

**Final Report
of
Fertilization Best Management Practices for Commercial Potato
Production in Northeast Florida**

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PI: Guodong Liu

Co-PIs: Dr. Mark Clark and Kelly Morgan

Research Assistant: Thioro Fall

Farm Owners: Danny Johns, Scott Parker, Steven Singleton, Tommy Wilson



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Project Manager: William Bartnick

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Summary

This study was conducted with two types of potatoes: chipping ‘Atlantic’ and tablestock ‘Red LaSoda’ on four cooperative potato farms in the Hastings area from December 1, 2017 through March 31, 2021. Before the trials started, soil samples were collected and analyzed with Mehlich-3 extractant. The results showed that the farms with chipping potato ‘Atlantic’ had 220-497 mg/kg P and those with tablestock potato ‘Red LaSoda’ had 247-520 mg/kg P. This high level of extractable P is up to 11 times greater than the UF/IFAS recommendation (45 mg/kg P) for zero P application for potato production. Potato growers, however, keep applying 100 lb/acre or more every growing season because they see the yield response to P application.

To evaluate the effects of P application on potato yield and quality in large-scale trials on the potato farms. Either of ‘Atlantic’ and ‘Red LaSoda’ was grown on two commercial farms. Plot size was 1.2 to 1.6 acres. Randomized complete block design (RCBD) was used with 4 replications. Three P rates were applied: 0, 50, and 100 lb/acre P_2O_5 . During the project period, the average tuber yields of ‘Atlantic’ were 38,446, 39,859, 40,828 lb/acre at Scott Parker Farms and 36,827, 37,728, 39,360 lb/acre at Farm Singleton & Sons Farms. The corresponding yields of ‘Red LaSoda’ were 30,807, 31,424, 32,433 lb/acre for Wilson Family Farm. Blue Sky had 4 P rates: 0, 50, 100, and 150 lb/acre P_2O_5 for only two years. The 2-year average yield for each of the 4 P rates was 36,410, 35,567, 37,799, and 37,219 lb/acre. There was not any significant difference in tuber yields between 0 and 50 lb/acre P_2O_5 for both cultivars on all the farms. The difference in the yields between 0 and 100 lb/acre P_2O_5 was not significant for ‘Red LaSoda’ either. However, ‘Atlantic’ with 100 lb/acre P_2O_5 always had significant ($p < 0.10$) greater yield than 0 P application for each of the three years. When we combined the three years’ yield data the difference between 0 and 100 lb/acre P_2O_5 was significant at 0.029 for ‘Atlantic’ and at 0.10 for ‘Red LaSoda’. This significant yield response can be attributed to high contents of aluminum and ferric iron in soil. The cooperative farms had up to almost 1,900 lb/acre aluminum and 620 lb/acre ferric iron. Additionally, soil pH in the growing seasons decreased to pH 5 or

even lower. The in-season reduction of soil pH can increase the activity of either aluminum or ferric iron by 1,000 times. These active metals chemically bind fertilizer P and legacy P in soil. Furthermore, growers apply P fertilizer one month before planting. During this month, most of the bioavailable P from either P fertilizer or soil legacy P can be immobilized and potato vines cannot take up much of P in soil.

The tuber specific gravity results showed that there was not any significant difference between the P rates in each of the three years. The results suggests that 100 lb/acre P_2O_5 is needed for potato production with the current P fertilizer programs in the area. This P requirement may be associated with the current P fertilizer programs (applying P fertilizer one month before planting) and with the unique potato root physiology. More research is needed.

Introduction

The Hastings area has cultivated potatoes since 1890s and fertilizer application has been common since 1920 and adopted in large scale since 1950 (Cumings and Houghland, 1939; Locasicio, 1987; Roy 2006). The Hastings area grew 28,000 acres of potatoes in 1990s (Hochmuth et al., 1993) but it is currently growing only about 20,000 acres. This decrease in acreage is due to the thin profit margins from potato producers, which resulted in five potato growers going out of business in 2017 alone. The goal of UF/IFAS recommendations, developed from scientific research, is to improve the economic and environmental sustainability of crop production. Local potato producers value soil testing as an invaluable tool for potato production and collect soil samples for soil test before planting every growing season.

