Soil Use
and Management

Soil Use and Management, June 2015, **31**, 308–312 doi: 10.1111/sum.12186

SHORT COMMUNICATION

Phosphorus availability and environmental risks in potato fields in North Florida

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Abstract

Soil phosphorus (P) availability was compared with Mehlich-1 soil testing and P fractionation at a research farm (RF) and 32 private farms (PFs) in north Florida. The environmental risks caused by P release were evaluated using the P saturation ratio (PSR). Soil Mehlich-1 P at the RF and the PFs was 41.9 ± 4.1 and 278 ± 13 mg/kg, respectively. The dominant inorganic P fraction for all farms was NaOH-Pi (Al/Fe-bound P) followed by HCl-Pi (Ca/Mg-bound P) at most of the PFs but by NaOH-Po for the RF. Furthermore, the high PSR at the PFs indicated high risks of P loss from soil. To improve P use efficiency and enhance ecological sustainability, better P nutrient management should be implemented for Florida crop production.

Keywords: Phosphorus fractionation, Mehlich-1, phosphorus saturation ratio, potato production

Introduction

Potato requires more phosphorus (P) than many other crops due to its high nutrient demand and relatively shallow root systems (Ekelöf, 2007). However, symptoms of P deficiency are rarely observed for vegetable crops in Florida because P has accumulated in agricultural soils for decades (Hochmuth *et al*., 2012). On the contrary, P loss from agricultural fields can result in eutrophication and environmental degradation. To enhance the economic and ecological sustainability of crop production, it is imperative to improve P use efficiency. The objectives of this study were to (i) characterize soil P bioavailability on potato farms and (ii) to evaluate the risk of P loss to the environment.

Materials and methods

Representative triplicate soil samples were collected from the plough layer (0–20 cm) at a research farm (RF) in Live Oak and 32 private farms (PFs) in St Johns County in north Florida in 2012. The annual rates of P application were 14.8–24.5 and 48.9–58.5 kg/ha P_2O_5 for the RF and PFs, respectively. No gypsum was applied at the RF, but 896–2240 kg/ha gypsum was applied at the PFs every year.

Soil pH was determined with a soil-to-water ratio of 1:2. The soil samples were extracted with water for P analysis, and with Mehlich-1 extractant for the analysis of P, Al, Fe and Ca with inductively coupled plasma–optical emission spectroscopy (ICP) (Elan 6100 DRC II, Perkin Elmer, Waltham, MA, USA).

Thirteen soils including the samples with highest and lowest Mehlich-1 P from all 33 farms were selected to run P fractionation. Briefly, after water extraction to determine water soluble P (WSP), triplicate soil samples were sequentially extracted by 1.0 M KCl, 0.1 M NaOH and 1.0 M HCl. Labile P (water and KCl extraction), Al/Fe-bound inorganic P (NaOH–Pi), Ca/Mg-bound P (HCl–Pi), organically bound P (NaOH–Po) and residual P were obtained. The details were described in Irick *et al.* (2012). Phosphorus concentration was determined by a discrete analyzer (AQ2, Seal Analytical, Mequon, WI, USA) based on USEPA Method 365.1.

The P saturation ratio (PSR) was calculated as the molar ratio of Mehlich-1 P (P_{M1}) to Mehlich-1 Fe and Al (Fe_{M1} and Al_{M1}).

$$PSR_{M1} = \frac{\left(\frac{P_{M1}}{31}\right)}{\left[\left(\frac{Fe_{M1}}{56}\right) + \left(\frac{Al_{M1}}{27}\right)\right]} \tag{1}$$

Data were analysed with JMP (SAS Institute Inc., Cary, NC, USA). Differences between sampling sites were tested with Student's *t*-test ($P < 0.05$). Ordinary least squares

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Received October 2014; accepted after revision March 2015

regression was used to examine the relationship between different parameters.

Results

The soil at the RF had lower WSP and Mehlich-1 P than that from the PFs except PF8 (Table 1). All of them fell into the 'high' or 'very high' category based on Florida recommendations (Table 2). Soil Mehlich-1 Ca at the PFs (1070 ± 64 mg/kg) was approximately four times that at the RF (285 ± 57 mg/kg) (Table 1). Among all 33 farms, the RF had the lowest PSR (Figure 1). A significant positive correlation was found between WSP and PSR ($P < 0.001$, Figure 1).

