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CONVERTING SOIL PHOSPHORUS READINGS BASED ON MECHLICH 3 EXTRACTION METHODS INTO MECHLICH 1 IN TWO FLORIDA FLATWOODS CITRUS GROVES

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Abstract. **In the Southern U.S., the adoption of the Mechlich-3 (M3) soil extraction method by farmers far surpasses that of governmental entities. To benefit from the superior versatility of the M3 over Mechlich 1 (M1), particularly in regards to phosphorus (P), a grower either can accept the recommendations devised by commercial soil testing laboratories or must convert the M3 readings into M1 values to use University recommendations. The relationships between M1P and M3P appear to be unique to each region of the U.S. where studies have been made. This suggestion of local dependency was confirmed by this study. In a citrus grove with sandy soils, the relationship between M3P to M1P had an r^2 of 0.68 and a slope of 0.47. In a grove with loamy soils less than 32 km (20 miles) away, these values were 0.73 and 0.56, respectively. Where soil pH ≤ 6.3, M3P > M1P and when pH > 6.3 then M1P > M3P. Only where M1P > M3P was there a dependency on pH suggesting that soil pH was a more significant factor influencing an increase of M1P over M3P than soil P concentration. When soil pH > 6.5, the use of a conversion equation to convert M3P to M1P appeared to be a more reliable method to assess available P in the soil than the analysis with M1.**

Mechlich 1 (M1) extraction cannot be used reliably where soil pH is high (Alva, 1993; Mechlich, 1978). M1 has been found to extract excessive P from calcareous soils and where rock phosphate has been applied recently (Barnes and Kamprath, 1975; Mechlich, 1978). Even though Mechlich (1978) did not consider M1 suitable above a pH of 6.2, it is generally accepted to be reliable up to pH of 6.5 (Hanlon, 2001; Isaac et al., 1983; Mylavarapu, 2002). The method is often utilized for much wider pH range, up to 7.4 in Florida (Mylavarapu, 2002; T. Obreza, University of Florida, personal communication). The shortcomings of the M1 method (Alva, 1993) resulted in the development of Mechlich 3 (M3) extraction chemistry (Mechlich, 1984). Since then, the M3 method has been noted to be a universal and versatile method for evaluation of plant nutrient availability (Mechlich, 1984) in wide range of soil conditions (Hanlon, 2001). The consequent adoption of the M3 method by the farmers throughout the Southern U.S. has grown well beyond the governmental and institutional adoption (J. Cooper, Waters Agricultural Laboratory, personal communication). Currently, only four southern states recognize the M3 extraction, whereas six states, including Florida, continue to use M1 (Hanlon, 2001). Where the M3 has not been adopted, a grower may use commercial guidance or must convert M3 results into M1 in order to use university recommendations. This is not easy since the reported M1 to M3 relationships vary by element, region, and report (Sikora et al., 2005). Mylavarapu et al. (2002) studied phosphorus (P) in 519 soils and found the slope for M1P to M3P relationships to change from 0.73 to 1.43 if M1P ≤ 240 $mg \cdot kg^{-1}$ and M3P ≤ 445 $mg \cdot kg^{-1}$. Five Georgia coastal plain soils with low P levels had a regression slope of 1.46 (Gascho et al., 1990), whereas 21 Florida soils with high P levels found had a slope of 0.64 (Alva, 1993). At high P concentrations, M1 appeared to extract a larger portion of soil P than M3 but at lower soil P concentrations, M3 extracted more P than M1. Gartley et al. (2002) in Delaware reported slope of 2.04 and r^2 of 0.90 and Sikora (2005) in Kentucky showed pH dependent relationship where the slope changed from 2.13 (pH < 6.0) to 1.44 (pH > 6.0) with r^2 of 0.92 and 0.86, respectively.

Due to the shortcomings of the M1 method and the desire to use M3 to evaluate requirements for citrus P nutrition, this study compared M1 with M3. Localized variations in the correlation of M1 to M3 were expected based on the previous studies, and some level of pH dependency was hypothesized due to the chemistry of P.