The producers apply 200 lb/acre nitrogen (N) in 3 or 4 split applications and apply 30 lbs/acre N following leaching rains as UF/IFAS recommended for potato production. Also, the adoption of the recommendations has been facilitated by cost sharing of fertilizer banding equipment and more efficient irrigation systems resulting in nutrient load reductions and significant water savings. The recommendations save tons of N fertilizers and ensure minimizing environmental risks from N fertilizer application for potato production in the area.

Compared to N, phosphorus (P) is relatively immobile in soil under moderate soil pH. As a result of long-term P applications, the soils in the area are high in phosphorus (P). Research data collected from more than 30 commercial potato farms in the Hastings area in 2012 and 2013 indicated that the soils are all rich in P, with an average of 14 mg/kg of water-soluble P (range 6 to 20) and an average of 351 mg/kg Mehlich-3 P (range 81 to 599). Average soil pH is 6.2 (range 5.3 to 7.5) (Liao et al., 2015).

The IFAS P fertilizer recommendations are 1) 120 lb/acre P_2O_5 when Mehlich-3 extractable P is <25 mg/kg; 2) 100 lb/acre P_2O_5 when Mehlich-3 P is between 26 and 45 mg/kg; and 3) zero P_2O_5 when Mehlich-3 P is >45 mg/kg

(<http://edis.ifas.ufl.edu/cv296>). The data cited in the previous paragraph show that the Mehlich-3 extractable P contents in the soils are 2- to 13-fold greater than the threshold point of high soil test P. Consequently, based on the recommendations, potato growers should NOT apply any P fertilizer for potato production. However, growers apply 100 or more lb/acre P_2O_5 every growing season because they perceive that tuber yield increase in response to these P applications.

Our recent on-farm study examined the addition of P to soils rich in Mehlich-3 extractable P and showed that the zero P treatment had significantly lower tuber yield than other P rates including 80, 120, 160, and 200 except 40 lbs/acre P_2O_5 . Average soil pH was 6.2 and drops to 4.8 in growing season when the applied ammonium nitrogen was converted into nitrate nitrogen. We also analyzed Mehlich-3 extractable aluminum and iron. The farms averaged 250 mg/kg Al (range 69 to 417) and 60 mg/kg Fe (range 12 to 178) in soils. Aluminum is not a nutrient for plants but instead is toxic and damages plant root systems. Iron is a micronutrient essential for potato plants. Potato vines remove roughly 2 pounds of iron and tubers do approximately 1 pound of iron per acre per season. Growers only apply a few pounds of chelated ferrous iron per acre if needed. Thus, the metals in soil have no relation to fertilization. In fact, these metals are from the parent materials. The phosphate fractionation data showed that approximately 70% of P was bound with Al and Fe. Liming can increase soil pH and reduce Al and Fe activity in soil. However, potato is susceptible to common scab (*Streptomyces scabies*). *Streptomyces scabies* does not grow at pH 4.5. It does not cause disease in soils of pH lower than 5.2. Thus, potato growers must keep soil pH low until resistant cultivars are available. In other words, application of agricultural lime cannot be employed as a tool to free P from soil.

The challenge is to understand the disparity between previous and current research regarding P fertilizer response observed on high P soils. Therefore, the objectives of these large-scale trials were to (1) better understand why there was a

yield response to P application on soil with high extractable P and (2) provide P fertilizer suggestions to local growers for potato production.

Materials and Methods

These large-scale on-farm trails were conducted with chipping potato ‘Atlantic’ and tablestock potato ‘Red LaSoda’ with 4 replications from spring 2018 through summer 2020. Either type of potato was grown on two commercial potato farms: Parker Farms and Singleton & Sons Farms for ‘Atlantic’ and Blue Sky Farms and Wilson Family Farm for ‘Red LaSoda’. Three P rates were used: 0, 50, and 100 lb/acre P_2O_5 . Blue Sky Farms had an additional P rate: 150 lb/acre P_2O_5 but participated in the study only for the first two growing seasons because the land used for the trials was leased out by the owner for the third season. The other field practices all followed the UF/IFAS recommendations and completed by the cooperative growers.



