table 18. Most important benefit of adopting precision agriculture technologies by operation size – New York.

Most important benefit	Frequency (%) of respondents identifying a PA category as its most important benefit						
	<15 N=8	15-99 N=14	100-249 N=14	250-499 N=12	500-999 N=1	>1000 N=0	Total N=49
Improvement in effectiveness of green fruitlet thinning	3 (38%)	5 (36%)	4 (29%)	4 (33%)	1 (100%)	0 (0%)	17 (35%)
Nutrient application based on real-time needs of each plant	3 (38%)	2 (14%)	6 (43%)	2 (17%)	0 (0%)	0 (0%)	13 (27%)
Improvement in effectiveness of dormant pruning	1 (13%)	2 (14%)	4 (29%)	5 (42%)	0 (0%)	0 (0%)	12 (24%)
Other	0 (0%)	3 (21%)	0 (0%)	1 (8%)	0 (0%)	0 (0%)	4 (8%)
Better targeted irrigation programs	1 (13%)	2 (14%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (6%)

3.7 Grower concerns regarding adoption of precision agriculture technologies

Across all three states, both the cost of the service and the reliability/quality of results to drive decisions that improve management were cited as the main concern (34%). Availability/cost of technical expertise was identified by 17%, customer service of the provider by 6% and other concerns by 6%. Only 3% saw no benefit from implementing PA technologies (see Table 19).

Table 19. Main concern regarding adoption of precision agriculture technologies by region

Main concern	Number and frequency (%) of respondents identifying a category as their main concern			
	Washington N=43	Michigan N=27	New York N=49	Total N=119
Cost of the service	16 (37%)	12 (44 %)	13 (27%)	41 (34%)
Reliability/quality of results to drive decisions that improve management	11 (26%)	12 (44%)	18 (37%)	41 (34%)
Availability/cost of technical expertise	6 (14%)	2 (7%)	12 (24%)	20 (17%)
Customer service of the provider	4 (9%)	0 (0%)	3 (6.12%)	7 (6%)
Other[1]	4 (9%)	0 (0 %)	3 (6.12%)	7 (6%)
Do not see significant benefit	2 (5%)	1 (4%)	0 (0%)	3 (3%)
Total in each region	43	27	49	119

[1]Examples: Time management, reliance on high speed internet connection, lack of autonomous equipment, annual fees, time needed to do precision management, especially fruitlet counting, technical support of both hardware and software for adopted WSU precision technologies, and equipment becomes obsolete quickly.

Most Washington growers (37%) cited cost of the service as their most important concern in adopting precision agriculture technologies, followed by the reliability/quality of results to drive decisions that improve management (26%), availability/cost of technical expertise 14%), Customer service of the provider (9%) and other (9%). Only 5% did not indicate a specific concern (see Table 20).

Table 20. Main concern regarding adoption of precision agriculture technologies by operation size – Washington.

Main concern	Number and frequency (%) of respondents identifying a category as their main concern						
	<1 N=5	15-99 N=16	100-249 N=5	250-499 N=4	500-999 N=2	>1000 N=11	Total N=43
Cost of the service	2 (40%)	8 (50%)	2 (40%)	0 (0%)	1 (50%)	3 (27%)	16 (37%)
Reliability/quality of results to drive decisions that improve management	1 (20%)	3 (19%)	0 (0%)	1 (25%)	0 (0%)	6 (55%)	11 (26%)
Availability/cost of technical expertise	1 (20%)	1 (6%)	2 (40%)	1 (25%)	0 (0%)	1 (9%)	6 (14%)
Customer service of the provider	0 (0%)	1 (6%)	1 (20%)	1 (25%)	1 (50%)	0 (0%)	4 (9%)
Other[1]	1 (20%)	2 (13%)	0 (0%)	0 (0%)	0 (0%)	1 (9%)	4 (9%)
Do not see significant benefit	0 (0%)	1 (6%)	0 (0%)	1 (25%)	0 (0%)	0 (0%)	2 (5%)

[1]Examples: Time management, reliance on high speed internet connection, lack of autonomous equipment, annual fees, time needed to do precision management, especially fruitlet counting, technical support of both hardware and software for adopted WSU precision technologies, and equipment becomes obsolete quickly.

An equal percentage of Michigan growers (44%) cited cost of the service and the reliability/quality of results to drive decisions that improve management as their most important concerns for adopting precision agriculture, followed by the availability/cost of technical expertise (7%). None cited customer service of the provider or other as a main concern. Only one grower (4%) saw no significant benefit.. Table 21.