The NaOH-Pi fraction was the greatest P form for all of the soils (Figure 2) with the HCl-Pi and NaOH-Po fractions

Table 2 Interpretation of soil test and fertilizer recommendations for vegetable crops grown on mineral soils in Florida (mg/kg except where stated)

	Very low	Low	Medium	High	Very high
Mehlich-1 P[a]	<10	10–15	16–30	31–60	>60
Mehlich-3 P[b]		≤25	26–40	>40	
Mehlich-1 Ca[a]	<100	100–200	201–300	301–400	>400
P_2O_5 (kg/ha)[c]	134	134	67	0	0

[a] Adopted from Hochmuth *et al.*, 2012. [b] The Institute of Food and Agricultural Sciences (IFAS) at University of Florida recommendation switching from Mehlich-1 to Mehlich-3 in August 2013. [c] Fertilizer recommendation (Zotarelli *et al.*, 2012).

Table 1 Soil pH; water soluble P (WSP); Mehlich 1-P, Al, Ca and Fe; and Mehlich 3-P at the research farm (RF) and 32 private farms (PFs) [mean (standard deviation), $n = 5$ for RF and $n = 3$ for private farms]

Farm	pH	WSP mg/kg	M 1-P mg/kg	M 3-P mg/kg	M 1-Fe mg/kg	M 1-Al mg/kg	M1-Ca mg/kg
RF	5.4 (0.1)	2.3 (0.2)	41.9 (4.1)	190 (16.4)	12.4 (0.7)	388 (21)	285 (57)
PF1	5.9 (0)	11.4 (1.5)	182 (8.2)	250 (3.5)	97.1 (7.9)	147 (28)	1128 (77)
PF2	6.0 (0.1)	11.5 (1.3)	230 (17)	272 (3.6)	78.7 (5.9)	157 (8.2)	933 (93)
PF3	6.5 (0.2)	11.6 (2.4)	229 (37)	229 (37)	73.3 (3.8)	106 (3.2)	1515 (130)
PF4	5.8 (0.1)	8.6 (1.5)	111 (16.3)	166 (34)	100 (6.6)	69.2 (9.2)	536 (82)
PF5	6.1 (0.1)	9.0 (0.7)	130 (14.6)	164 (21)	43.9 (2.8)	106 (6.5)	920 (57)
PF6	6.1 (0.2)	8.5 (1.3)	136 (33.1)	190 (43)	14.2 (3.7)	164 (24)	685 (20.2)
PF7	5.8 (0.1)	11.3 (0.7)	168 (1.7)	264 (17)	25.2 (1.4)	259 (19.3)	499 (46.9)
PF8	5.8 (0)	6.1 (0.5)	39.0 (9.2)	80.6 (14)	12.0 (3.2)	123 (24.5)	584 (19.9)
PF9	5.9 (0)	19.8 (1.4)	484 (60)	599 (56)	29.2 (0.1)	417 (39.9)	1250 (162)
PF10	5.6 (0)	6.7 (0.4)	122 (14.9)	164 (16)	20.3 (2.9)	155 (15.8)	524 (29.1)
PF11	6.2 (0.1)	18.9 (0.5)	268 (47.6)	370 (69)	21.0 (4.1)	286 (30.3)	1184 (190)
PF12	6.4 (0.1)	18.6 (0.7)	423 (17.6)	430 (47)	56.4 (2.5)	306 (5.3)	1475 (47)
PF13	6.3 (0.1)	18.5 (2.4)	266 (11.7)	346 (22)	27.6 (5.4)	297 (17.1)	1292 (21.7)
PF14	6.4 (0.1)	15.9 (1.3)	358 (28.9)	433 (37)	53.8 (3.7)	285 (15.2)	1581 (253)
PF15	6.5 (0)	16.6 (1.8)	298 (3.4)	399 (4)	72.4 (0.6)	261 (4.2)	1292 (24.2)
PF16	6.2 (0)	16.1 (0.1)	310 (1.2)	364 (6.8)	71.2 (0.3)	205 (1.6)	1063 (5.8)
PF17	6.3 (0)	15.0 (0.2)	308 (2.1)	450 (7.2)	104 (0.9)	263 (1.9)	1316 (9.7)
PF18	6.6 (0)	9.7 (0.2)	233 (2.3)	309 (5.9)	50.4 (1.5)	281 (4.2)	884 (17.3)
PF19	6.2 (0.1)	16.9 (1.2)	258 (15)	298 (6.9)	78.6 (4.7)	149 (8.7)	628 (42.4)
PF20	6.3 (0)	17.9 (0.6)	406 (3.2)	440 (10)	63.2 (0.7)	245 (2.5)	1020 (6.6)
PF21	6.2 (0)	13.1 (0.2)	172 (3.5)	279 (5.5)	47.2 (0.5)	188 (4.2)	643 (10.9)
PF22	6.1 (0)	14.1 (0.3)	362 (28)	448 (18)	73.9 (2.2)	260 (18.1)	896 (79.2)
PF23	6.9 (0.1)	8.3 (0.2)	444 (4)	514 (18)	48.5 (0.9)	397 (7.0)	1807 (20.8)
PF24	7.5 (0)	15.5 (1.0)	499 (16)	479 (4)	34.4 (2.0)	261 (4.4)	3362 (118)
PF25	6.8 (0)	14.6 (1.0)	538 (8.4)	591 (20)	78.4 (1.0)	384 (6.0)	2294 (56.8)
PF26	6.9 (0)	12.6 (0.1)	377 (6)	472 (14)	27.3 (0.5)	634 (5.6)	1572 (28.8)
PF27	5.3 (0.1)	17.2 (0.2)	291 (7)	508 (6.6)	79.5 (2.0)	214 (6.4)	582 (13.7)
PF28	6.3 (0.1)	15.3 (0.1)	170 (6.4)	322 (5.6)	29.8 (0.6)	267 (7.9)	422 (29.3)
PF29	5.9 (0)	10.5 (0.1)	192 (5.4)	308 (7.3)	23.4 (0.2)	334 (7.0)	491 (9.8)
PF30	5.4 (0)	9.4 (0.2)	119 (2.6)	257 (2.8)	54.3 (0.8)	301 (7.3)	374 (12.3)
PF31	6.0 (0)	20.4 (1.5)	305 (11)	384 (26)	148 (2.3)	165 (4.9)	758 (29.1)
PF32	6.1 (0)	18.9 (0.3)	239 (3.4)	460 (24)	178 (3.4)	230 (3.3)	722 (2.4)