Materials and Methods

In the Winter of 2006, 106 zones out of 1000 located in two citrus groves in the Eastern Florida Flatwoods, were sampled based on their gradually increasing M3P ranging from 19.07 $kg \cdot ha^{-1}$ (17 lb/acre) up to 363.48 $kg \cdot ha^{-1}$ (324 lb/acre) of P_2O_5. Soil samples were collected using GPS guidance and predetermined soil core locations within each zone. The number of sampling points per zone varied from 10 to 20 depending on the zone size which was 2 to 8 hectares (~5 to 20 acres). There were 2 to 3 soil cores at each sampling point. The number of cores per sampling site in each zone was kept the same to alleviate errors due to uneven contribution of single sample site. The core samples were taken from a depth of 20 cm (8.0 inch) and were collected in the herbicide band at the drip line of the tree canopy. Surface debris was removed prior to sampling. The soil was mixed thoroughly after completion of each zone. Sub-samples for M3 and M1 were prepared and were sent to a commercial soils laboratory for analysis.

The data was sorted by pH and outliers were eliminated using methods shown in Table 1. Four principal data groups resulted: Main Body of data with pH ≤ 6.3, High pH Group with pH > 6.3, and Site 1 and Site 2 data sets which used data from the Main Body. The soil pH of 6.3 reflected the recommended upper pH limit of 6.2 of M1 (Alva, 1993; Mechlich, 1978) and acceptance of the method up to pH 6.5 (Hanlon, 2001; Isaac et al., 1983). This left a total of 82 sample pairs for the Main Body and 20 for the High pH Group. Under the conditions of Main Body, Site 1 had 50 samples and site 2 had 33. Initially there were 53 samples collected from each location. Site 1 consisted predominantly of Basinger (Siliceous, hyperthermic Spodic Psammaquents) fine sand and Immokalee (Sandy, siliceous, hyperthermic Arenic Alaquods) sandy soils, whereas Site 2 was dominated by Floridana (Loamy, siliceous, superactive, hyperthermic Arenic Argiaquolls), Malabar (Loamy, siliceous, active, hyperthermic Grossarenic

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Table 1. Means, standard deviations, and regression data for all 106 points, Main Body of the data, and for selected subsets regardless of location. Soil pH ≤ 6.3 for all groups except for all data.

Data group and selection criteria	Outliers	N	M3P (kg·ha^{-1}) Mean	M3P (kg·ha^{-1}) SD	M1P (kg·ha^{-1}) Mean	M1P (kg·ha^{-1}) SD	r	Observed M3 to M1 Intercept	Observed M3 to M1 Slope	Observed M3 to M1 r^2	Calculated M1 to M3 Slope	p
All data		106	136.45	81.02	109.13	96.47	0.69	-2.88	0.82	0.48	1.22	
	+/-2*SD	95					0.82	11.60	0.66	0.68	1.52	
	+/-2*SD, M1P											
Main Body	> 392.65	82	128.23	77.58	87.46	49.00	0.87	17.20	0.55	0.75	1.82	
	M3P / M1P < 0.2											
M3P ≤ 224.37 kg / ha		75	107.46	51.10	76.60	31.57	0.71	29.03	0.44	0.51	2.27	
M3P ≤ 112.19 kg / ha		45						34.21	0.34	0.14	2.94	0.0110
M3P > 112.19 kg / ha		56						84.71	0.12	0.02	8.33	0.4550
M3P < 224.37 kg / ha												
M3P > 224.37 kg / ha		11	307.69	36.59	232.12	148.83		-348.93	1.88	0.22	0.53	0.1503
M1P ≤ 112.19 kg / ha	M3 > 246.81	65	102.30	51.07	67.52	26.61	0.72	28.27	0.40	0.52	2.50	
M1P < 280.46 kg / ha		83					0.76	29.73	0.43	0.59	2.33	
M3P < M1P		13	141.95	159.58	96.48	102.99	0.98	-5.66	1.52	0.96	0.66	

Where not reported p < 0.0001 and r > 0.70.

Endoaqualfs), and Pineda (Loamy, siliceous, active, hyperthermic Arenic Glossaqualfs) series with depressional / loamy sand pockets of Valkaria sandy soil (Siliceous, hyperthermic Spodic Psammaquents).