Figure 1. The layout of the large-scale trials with a summary of the experimental design with chipping potato ‘Atlantic’ and tablestock ‘Red LaSoda’.

The plot size was 1.53 and 1.20 acres at Parker Farms and Singleton & Son Farms and 1.40 and 1.60 acres at Blue Sky Farms and Wilson Family Farm (Figure 1). Regular plot size is only 533 square feet at Hastings Agricultural Extension Center. Thus, the plot size of the large-scale trials was 100 to 140 times greater than the regular plot size. These large-scale trials were more representative for the real world of potato production and had much greater variation of the data collected because the number of replications was not able to increase.

There were 6 soil samplings including pre-plant and 5 inseason samplings with intervals of two weeks after planting in each of the three growing seasons. Soil samples were collected from the root zones for measuring Mehlich-3 nutrients, soil pH, soil nutrients, and CEC. Morgan P and P fractionation were also completed for some representative soil samples.

Ninety-five to 100 days after planting, every potato tuber from the trials was mechanically harvested (Figure 2) and measured for tuber yields by using a truck scale for Blue Sky Farms, Parker Farms, and Singleton & Sons Farms and Optima OP-928 Portable Weigh Pads Axle Scale Truck Scale for Wilson Family Farm (Figure 3). Tuber quality and specific gravity were measured for the first two growing seasons but were not done for the third growing season because of the COVID-19 pandemic.



Figure 2. Potato harvest of the large-scale trial.



Figure 3. Measuring potato tuber yield. Above: A wagon full of potatoes is on the scale pads. Bottom: remote display.

Results

Table 1 shows the differences in potato tuber yields at different P rates. The tuber yield always increases with P fertilization except for Blue Sky Farms with a couple of exceptions. The yield increase between 0 and 50 lb/acre P_2O_5 was never significant for either of the cultivars. The yield increase between 0 and 100 lb/acre P_2O_5 was always significant for 'Atlantic' at $p < 0.10$ for each of the three years and at $p < 0.05$ for the three years combined. For 'Red LaSoda', the yield increase either between 0 and 50 or between 0 and 100 lb/acre P_2O_5 was not significant at all. When we combined the two cultivars, the yield increase between 0 and 100 lb/acre P_2O_5 was significant at $p < 0.10$ only for 2020. If all the data of the three years combined, the tuber yield increase of the two cultivars with 100 lb/acre P_2O_5 was significant at $p < 0.10$ greater than 0 P application (Table 2). The yield increase between 0 and 50 or 0 and 100 lb/acre P_2O_5 was not significant for each of the farms with either cultivar. However, if we combined the three years' data, the yield difference between 0 and 100 lb/acre P_2O_5 was significant at $p < 0.05$ for 'Atlantic'. If the two cultivars in the three years were combined, the yield was significant ($p < 0.10$) lower with 0 than with 100 lb/acre P_2O_5 (Table 3).

Table 1. Potato yield (lb/acre) in each of the three years and average potato yield of the three years and yield increase (lb/acre) with P fertilization from 2018 through 2020.

Variety	Farm	P ₂ O ₅ (lb/A)	2018	2019	2020	2018-2020	Yield Increase with P (lb/A)		
			Yield (lb/A)				50	100	150
Chipping Potato Atlantic	Parker	0	39735	43164	32440	38446	N/A	N/A	N/A
		50	43368	43590	32618	39859	1412		
		100	44627	44387	33471	40828	970	2382	
	Singleton	0	40421	40421	29639	36827	N/A	N/A	N/A
		50	40358	40533	32292	37728	901		
		100	41675	41963	34442	39360	1632	2533	
Tablestock Potato Red LaSoda	Blue Sky	0	36475	36344	N/A	36410	N/A	N/A	N/A
		50	35631	35504		35567	-842		
		100	37867	37731		37799	2232	1390	
		150	37286	37152		37219	-580	1652	810
	Wilson	0	27773	27815	36834	30807	N/A	N/A	N/A
		50	27926	28647	37700	31424	617		
		100	28891	29255	39154	32433	1009	1626	

Table 2. Significance in the potato yield difference between 0 and 50 or between 0 and 100 lb/acre P₂O₅ of either cultivar or two cultivars combined in each of the three years year and in the three years combined. The difference in ‘Atlantic’ tuber yields between 0 and 100 lb/acre P₂O₅ was always significant at $p < 0.10$ for each of the three years and at $p < 0.05$ for the three years combined. However, the difference in ‘Red LaSoda’ tuber yields was significant at $p < 0.10$ only for the three years combined.

