Evaluation of Six Different Soil Test Phosphorus Extraction Methods for Relationship with Cranberry

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Abstract

As with other perennial fruit crops, plant tissue analysis is the standard technique used for assessing nutrient status in cranberry (Vaccinium macrocarpon Ait.). Additionally, the low pH and high iron and aluminum environment in cranberry soils are unlike the chemical conditions for which routinely used soil phosphorus (P) extracts were developed. There is increasing pressure to base farm nutrient management plans on soil test P, although past studies have shown poor relationships between soil test P and cranberry P response. Field trials to study cranberry yield response to P fertilizer between 0-34 kg/ha were established on two fields each in Massachusetts and Wisconsin. From 2004 through 2007, soil samples were collected from replicated plots in each of these four fields. Four replicates of each soil sample were extracted with six methods: dilute acid, dilute acid plus fluoride (Bray P, current cranberry standard), sodium bicarbonate, ammonium acetate, calcium chloride extraction, and an iron hydroxide impregnated strip (Fe strip). The first four methods are routinely used in soil test laboratories, the fifth has been used less frequently and the sixth uses iron oxide as a sink for P and has shown promise in acid soils. Sample extraction and analysis for the Fe strip method was only complete for 1 year versus the other five methods where analysis was complete for all years except 2007. Soils from one site were highly organic and there were no statistical differences in soil test P based on P fertilizer rates in this soil. Of the five extraction methods, only two, the calcium chloride and sodium bicarbonate showed statistically significant relationships between soil test P and P fertilizer application rates for multiple sites in multiple years. Additionally, when there were significant relationships with these methods, soil test P increases showed good consistency with P fertilizer rate increments. The soil test P concentrations with these methods were consistently lower than with the Bray method, the current cranberry standard and an acidic extraction, suggesting that the calcium chloride and sodium bicarbonate methods do not over extract plant unavailable P in acidic cranberry soils. However, there were differences related to the fertilizer trial site and year with these two methods, suggesting that there may not be one best “universal” extractant for all cranberry soils.

INTRODUCTION

The concept of a soil test is to chemically extract a mineral nutrient from a representative field sample that will provide an indication of how much of the mineral nutrient will be plant available during a single growing season. Classically, soil test standards are developed from long-term fertilizer rate and yield response trials. In the recent past, interest in multiple-element universal extractants has influenced the choice of soil test procedures (Wendt, 1995).

Unlike most commercial crops, cranberry (Vaccinium macrocarpon Ait.) grows in a very acidic soil environment, with pH values most often in the 4.0 to 5.0 range (Davenport et al., 2003). Additionally, high iron and aluminum contents in these soils severely restrict the amount of plant available P (Parent and Marchand, 2006).
Historically, a dilute acid fluoride soil extract has been used for testing cranberry soils for plant available P. This test was developed for acidic soils in eastern United States (Kuo, 1996) and as such seems a logical fit for cranberry systems. However, soils for which this test was developed differ in many physical and chemical characteristics from cranberry soils, which can have a broad range of organic matter and a predominantly sand mineral fraction (Davenport and DeMoranville, 1992; Davenport and Patten, 2002). Additionally, cranberry soils are flooded for extended periods of time for harvest and winter protection, affecting the redox status of the soil (Davenport et al., 1997). Iron phosphate interactions and P availability are affected as a result (Shahandeh et al, 1994).

Across all of agriculture, there is increasing pressure to minimize P fertilizer additions to aid in the protection of surface waters (Sharpley et al., 1999). In many cases, soil test P criteria are being used to determine if fertilizer P can be applied in a given year. Due to the close proximity of surface water to cranberry production systems, P reduction has been a focus of interest (DeMoranville, 2006). However, dilute acid fluoride soil test extracts tend to show very high P levels in cranberry soils when compared to other crops, but not always in association with tissue test P in the adequate range (Davenport and Schiffhauer, unpublished data).

Concurrent with a study looking at cranberry yield and tissue nutrient concentration under a low range of P fertilizer inputs, this portion of the project was designed to look at soil test alternatives. Our objective was to compare six different soil extraction procedures for P to determine if there is an alternative extraction procedure that better reflects P availability than the currently used technique.

**MATERIALS AND METHODS**

Small scale research plots were established in either 2003 or 2004 on two cranberry beds in Massachusetts (sites 1 and 2) and two cranberry beds in Wisconsin (sites 3 and 4). Details of plot size, experimental design, and sources and timing of P fertilizer applications are reported elsewhere (Roper, 2008).