The groves were irrigated by drip irrigation systems and there was no rain during the sampling events, nor did it rain between the initial sampling and the sampling made for this study. The data were analyzed using spreadsheet regression methods and Statistica software.

Results and Discussion

The average M3P of the 106 samples was 136.45 kg·ha^{-1} (121.48 lb / acre) with a standard deviation (SD) of 81.02. The pH of all the samples varied from 4.6 to 8.2 with the mean pH of 5.86, a mean of 5.61 for the Main Body, and 6.93 for the High pH Group. Mean M3P and M1P concentrations with standard deviations are shown in Table 1. Figure 1 displays three data sets, the Main Body, outliers, and samples with pH > 6.3. The regression line was based on the Main Body data. The M3P to M1P conversion equation for the Main Body was

$$1)\ M1P = 17.20 + 0.55 * M3P,\ r^2 = 0.75$$

The calculated slope of 1.67 for M1P to M3P relationship follows patterns observed by Mylavarapu et al. (2002) and Sims (1989). The calculated M1P to M3P slopes were at or above previous observations in North Carolina, 1.43, Georgia coastal soils, 1.46 (Gashco et al., 1990), and in Florida, 0.63 (Alva, 1993) and 1.45 (Mylavarapu et al., 2002). Mylavarapu et al. (2002) observed the slope to rise from 0.73 (all data) to 1.43 (M1P ≤ 240 mg·kg^{-1}). We observed similar change, from slope of 1.82 with Main Body of data to slope of 2.27 when M3P maximum was 224.37 kg·ha^{-1} (200 lb / acre).

Analysis of the data in increments of 112.19 kg·ha^{-1} (100 lb / acre) showed that if the maximum concentration was M3P = 112.19 kg·ha^{-1} (100 lb / acre), if 119.19 kg·ha^{-1} < M3P < 224.37 kg·ha^{-1} (100 lb / acre and 200 lb / acre, respectively), or when M3P > 224.37 kg·ha^{-1} (200 lb / acre), any predictive relationship between the two data sets ceased to exist (Table 1). A relationship developed only when the M3P maximum was at or above 224.37 kg·ha^{-1} (200 lb / acre). Consequently, a large error will occur if a narrow range or only a few samples of M3P concentrations are used to derive a M3P to M1P conversion equation. Consideration for soil types, units used, and errors inherent to processes in creating conversion equations also should be recognized (Sikora et al., 2005).

The 20 data points with pH > 6.3, except two, came from Site 2 (Fig. 2). In this group, eight sample pairs (40%) had M3P < M1P and caused the mean of the entire High pH Group to have M3P < M1P despite the remaining 12 samples (60%) which had M3P > M1P. In the Main Body, only 16.28% of the cases had M3P < M1P. The pH of the high pH group varied between 6.5-7.9 and 6.4-8.2 with a mean pH of 7.03 and 6.89 for the 40% and the 60% of High pH Group samples, respectively. Correlations of 0.80 and 0.67 with pH for M3P and M1P correspondingly was found in this group, and they existed only where M3P < M1P. In the Main Body where M3P < M1P, the correlation with pH was 0.22 (P < 0.05). The M3P mean for M3P < M1P samples in the High pH Group was only