Table 21. Main concern regarding adoption of precision agriculture technologies by operation size – Michigan.

Main concern	Number and frequency (%) of respondents identifying a category as their main concern						
	<15 N=2	15-99 N=9	100-249 N=7	250-499 N=5	500-999 N=3	>1000 N=1	Total N=27
Cost of the service	1 (50%)	7 (78%)	3 (43%)	1 (20%)	0 (0%)	0 (0%)	12 (44%)
Reliability/quality of results to drive decisions that improve management	1 (50%)	1 (11%)	3 (43%)	4 (80%)	2 (67%)	1 (100%)	12 (44%)
Availability/cost of technical expertise	0 (0%)	0 (0%)	1 (14%)	0 (0%)	1 (33%)	0 (0%)	2 (7%)
Do not see significant benefit	0 (0%)	1 (11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (4%)
Customer service of the provider	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Other[1]	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

[1]Examples: Time management, reliance on high speed internet connection, lack of autonomous equipment, annual fees, time needed to do precision management, especially fruitlet counting, technical support of both hardware and software for adopted WSU precision technologies, and equipment becomes obsolete quickly.

Most New York growers (37%) cited reliability/quality of results to drive decisions that improve management as their most important concern for adopting precision agriculture, followed by the cost of the service (27%), the availability/cost of technical expertise (24%), customer service of the provider (6%) and other (6%). None cited did not see any significant benefit (see Table 22).

Table 22. Main concerns regarding precision agriculture technologies by region and operation size – New York.

Main concern	Number and frequency (%) of respondents identifying a category as their main concern						
	<15 N=8	15-99 N=14	100-249 N=14	250-499 N=12	500-999 N=1	>1000 N=0	Total N=49
Reliability/quality of results to drive decisions that improve management	1 (13%)	7 (50%)	4 (29%)	5 (42%)	1 (100%)	0 (0%)	18 (37%)
Cost of the service	4 (50%)	3 (21%)	2 (14%)	4 (33%)	0 (0%)	0 (0%)	13 (27%)
Availability/cost of technical expertise	3 (38%)	1 (7%)	6 (43%)	2 (17%)	0 (0%)	0 (0%)	12 (24%)
Customer service of the provider	0 (0%)	0 (0%)	2 (14%)	1 (8%)	0 (0%)	0 (0%)	3 (6%)
Other	0 (0%)	3 (21%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (6%)
Do not see significant benefit	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

3.8 Years of experience with precision agriculture technologies in apples as of 2017, by region.

Differences in years of experience among regions were not of great magnitude. Washington growers have the most experience with precision agriculture technologies, 8.6 years on average, followed by Michigan (6.7 years), and New York (6.4 years). Overall, the average grower who uses precision agriculture technologies has 7.3 years of experience. Only five growers had more than 20 years of experience (see Table 23).

Table 23. Years of experience with precision agriculture technologies in apples as of 2017 by region

State	Number and frequency (%) of respondents selecting each experience category					
	< 5 N=78	6-10 N=21	11-20 N=10	21-30 N=2	30 N=2	Average N=113
Washington	25 (32%)	7 (33%)	8 (80%)	1 (50%)	1 (50%)	9
Michigan	19 (24%)	7 (33%)	0 (0%)	0 (0%)	1 (50%)	7
New York	34 (44%)	7 (33%)	2 (20%)	1 (50%)	0 (0%)	6
Total						7

Within regions, there were no obvious associations of scale of operation with years of experience working with precision agriculture technologies (see Table 24).

Table 24. Years of experience with precision agriculture technologies in apples as of 2017 by region and operation size

Years of experience	Number and frequency (%) of respondents who marked each category (N=113)						
	<15	15-99	100-249	250-499	500-999	>1000	Total/ Average
	N=5	N=15	N=5	N=4	N=2	N=11	N=42
				Washington			
<5	5 (100%)	9 (60%)	2 (40%)	1 (25%)	2 (100%)	6 (55%)	25 (60%)
6-10	0 (0%)	0 (0%)	1 (20%)	3 (75%)	0 (0%)	3 (27%)	7 (17%)
11-20	0 (0%)	4 (27%)	2 (40%)	0 (0%)	0 (0%)	2 (18%)	8 (19%)
21-30	0 (0%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)
30	0 (0%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)
Average	5.0	10.8	9.8	7.3	5.0	7.7	8.6
				Michigan			
	N=1	N=9	N=7	N=4	N=3	N=1	N=27
<5	2 (100%)	8 (89%)	5 (71%)	3 (60%)	1 (33%)	0 (0%)	19 (70%)
6-10	0 (0%)	1 (11%)	2 (29%)	1 (20%)	2 (67%)	1 (100%)	7 (26%)
11-20	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
21-30	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
30	0 (0%)	0 (0%)	0 (0%)	1 (20%)	0 (0%)	0 (0%)	1 (4%)
Average	5.0	5.3	5.9	10.6	7.0	8.0	6.7
				New York			
	N=8	N=10	N=14	N=11	N=1	N=0	N=44
<5	6 (75%)	7 (70%)	12 (86%)	8 (73%)	1 (100%)	0 (0%)	34 (77%)
6-10	1 (13%)	3 (30%)	2 (14%)	1 (9%)	0 (0%)	0 (0%)	7 (16%)
11-20	0 (0%)	0 (0%)	0 (0%)	2 (18%)	0 (0%)	0 (0%)	2 (5%)
21-30	1 (13%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)
30	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Average	7.9	5.9	5.4	7.2	5.0	0.0	6.4