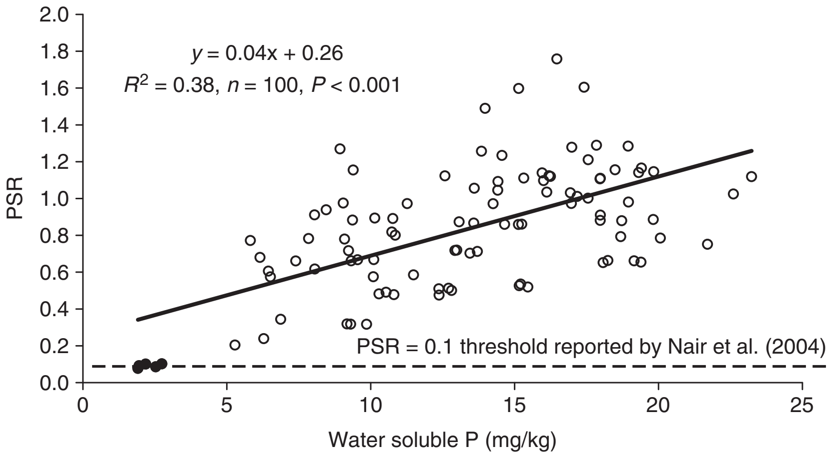

Figure 1 Correlation of water soluble P (mg/kg) with phosphorous saturation ratio (PSR) from the research farm (RF, closed dots) and 32 private farms (PFs, open dots). $n = 100$.