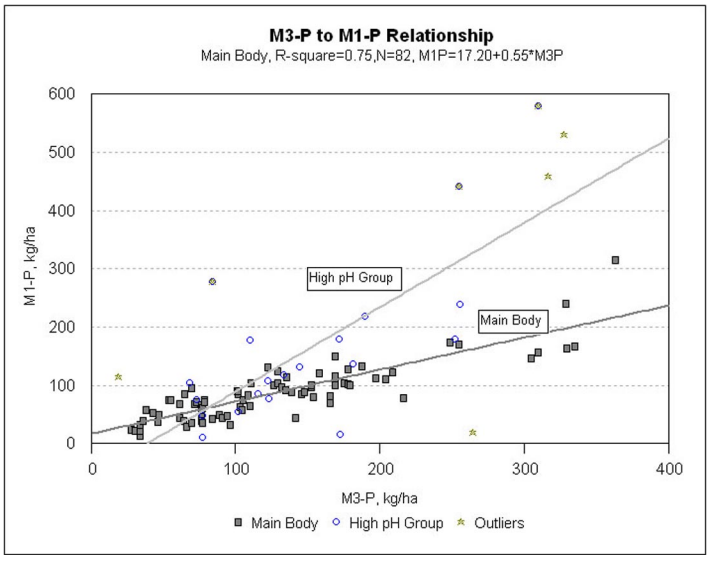

Fig. 1. All data are shown as a compilation of Main Body of the data, the High pH Group, and outliers, which were not used in the analysis. The regression results show fitted lines to the Main Body and High pH Group data.