3.9 Grower investment in precision agriculture technologies

Across all three states, 67% of growers would consider investing in precision agriculture technologies, around 25% did not know or needed more information, and around 8% said they would not consider investing in these technologies. Washington growers indicated the highest likelihood of investing at 72%, followed by New York (59%) and Michigan growers (59%) (see Table 25).

Table 25. Grower inclination to invest in precision agriculture technologies by region

State	Number and frequency (%) of respondents indicating they would consider investing in precision agriculture technologies		
	Yes	No	I don't know
Washington (N=43)	31 (72%)	4 (9%)	8 (19%)
Michigan (N=27)	16 (59%)	1 (4%)	10 (37%)
New York (N=49)	33 (67%)	4 (8%)	12 (24%)
Average	67%	8%	25%

Neither size of operation or regions was associated with the decision to adopt precision agriculture technologies (see Table 26).

Table 26. Grower inclination to invest in precision agriculture technologies by region and operation size

State	Number and frequency (%) of respondents indicating they would consider investing in precision agriculture technologies						Total	Average Size
	<15	15-99	100-249	250-499	500-999	>1000		
				Washington (N=43)				
Yes	2 (40%)	9 (56%)	4 (80%)	4 (100%)	2 (100%)	10 (91%)	31 (72%)	459
No	1 (20%)	3 (19%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	4 (9%)	47
I don't know	2 (40%)	4 (25%)	1 (20%)	0 (0%)	0 (0%)	1 (9%)	8 (19%)	179
				Michigan (N=27)				
Yes	1 (50%)	5 (56%)	4 (56%)	3 (60%)	2 (100%)	1 (100%)	16 (59%)	289
No	0 (0%)	0 (0%)	0 (0%)	1 (20%)	0 (0%)	0 (0%)	1 (4%)	375
I don't know	1 (50%)	4 (44%)	1 (44%)	1 (20%)	0 (0%)	0 (0%)	10 (37%)	189

	New York (N=49)							
Yes	3 (38%)	8 (57%)	13 (93%)	8 (67%)	1 (100%)	0 (0%)	33 (67%)	197
No	2 (25%)	1 (7%)	0 (0%)	1 (8%)	0 (0%)	0 (0%)	4 (8%)	115
I don't know	3 (38%)	5 (36%)	1 (7%)	3 (25%)	0 (0%)	0 (0%)	12 (24%)	136

3.10 Trusted providers of information on precision agriculture technologies

Across the three states surveyed, 18 growers cited university researchers and extensionists as their trusted source of information when considering investing in precision agriculture technologies, followed by agriculture service providers (13 growers), other growers (8 growers), and some other source, including internet, combination of all three or no single provider is totally reliable (2 growers) (see Table 27).

Table 27. Trusted providers of information on precision agriculture technologies by region

State	Frequency (%) of respondents marking a particular category				
	Other growers	University researchers and extensionists	Ag service providers	Other[1]	% in each region
Washington	13 (30%)	15 (35%)	13 (30%)	2 (5%)	36%
Michigan	4 (15%)	14 (52%)	8 (29%)	1 (4%)	23%
New York	6 (12%)	23 (47%)	16 (33%)	4 (8%)	41%
Weighted average by region	8.08	18.07	13.10	2.60	100%

[1]Examples: Internet, combination of all three, no one provider is totally reliable

Washington growers of a particular acreage their most cited source of information were other growers (3 growers on average), followed by agriculture service providers (3 growers on average), and university researchers and extensionists (2 growers on average). Michigan growers cited university researchers and extensionists the most (3 growers on average), followed by agriculture service providers (2 growers on average), and other growers (1 grower on average). For New York growers their most trusted source of information were university researchers and extensionists (5 growers on average), followed by agriculture service providers (4 growers on average), and a different source (2 growers on average) (see Table 28).