From 2004-2007, soil samples were collected from replicated (four per treatment) plots that received 0, 6, 11, 17, 22, or 34 kg/ha P. Samples were composited from three cores per plot, collected to a depth of 15 cm, with a standard soil probe. Soil samples were air-dried and sieved to < 2 mm. An exception was made for soils from site 3, which were organic soils. Since organic soils can become hydrophobic upon drying, making reliable wet extraction difficult, the soils from this site were dried to a low moisture level (approximately 5% by weight, tested by weighing), sieved, and refrigerated until analyzed.

Soils were extracted using six different soil test procedures. Soil extraction methods used were (Kuo, 1996): Dilute Salt Solution (calcium chloride, CaCl), Melich-1 (dilute concentration of strong acids, DA), Bray-1 (dilute concentration of strong acids plus fluoride, DAF), Olsen (buffered sodium bicarbonate solution, NaBicarb), Iron Impregnated Strips (Fe strip), and Modified Kewlona (ammonium acetate, AA; Gavlak et al., 2003). With the exception of the Fe strip technique, these methods are routinely used in commercial soil test laboratories in North America. When adequate sample was available, each soil sample was extracted four times (soil replication) with each method to test repeatability of the test procedure. In some cases, small sample size resulted in two to three extractions of each sample for a given test.

All extracts were analyzed on an EasyChem direct injection analyzer (Systea, Chicago, Ill., USA) for molybdate reactive P (MRP; Kuo, 1996). Data were analyzed using ANOVA and or regression analysis (PROC RSREG) with PC SAS (SAS Institute, Cary, N.C., USA).

As this is being written, extractions using the Fe strip technique have only been completed on the 2004 soil samples and none of the 2007 samples have been extracted. The majority of the extractions for the other five techniques have been completed on the 2005 and 2006 samples, so these data (five techniques, 3 years) are reported.
RESULTS AND DISCUSSION

Soil test phosphorus (STP) was significantly different for all five extracts by year, site, phosphorus fertilizer rate, and soil replication (Table 1). However, with the exception of the DA technique, the year by site by soil replication interaction was not significant, implying that analyzing these techniques for individual sites each year could indicate where STP was related to phosphorus fertilizer rates.

For the organic soil (site 3), STP did not significantly differ with P rate in any year (Table 2). For all of the other sites, in all years, of the nine possible year and site combinations, STP was significantly related to P fertilizer rate for three to six occasions. Of extraction techniques, ammonium acetate (AA) had the fewest significant relationships and the relationship showed increasing soil test P with increasing P application rate only at site 4 (Table 2). Similarly, while the DAF extraction procedure had five site year combinations where STP significantly differed with P fertilizer rate, STP increase with increasing P rate again occurred only at site 4. Few relationships and lack of consistent correlation between P fertilizer rates and STP suggest that these two tests are not good techniques for estimating plant available P in cranberry soils. Ironically, DAF is the current industry standard.

STP was significantly related to P fertilizer rates for four of the site and year combinations for the CaCl extractions and for six of the Na Bicarb extractions (Table 2). With the CaCl extractions, when the relationships were significant, the low and high extreme STP values were found with the low and high rates of P fertilizer. The relationship was slightly more pronounced at site 4. With Na Bicarb extraction, STP distinctly increased with increasing P fertilizer rate at linearly and quadratically at site 1 in all three years. For the other site-year combinations, the pattern was for a linear increase, although the highest actual values at site 4 were with a mid rate fertilizer application rather than at the highest (Table 2).

The two extraction techniques that show regression relationships between STP and P fertilizer rate are actually techniques developed for use in neutral to high pH soils (Kuo, 1996). It is counter intuitive that these techniques show more likelihood of predicting plant available P in the acidic cranberry soil environment. A possible explanation for this is that these techniques do not dissolve soil P that is bound by Fe and/or Al in the system. Fe and Al concentrations have clearly been shown to be related to reduced P availability in cranberry soils (Parent and Marchand, 2006). Reduced extraction of bound P is also supported by the relatively low values for STP with these techniques, particularly when compared with the DAF industry standard.

Although two of the five extraction techniques reported here show meaningful relationships between STP and P fertilizer application rates, the variability in response by year and site indicates some limitation to adoption of either of these techniques. Although there was a fairly small range in STP values using CaCl, with Na Bicarb, site 1 had much higher values than sites 2 or 4 (Table 2).