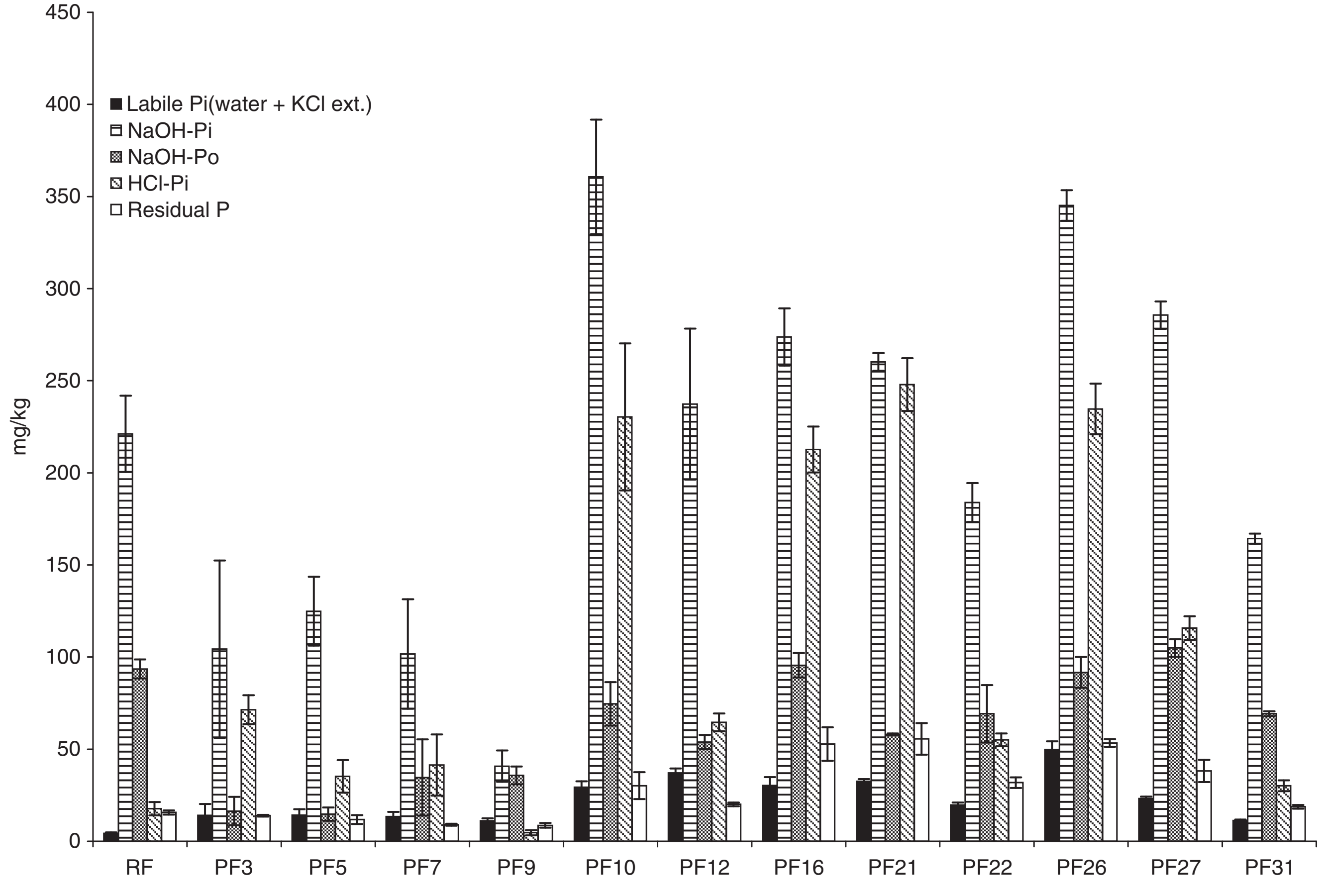

Figure 2 Phosphorus fractionation for the research farm (RF) and the selected 12 private farms (PFs). Labile Pi denotes labile inorganic P including water and KCl extractable P; NaOH-Pi denotes NaOH extractable inorganic P; NaOH-Po denotes NaOH extractable organic P; HCl-Pi denotes HCl extractable inorganic P.

as the second greatest form for the PFs and RF, respectively (Figure 2). A significant positive correlation was found between NaOH-Pi and Mehlich-1 Al ($R^2 = 0.51$, $P < 0.05$), and HCl-Pi and Mehlich-1 Ca ($R^2 = 0.54$, $P < 0.05$) (Figure 3).

Discussion

It has been estimated that potatoes absorb less than 15% of the applied P fertilizer, which means that more than 85% of the fertilizer P applied each year remains in the