Table 28. Trusted providers of information on precision agriculture technologies by region and operation size

State	Frequency (%) of respondents marking a particular category						
	<15	15-99	100-249	250-499	500-999	>1000	Weighted Avg.
				Washington (N=43)			
Other growers	1 (20%)	6 (38%)	2 (40%)	0 (0%)	0 (0%)	4 (36%)	3
University researchers and extensionists	3 (60%)	3 (19%)	1 (20%)	2 (50%)	2 (100%)	4 (36%)	2
Ag service providers	1 (20%)	6 (38%)	2 (40%)	2 (50%)	0 (0%)	2 (18%)	3
Other	0 (0%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	1 (9%)	0.7
% in each operation size	10%	33%	13%	10%	5%	28%	100%
				Michigan (N=27)			
Other growers	1 (50%)	1 (11%)	1 (14%)	0 (0%)	1 (33%)	0 (0%)	0.8
University researchers and extensionists	1 (50%)	6 (67%)	4 (57%)	2 (40%)	1 (33%)	0 (0%)	3
Ag service providers	0 (0%)	1 (11%)	2 (29%)	3 (60%)	1 (33%)	1 (100%)	2
Other	0 (0%)	1 (11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0.6
% in each operation size	6%	31%	25%	25%	6%	6%	100%
				New York (N=43)			
Other growers	2 (25%)	1 (7%)	2 (14%)	1 (8%)	0 (0%)	0 (0%)	1
University researchers and extensionists	4 (50%)	7 (50%)	6 (43%)	5 (42%)	1 (100%)	0 (0%)	5
Ag service providers	2 (25%)	4 (29%)	6 (43%)	4 (33%)	0 (0%)	0 (0%)	4
Other	0 (0%)	2 (14%)	0 (0%)	2 (17%)	0 (0%)	0 (0%)	2
% in each operation size	17%	21%	31%	29%	2%	0%	100%
% in each operation size (total)	14%	28%	23%	20%	4%	12%	100%

3.11 Importance of agriculture service company or consultant expertise for guidance and implementation

We can see that growers most cite their agriculture service or consultant expertise as extremely important, 43 growers (34.96%), followed by very important (42 growers), and important (26 growers). All but 12 growers cite the expertise they receive as at least important. There are 10 growers who are neutral, only 1 grower saw the expertise as unimportant, and 1 did not apply. New York placed the highest average importance on expertise, very important on average, and Michigan the least average importance. On average, growers find the expertise they receive to be very important (see Table 29).

Table 29. Importance of agriculture service company or consultant expertise for guidance and implementation by region

State	Frequency (%) of respondents marking a particular category								
	Extremely important =7	Very important =6	Important =5	Neutral =4	Unimportant =3	Very unimportant =2	Extremely unimportant =1	Does not apply	Average Importance
WA[1]	18 (42%)	11 (26%)	9 (21%)	4 (9%)	1 (2%)	0 (0%)	0 (0%)	0 (0%)	5.95
MI	7 (26%)	12 (44%)	6 (22%)	1 (4%)	0 (0%)	0 (0%)	0 (0%)	1 (4%)	5.74
NY	17 (35%)	17 (35%)	11 (22%)	4 (8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.96
Total/ Avg.	43 (35%)	42 (34%)	26 (21%)	10 (8%)	1 (0.8%)	0 (0%)	0 (0%)	0 (0%)	5.90

[1]Used state abbreviations to fit the whole table, WA (Washington), MI (Michigan), NY (New York)

Washington growers with 250-499 acres cited the expertise they receive as extremely important on average. Washington growers with less than 15 acres placed the lowest average importance on expertise where they were neutral on average. Washington growers on average cited expertise as very important. Those who cited it as extremely important had an average of 367 acres.

Michigan growers with 500-999 acres cited the expertise/services they receive as very important on average along with growers with less than 15 acres and 250-499 acres. Michigan growers, on average, cited expertise as very important. Growers who cited it as extremely important indicated their average size was 362 acres. New York growers with 500-999 acres cited the expertise/services they receive as extremely important on average. The lowest average importance were growers with 15-99 acres who still had an average importance of very important. Growers in New York, on average, cited expertise as very important (see Table 30).