Year	Atlantic		Red LaSoda		Two Cultivars Combined	
	P ₂ O ₅ applied (lb/acre)		P ₂ O ₅ applied (lb/acre)		P ₂ O ₅ applied (lb/acre)	
	50	100	50	100	50	100
2018	0.328	0.035	0.334	0.272	0.464	0.281
2019	0.720	0.076	0.998	0.433	0.926	0.330
2020	0.421	0.096	0.830	0.438	0.410	0.054
2018-2020	0.384	0.029	0.602	0.293	0.455	0.089

Table 3. Significance in potato yield difference of each of the four farms between 0 and 50 or between 0 and 100 lb/acre P₂O₅ in each of the three years or in the three years combined. For each of the four farms, the yield difference was not significant for ‘Red LaSoda’ at any scenario but significant or marginal significant for ‘Atlantic’ for Singleton & Sons Farms (p < 0.05) or Parker Farms p = 0.055).

Year	Atlantic				Red LaSoda			
	Parker		Singleton		Blue Sky		Wilson	
	P ₂ O ₅ applied (lb/acre)				P ₂ O ₅ applied (lb/acre)			
	50	100	50	100	50	100	50	100
2018	0.798	0.236	0.227	0.086	0.879	0.796	0.161	0.144
2019	0.640	0.198	0.932	0.258	0.693	0.517	0.799	0.661
2020	0.900	0.473	0.427	0.174	N/A	N/A	0.830	0.438
2018-2020	0.635	0.055	0.208	0.013	0.939	0.558	0.258	0.111

Table 4. Yield return at each of the four farms with P fertilization. For ‘Atlantic’, each pound of P₂O₅ returned 24 pounds of potato tubers at the P rate of 100 lb/acre P₂O₅ but ‘Red LaSoda’ did only 15 pounds on average.

Variety	Farm	P rates (lb/A)	Yield Increase with P (lb/A)			Yield Return with P Rate (lb/lb)		
			50	100	150	50	100	150
Chipping Potato Atlantic	Parker	0	N/A			N/A		
		50	1412	N/A	N/A	28.2	N/A	N/A
		100	970	2382		19.4	23.8	
	Singleton	0	N/A	N/A		N/A	N/A	
		50	901	N/A	N/A	18.0	N/A	N/A
		100	1632	2533		32.6	25.3	
Tablestock Potato Red LaSoda	Blue Sky	0	N/A			N/A		
		50	-842	N/A	N/A	-16.8	N/A	N/A
		100	2232	1390		44.6	13.9	
	Wilson	150	-580	1652	810	-11.6	16.5	5.4
		0	N/A			N/A	N/A	
		50	617	N/A	N/A	12.3	N/A	N/A
		100	1009	1626		20.2	16.3	

Table 4 shows the details for tuber yield return of every single pound of P_2O_5 applied at either P application rate of 50 or 100 lb/acre P_2O_5 . Basically, for the 100 lb/acre P_2O_5 , each single pound of P_2O_5 applied increase 24.5 pounds of chipping potato tubers and 15.1 pounds of tablestock potato tubers. Blue Sky Farms was the only farm that had a P application rate of 150 lb/acre P_2O_5 for two years. This P rate had a greater yield loss than the P rate of 100 lb/acre P_2O_5 for either year. This yield decrease implies that growers should NOT apply more than 100 lb/acre P_2O_5 for potato production.