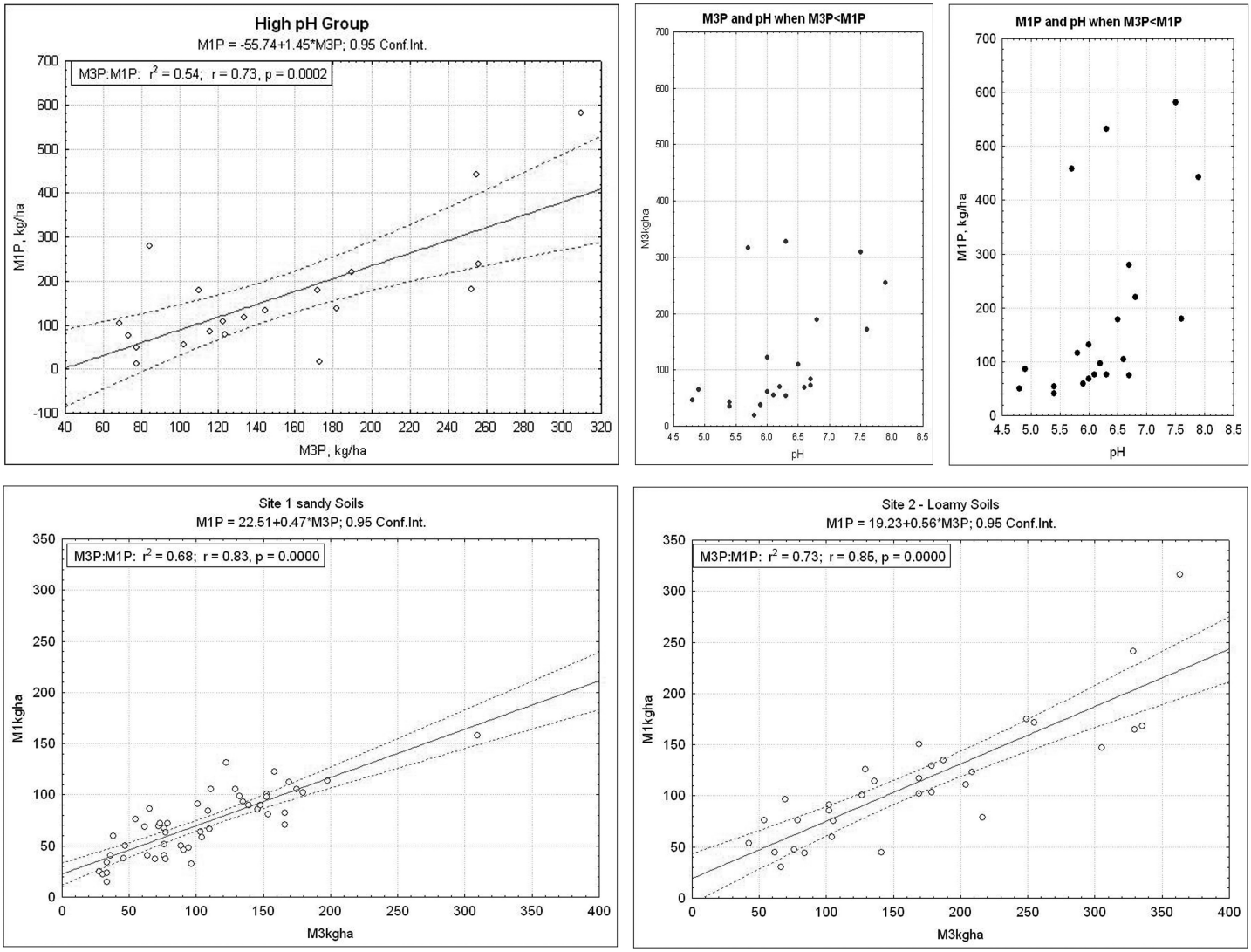

Fig. 2. Five graph compilation. High pH Group with 95% confidence boundaries, M3P and M1P when M3P < M1P plotted against pH, and M3P to M1P regressions for Site 1 and Site 2.

slightly higher than that of the entire group, but the corresponding M1P mean was doubled. The relationship between M1P, M3P, and pH, where M3P < M1P, is shown as a 3D image for all data (Fig. 3). Individual relationships to pH for M1P and M3P are shown (Fig. 2) and data are summarized in Table 2. The slope of 0.69 for samples with pH > 6.3 was similar to the slope of 0.62 observed by Alva (1993) with 21 Florida soils with pH ranging from 3.6 to 7.3. The decrease in slope with soil pH from 1.82, pH ≤ 6.3, to 0.69, pH > 6.3, depicted a similar pattern but with lower slopes than described by Sikora (2005). These data suggest that soil pH is a more significant factor influencing an increase of M1P over M3P than soil P concentration. The difference between M1P and M3P means where M3P < M1P shows that the M1 method begins to over estimate P levels starting at pH of 6.5, the lowest pH of the High pH Group with M3P < M1P. Consequently, the use of the M1 method for analysis or correlations with M3P where soil pH > 6.5, is questionable. The existence of samples with M3P < M1P in the Main Body suggests that limiting the use of M1 method to pH of 6.2 as reported by Mechlich (1984) and Alva (1993) is well warranted. The stability of the M3P mean and SD values in the high pH group and the correspondingly high variability of M1P, particularly when M3P > 250 kg·ha^{-1}, suggests that the use of the linear conversion equation (Equation 1) might be a more reliable way of estimating available P concentrations than it is to analyze the soil with the M1 method where soil pH > 6.5.

Figure 2 shows the regression data for Site 1 and 2 for data sets derived with Main Body restrictions. Of the two locations, Site 1 with sandy soils produced a higher slope than what the loamy soils did. Hence, the conversion equation from M3P to M1P for respective sites with Main Body data restrictions was:

$$2)\ M1P = 22.51 + 0.47 * M3P,\ r^2 = 0.68,$$

$$3)\ M1P = 19.23 + 0.56 * M3P,\ r^2 = 0.73,$$

for the sandy and the loamy soils. The data show that there was more variability in the sandy than in the loamy soils. This was perhaps due to lower P holding capacity of the sandy soils or because of differences in organic matter. The difference in the slopes between the two sites remained or increased as

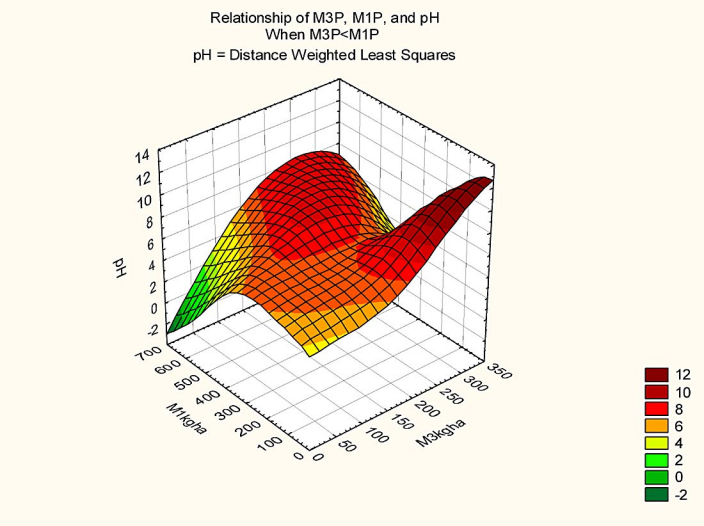

Fig 3. A 3D representation of M3P, M1P and pH when M3P < M1P. All data are included.