CONCLUSIONS

Sample extraction and analysis has been completed for five of six techniques for three years to evaluate different STP extraction methods. Of these, the dilute acid technique showed high variability with repeated analysis of the same soil sample and was therefore deemed unsuitable for assessing plant available P in cranberry soils. None of the tests showed a relationship between STP and P fertilizer rates on samples from the organic soil site, suggesting that a meaningful soil test cannot be developed for cranberry grown on organic soils.

Of the four techniques that showed some significant relationships between STP and P fertilizer application rates, the two that showed some promise for predicting plant available P, CaCl and Na Bicarb, were developed for soils with pH values at the opposite end of the spectrum from the acid pH in cranberry systems. However, the low values of STP with these techniques, when compared with acid extractants, suggest that STP from these tests may better reflect plant available P in cranberry soils.
identify two promising techniques based on regression relationships between STP and fertilizer P rate, there was high site to site and year to year variability in those STP values. Thus, based on STP data and P fertilizer rates alone, neither of the two promising extraction techniques presents itself as a robust standard. However, other data including crop yield and tissue test P has been collected and additional data analysis including these factors is planned. Upon completion of all soil analyses and integration of yield and tissue data, if ANOVA suggests a promising method, data will be analyzed by regression to see if a relationship can be established.

ACKNOWLEDGEMENTS

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Literature Cited


Table 1. Levels of statistical significance ($P$) for analysis of variance relationships between cranberry soil test P by five different extraction methods and other parameters in a study evaluating cranberry response to P fertilizer rates from 0-34 kg/ha in Massachusetts and Wisconsin from 2004-2006. Each region had two field test sites.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dilute Acid (DA)</th>
<th>Dilute acid fluoride (DAF)</th>
<th>Ammonium acetate (AA)</th>
<th>Calcium chloride (CaCl)</th>
<th>Sodium bicarbonate (Na Bicarb)</th>
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<tr>
<td>Year (Y)</td>
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<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0034</td>
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<tr>
<td>Site (S)</td>
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<td>0.0001</td>
<td>0.0001</td>
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<td>P fertilizer (P)</td>
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<td>Soil rep. (R)</td>
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<td>0.0001</td>
<td>0.0001</td>
<td>0.0954</td>
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<td>Y*S</td>
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<tr>
<td>Y*P</td>
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<tr>
<td>Y<em>S</em>P</td>
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<td>0.8370</td>
<td>0.6752</td>
<td>0.0804</td>
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<tr>
<td>Y<em>S</em>R</td>
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<tr>
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<tr>
<td>Y<em>S</em>P*R</td>
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<td>0.9299</td>
<td>0.8965</td>
<td>0.9887</td>
<td>0.9902</td>
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Table 2. Average soil test P concentrations by year and site using four different soil extraction methods in a study evaluating cranberry response to P fertilizer rates from 0-34 kg/ha in Massachusetts and Wisconsin from 2004-2006. Each region had two field test sites.

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<tbody>
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<td>1 (MA)</td>
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<tr>
<td>6 (MA)</td>
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<td>67</td>
<td>57</td>
<td>50</td>
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<td>39</td>
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<tr>
<td>17</td>
<td>44</td>
<td>36</td>
<td>39</td>
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<td>1.15</td>
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<td>1.45</td>
<td>41</td>
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<td>39</td>
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<td>49</td>
<td>50</td>
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<tr>
<td>22</td>
<td>63</td>
<td>49</td>
<td>50</td>
<td>1.27</td>
<td>1.54</td>
<td>1.64</td>
<td>0.93</td>
<td>1.50</td>
<td>1.60</td>
<td>53</td>
<td>47</td>
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<td>76</td>
<td>63</td>
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<td>1.53</td>
<td>1.56</td>
<td>1.09</td>
<td>1.55</td>
<td>1.99</td>
<td>69</td>
<td>55</td>
<td>57</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Significance: 0.0071 0.0660 0.0009 0.0003 0.0156 0.0938 0.0028 0.0118 0.0241 0.0001 0.0003 0.0001

Dilute acid fluoride (DAF) | Ammonium acetate (AA) | Calcium chloride (CaCl) | Sodium bicarb. (Na Bicarb)

Significant linear (L) and quadratic (Q) regression relationships are indicated at the $P < 0.01$ level.