The most important thing is economic return from P fertilizer application for potato production. Every 100 pounds of P_2O_5 per acre costed \$75/acre for planting potatoes, the yield return was 2,382 and 2,533 pounds of chipping potato tubers for Parker Farms and Singleton & Sons Farms, and 1,390 and 1,626 pounds of tablestock potatoes for Blue Sky Farms and Wilson Family Farm, respectively. The tuber price was in the range from \$0.139 to \$0.320 per pound of potato tubers. The respective net dollar return was \$274.31/acre and \$317.10/acre for Parker Farms and Singeton & Sons Farms and \$268.20/acre and \$182.01/acre (Table 5) for Blue Sky Farms and Wilson Family Farm. On average, the net economic return was \$260.41 per acre. The acreage of potato production is approximately 20,000 acres in the Hastings area. By applying 100 lb/acre P_2O_5 in the area, the growers in the area made an annual income of approximately \$5.21 million during the research period from 2018 through 2020.

Table 5. Net economic return at each of the four farms with P fertilization. ‘Atlantic’ returned \$295.71 to the 100 pounds of P₂O₅ per acre but ‘Red LaSoda’ did only \$224.11 on average during the three growing seasons.

Variety	Farm	P rates (lb/A)	Economic Increase with P Rate (\$/A)			Net Economic Return with P Rate (\$/A)		
			50	100	150	50	100	150
Chipping Potato Atlantic	Parker	0	N/A	N/A		N/A		
		50	184.87		N/A	147.37	N/A	N/A
		100	126.95	311.81		89.45	274.31	
	Singleton	0	N/A	N/A		N/A		
		50	126.12		N/A	88.62	N/A	N/A
		100	228.49	354.60		190.99	317.10	
Tablestock Potato Red LaSoda	Blue Sky	0	N/A	N/A		N/A		
		50	-185.30		N/A	-222.80	N/A	N/A
		100	491.00	305.70		453.50	268.20	
		150	-127.58	363.41	178.12	-165.08	325.91	140.62
	Wilson	0	NA/	N/A		N/A		
		50	83.29		N/A	45.79	N/A	N/A
		100	136.22	219.51		98.72	182.01	

Table 6. Specific gravity of potatoes with different P application rates.

Potato Type	Farm	P Rate (lb/acre)	Specific Gravity
Chipping Atlantic	Parker	0	1.09
		50	1.09
		100	1.09
	Singleton	0	1.08
		50	1.09
		100	1.08
Tablestock Red LaSoda	Blue Sky	0	1.06
		50	1.06
		100	1.06
		150	1.06
	Wilson	0	1.06
		50	1.06
		100	1.06

There was almost no difference in specific gravity of potato tubers of either cultivar with each of P application rates (Table 6).

Discussion

The soils of the four cooperative farms were all rich in extractable P in a range from 220 to 520 mg/kg. This range is 5 to 12 times greater than the UF/IFAS recommendation (45 mg/kg P) for zero P application. Why did growers still have the yield response to P application on the P-rich soils of the farms?

There are different reasons:

- **In each of the growing seasons, soil pH changed dynamically and decreased one pH unit from roughly pH 6 to pH 5 in season. In this low pH conditions, soil aluminum and ferric iron were active and immobilized fertilizer and legacy P in soil. This pH drops may be controlled or minimized by selecting the right fertilizer of nitrogen.**
- **The soils also contained much aluminum and iron—the chipping potato farms had 506 to 1,892 lb/acre aluminum and 374 to 624 lb/acre**

iron. The tablestock potato farms had 1,014-1,894 lb/acre aluminum and 186-334 lb/acre iron. These active aluminum and iron can immobilize thousands of pounds of fertilizer P and soil legacy P due to the chemical bindings between P and aluminum and/or iron in soil. This high contents of aluminum may also have caused aluminum toxicity issues to potato production. Developing aluminum-tolerant cultivars can be a solution.

- The optimal temperature for potato root growth is 68 °F. In NE Florida, the majority of the growing season has higher temperature. This high temperature disfavors potato root growth and hence mobilization and uptake of phosphate in soil.
- The beneficial soil microorganisms usually facilitate mobilizing insoluble phosphates such as aluminum phosphate and iron phosphate and enhancing uptake surface area of P uptake. To suppress nematodes, growers fumigate soil every growing season. This yearly fumigation is good for minimizing nematode damages but kills all beneficial soil microorganisms. Crop rotation may be needed to gradually reduce soil fumigation. The rotation strategy becomes possible because the acreage of ethnic vegetable production in the area is more than 7,000 acres.
- The current P fertilizer programs in the area are all one-time P application approximately one month before planting. During this month, most of the P applied is precipitated by aluminum and ferric iron. There is much room to adjust the P fertilizer programs for local growers. To maximize P use efficiency for potato production, we may need to consider developing new P fertilizer programs by minimizing contact time between P fertilizer applied and soil aluminum and iron by improving field practices. Growers well understood N fertilizer applied is easily leached out and hence split apply N fertilizer. To minimize P precipitation, split applications of