data selection criteria were changed (Table 1). The M3P and M1P concentrations for site 1 and 2were significantly different (at alpha = 0.01) between the two sites. When data were restricted to M3P < 224.37 kg·ha^{-1} (200 lb / acre), M1P and pH were different at alpha = 0.05 between the two locations but M3P was not. When the behavior of the M3P to M1P relationship was examined with pH the difference of the two sites was magnified (Fig. 4a, b). This suggests that the previously observed variation in the M1P to M3P relationship may not be only regional but localized, driven by M1 behavior at higher concentrations of P, and is possibly specific to soils or soil characteristics.

There were a total of 18 replicated M3P values with two to four M1P responses for each M3P value. All values came from different sampling zones and were plotted (Fig. 5). The average deviation of the M1P values from their respective means at each M3P concentration was 0.49 kg·ha^{-1} with a SD of 19.41 when M3P < 200 kg·ha^{-1}. Due to the non-standard replication, the data were categorized (Fig. 2). The +/-2SD (77.64 kg·ha^{-1}) which covers 95% of the data variation was a fairly wide concentration span but considering the predictive values associated with the observed r^2, this independently measured variation is reasonable.

Some of the variability in this study was due to use of a commercial laboratory (Ontermaa et al., 1996) and natural variability within the samples. This may be a shortcoming, but the results show that correlations derived in university laboratories can be repeated using commercial processes.

Table 2. The High pH Group, sample soil pH > 6.3.

Data group and selection criteria	Outliers	N	M3P (kg·ha^{-1}) Mean	M3P (kg·ha^{-1}) SD	M1P (kg·ha^{-1}) Mean	M1P (kg·ha^{-1}) SD	r	Observed M3 to M1 Intercept	Observed M3 to M1 Slope	Observed M3 to M1 r^2	Calculated M1 toM3 Slope	p
All		20	151.00	71.08	163.46	140.72	0.73	-55.74	1.45	0.54	0.69	0.0002
	+/-2*SD, M1 > 392.65	18						42.16	0.61	0.21	1.64	0.0545
M3 > M1		12	146.58	59.44	100.78	66.54	0.80	-31.14	0.90	0.65	1.11	
M3 < M1		8	157.62	89.88	257.47	173.10	0.88	-10.35	1.70	0.78	0.59	0.0032

Where not reported p < 0.0001 and r > 0.70.