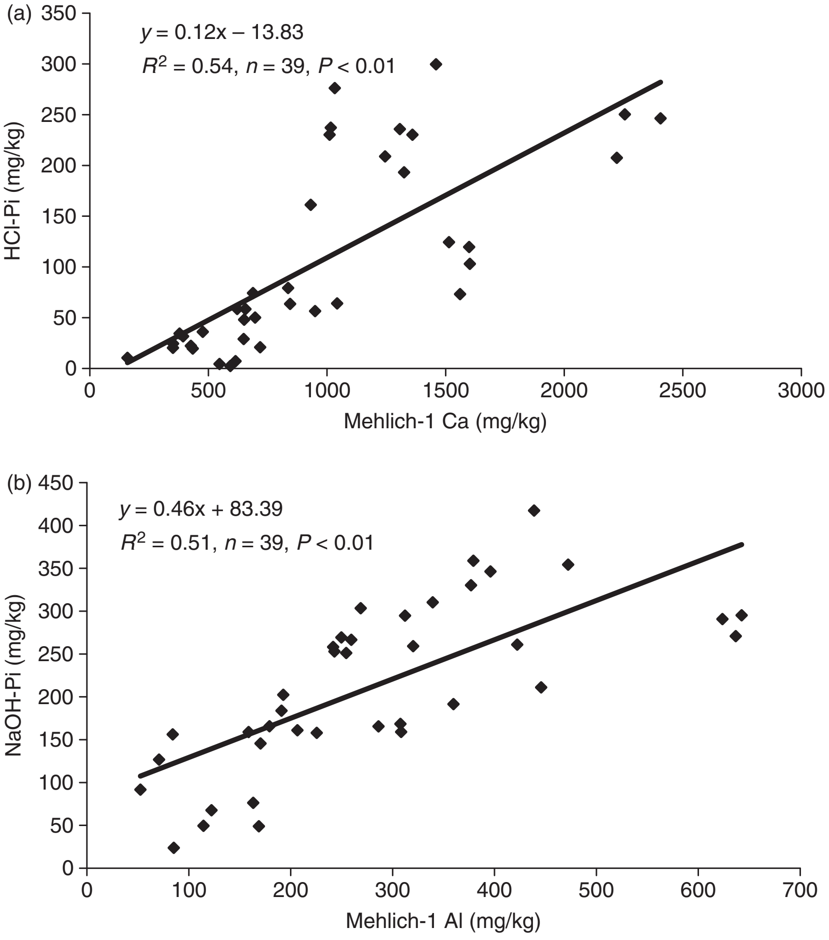

Figure 3 Correlations between (a) HCl-Pi and Mehlich-1 Ca, and (b) NaOH-Pi and Mehlich-1 Al.

Table 3 Pearson correlation coefficients for soil test P and different P fractions. All are significantly correlated ($P < 0.001$)

	Mehlich 1-P	Mehlich 3-P	WSP	KCl- Pi	NaOH-Pi	HCl- Pi	Residual P
Mehlich 1-P	1						
Mehlich 3-P	0.97	1					
WSP	0.75	0.72	1				
KCl-Pi	0.77	0.72	0.66	1			
NaOH-Pi	0.81	0.91	0.66	0.63	1		
HCl-Pi	0.90	0.86	0.73	0.59	0.74	1	
Residual P	0.73	0.71	0.69	0.58	0.67	0.84	1

WSP, water soluble P; KCl-Pi, KCl extractable inorganic P; NaOH-Pi, NaOH extractable inorganic P; HCl-Pi, HCl extractable inorganic P.

soil to build up P reserves and contributes to the next year's crop production (Houghland, 1960). It takes a long time to change soil P from a 'high' to an 'environmentally acceptable' concentration range. For example, it was reported that the rate of soil P decline was approximately 3 ppm per year (Havlin *et al.*, 2005). Optimizing P application is therefore imperative for high-P soils.

The P fractionation showed that most of the inorganic P was bound with Al/Fe and Ca/Mg at the PFs. The low HCl-Pi at the RF corresponded with low Mehlich-1 Ca, indicating that zero application of gypsum effectively reduced soil Ca reserves at the RF. Excessive Ca in soils from the PFs reduced P bioavailability, suggesting that the current problem with P management is probably not insufficient soil P, but rather limited available P (Table 3).

WSP is considered to be the amount of P released from a soil in contact with water. The lower WSP at the RF (Table 1) suggests less P will be released when it rains or the crop is over-irrigated. When we used a PSR of 0.1 as a P-release threshold as reported by Nair *et al.* (2004), the PFs had high risks of P loss to the environment compared with the RF, implying that more attention needs to be paid to P management on the PFs.

Acknowledgements

This study was financially supported by the 2014 Florida Specialty Crop Block Grant Program (Project #: 00120641) from the USDA-AMS. We thank the potato growers who let us access their farms and Steven Lands in the UF/IFAS Extension Office in St. Johns County who helped collect soil samples. Edward Hanlon and Thomas Obreza at the University of Florida provided insightful comments and suggestions.

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