P fertilizer with N fertilizer together may be also practical and beneficial. *In fact, a very recent study showed that split applications of P increased tuber yield by 26% and P uptake by 66% (Fan et al. 2020).*

- Extractable P and bioavailable P in soil are two distinct concepts. The current P fertilizer recommendations are all based on soil extractable P only. There may be some room to improve the recommendations by considering the mobilizing and uptake traits of crop roots to phosphates in soil.
- Potato crops are unique and require a high amount of P fertilizer because potato crops have shallow and short (~60 days) life-span root systems. The systems can't access much volume of soil. Based on *Approximate Accumulation of Nutrients by Some Vegetable Crops (Table 4.22) in Knott's Handbook for Vegetable Growers*, Wiley, Hoboken, ISBN: 9780470121474, potato, sweet corn, and tomato absorb 30, 20, and 21 lb/acre P. Both sweet corn and tomato plants have much more developed root systems than potato vines. For example, potato vines have only 25% root surface area of that of sweet corn. This small root surface area means that potato has much less ability to access or take up P from soil than sweet corn. However, our recommendations show that 120-150 lb/acre P_2O_5 for sweet corn but 120 lb/acre for potato for low P soil test index using Mehlich-3 extractant method. The recommended P rate for potato is up to 25% lower than that for sweet corn.
- By contrast, the recommendations in the *Southeastern US Vegetable Crop Handbook* are 200, 150, 100, and 50 lb/acre for potato and 160, 120, 80, and 20 lb/acre for sweet corn. Potato is recommended by 25% more P than corn.

Conclusions

The Tri-County Agricultural Area (TCAA) includes Flagler County, Putnam County and St. Johns County. This area has been producing potatoes since 1890s. During this long history of more than 130 years, the soil has accumulated much phosphorus (P). To better understand P dynamics and improve P management for sustainable potato production in the area, this large-scale (74.28 acres per season) study was conducted with both chipping potato ‘Atlantic’ and tablestock potato ‘Red LaSoda’ at four commercial potato farms in the TCAA area from December 1, 2017 through March 31, 2021.

The Mehlich-3 extractable P levels of the four cooperative farms were in the range from 220 to 520 mg/kg. Of these P-rich soils, all P applications had a positive tuber yield response. Every 100 lb of P_2O_5 applied increased more than 2,400 pounds of chipping potatoes or more than 1,500 lb of tablestock potatoes per acre. The yield increase of chipping potatoes was significant at $p < 0.10$ for each of the three growing seasons and at $p < 0.05$ for all the three years combined. That of tablestock potatoes was significant at $p < 0.10$ only for all the three years combined. These yield increases of both cultivars generated net incomes of \$295.71 and \$224.11 per acre for chipping and tablestock potatoes, respectively. The acreage of potato production in the area is 20,000 acres. The estimate of net economic return is approximately \$5.21 million for P application of 100 lb/acre P_2O_5 for the potato production acreage.

Also, the parent materials of soil in the area contain 1,327 pounds of aluminum and 290 pounds of ferric iron per acre on average. These metals have accumulated chemically bound P in soil and can tightly bind thousands of pounds of P fertilizer. Potato growers in the area didn’t know their soils contained so much aluminum and ferric iron. Growers always apply P fertilizer one month before planting. During this month, the P fertilizer applied is immobilized by aluminum and ferric iron in soil. This immobilization of P by the metals may be responsible for the low use efficiency of P fertilizer applied. Therefore, there is much room for us to

improve the current P fertilizer programs for potato production. Before the fertilizer programs get improved, the P rate of 100 lb/acre P_2O_5 may be practical for local potato production in the TCAA area.