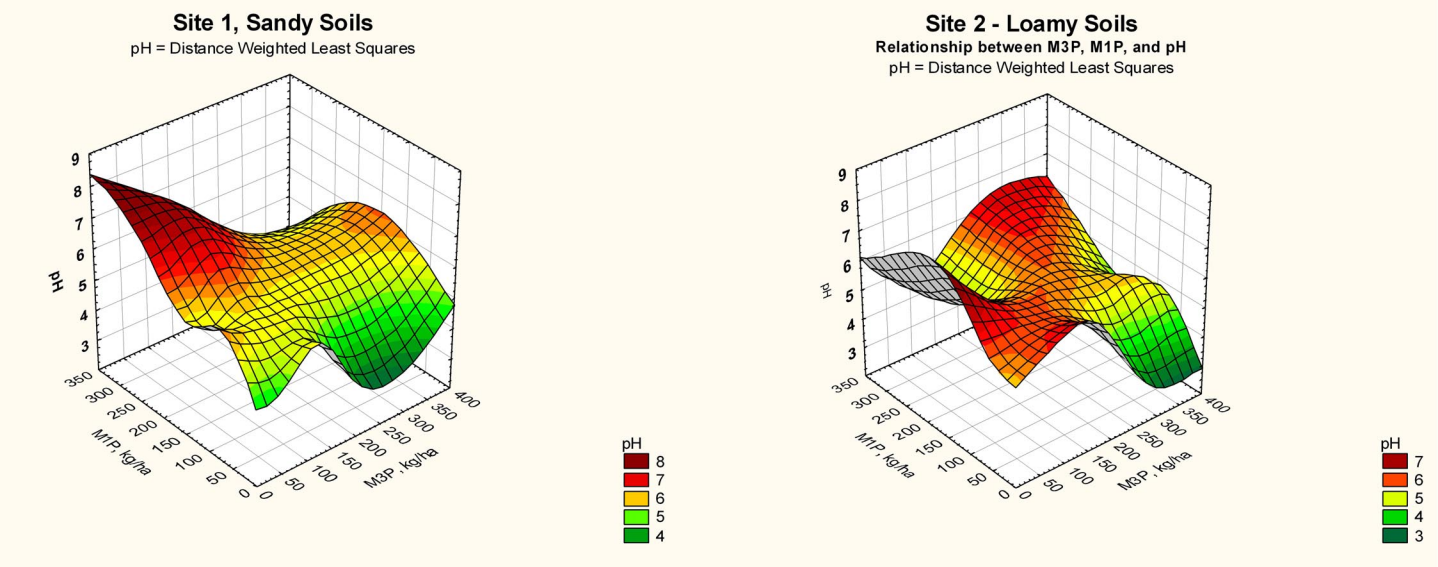

Fig. 4. Relationship of M3P and M1P to pH for Site 1 and Site 2. Data extracted from the Main Body.

Table 3. Site 1 and Site 2 data.

Data group selection criteria	pH	N	M3P (kg·ha^{-1}) Mean	M3P (kg·ha^{-1}) SD	M1P (kg·ha^{-1}) Mean	M1P (kg·ha^{-1}) SD	r	Observed M3P to M1P Intercept	Observed M3P to M1P Slope	Observed M3P to M1P r^2	Calculated M1P to M3P Slope	p
SITE 1 Sandy soils												
All	All	53	107.59	57.98	71.63	32.07	0.79	32.35	0.36	0.43	2.78	
Main Body	6.3	50	103.77*	55.07	71.46*	31.46	0.83	22.51	0.47	0.68	2.13	
M3P < M1P	All	8	57.36	28.77	68.29	31.01	0.96	9.10	1.03	0.92	0.97	
SITE 2 Loamy soils												
All	All	53	165.31	90.87	146.62	122.50		-3.65	0.91	0.46	1.10	
Main Body	6.3	32	162.02	94.08	112.56	59.48	0.85	19.23	0.56	0.73	1.79	
M3P < M1P	All	14	149.28	111.15	242.32	184.52	0.93	10.91	1.55	0.87	0.65	
pH > 6.3*	>6.3	18	153.94	74.47	170.34	146.97	0.73	-50.78	1.44	0.53	0.69	0.0006

*Site 1 had only 2 points where pH > 6.3.

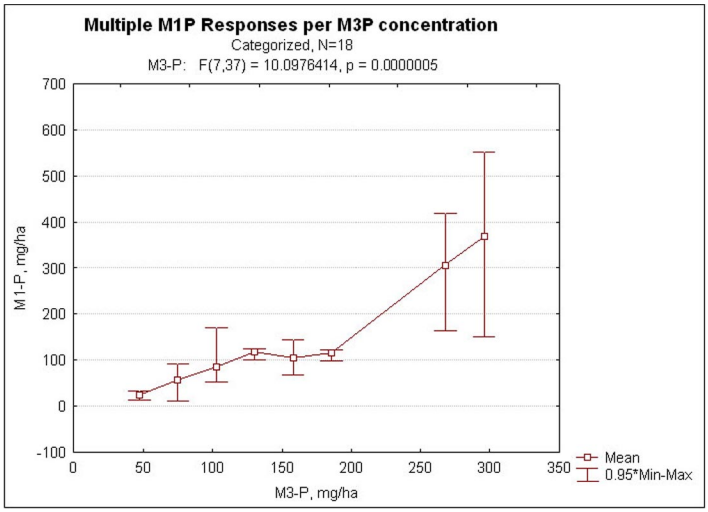

Fig. 5. Plot of categorized M1P responses to several M3P concentrations.

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