Table 30. Importance of agriculture service company or consultant expertise for guidance and implementation by region and operation size

Avg. size (acres)	Extremely important =7	Very important =6	Important =5	Neutral =4	Unimportant =3	Very unimportant =2	Extremely unimportant =1	Does not apply	Average Importance
	Frequency (%) of respondents marking a particular category								
					Washington				
<15	0 (0%)	2 (40%)	3 (60%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.40
15-99	9 (56%)	1 (6%)	2 (13%)	4 (25%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.94
100-249	2 (40%)	2 (40%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.20
250-499	2 (50%)	2 (50%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.50
500-999	0 (0%)	1 (50%)	1 (50%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.50
>1000	5 (45%)	3 (27%)	2 (18%)	0 (0%)	1 (9%)	0 (0%)	0 (0%)	0 (0%)	6.00
	367	449	343	57	1000	0	0	0	5.95
					Michigan				
<15	0 (0%)	2 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.00
15-99	2 (22%)	5 (56%)	0 (0%)	1 (11 %)	0 (0%)	0 (0%)	0 (0%)	1 (11%)	5.33
100-249	1 (14%)	4 (57%)	2 (29%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.86
250-499	2 (40%)	1 (20%)	2 (40%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.00
500-999	2 (67%)	0 (0%)	1 (33%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.33
>1000	0 (0%)	0 (0%)	1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.00
	362	116	475	57	0	0	0	57	5.74
					New York				
<15	4 (50%)	2 (25%)	2 (25%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.89
15-99	4 (29%)	3 (21%)	4 (29%)	3 (21%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.57
100-249	5 (36%)	4 (29%)	4 (29%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.93
250-499	3 (25%)	8 (67%)	1 (8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6.17
500-999	1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	7.00
>1000	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0
	59	229	121	86	0	0	0	0	6.46

3.12 Potential USDA funded project

On average, 30% of growers surveyed would be willing to participate as a stakeholder advisor and 50% would need more information. The remaining 20% would not be willing to participate.

Table 31. Willingness to participate as a stakeholder advisor in a USDA-funded project, by region

State	Number and frequency (%) of respondents willing to participate as a stakeholder advisor		
	Yes	No	Need more information
Washington (N=43)	14 (33%)	8 (19%)	21 (49%)
Michigan (N=27)	7 (26%)	6 (23%)	14 (52%)
New York (N=49)	15 (31%)	10 (20%)	24 (49%)
Average	30%	20%	50%

4. Summary

A survey conducted during November-December 2017 assessed the level of knowledge and use of precision agriculture technologies by apple growers in the three states producing the largest volumes of the fruit crop nationally. Of the total of 124 valid responses obtained, 36% were from Washington, 23% from Michigan, and 42% from New York. Respondents represented a wide range of scale of operations, from small (<100 acres) to medium (100-500 acres), to large (>500 acres). The cost/availability of labor for harvest activities was overwhelmingly the most important challenge across all production regions and scale of operations, with 42% of respondents citing this category. While weather was cited by 24% of respondents as their most important challenge, growers in New York and Michigan were far more likely to select this category that Washington growers. Michigan growers also had a relatively higher proportion of respondents identify competing markets as their most important challenge. Other categories of significance were availability/cost of labor for other pre-harvest activities, and pests and diseases.

Across regions and scale of operations, respondents were most familiar with precision agriculture technologies of soil mapping and nutrient management, followed by sensor-based irrigation management and remote sensing for canopy mapping. Across all three states, there is no evidence that large sized operations were more familiar with all three cited technologies that medium- or small-sized operations.

Most respondents identified green fruitlet thinning as an important benefit of adopting precision agriculture, followed by nutrient application based on real-time needs of each plant, improvement effectiveness of dormant pruning, and targeted irrigation programs. Washington growers indicated that better targeted irrigation programs was the most important perceived benefit, while Michigan and New York growers indicated that improvement in effectiveness of green fruitlet thinning was the most important benefit. Respondents across three states indicated cost of the service and reliability/quality of results to drive decisions that improve management were their chief concerns.

Average years of experience with precision agriculture technologies across all three states were 7.3 years. Most experienced growers were in Washington, followed by Michigan and New York. The majority of respondents (67%) across regions and scale of operation indicated they would consider investing in precision agriculture technologies.

Across all three states university researchers and extensionists were cited as the most trusted source of information on PA technologies, although Washington growers cited other growers as most trusted sources of information, while in Michigan and New York it was university researchers and extensionists. Across all three states, agriculture service companies were considered important or very important on the guidance and implementation of precision agriculture technologies.

Finally, 30% of all respondents indicated a willingness to participate as stakeholder advisor in a grant funded project dealing with precision agriculture technologies application to the apple industry, while 50% indicated they needed more information.

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