Development of Soil Testing Conversion Indices

For Regional Soil Testing Laboratories

Maryland Department of Agriculture

and

University of Maryland,

Department of Natural Resource Sciences and Landscape Architecture

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Introduction

An ongoing mission of Maryland Cooperative Extension has been development of programs and dissemination of information pertaining to soil fertility management. Maryland Cooperative Extension is dedicated to generating crop fertilization recommendations based on crop nutrient requirements, soil testing, yield goals, and environmental protection considerations. Maryland Cooperative Extension strives to present new technologies that promote the implementation of best management practices that help ensure crop productivity while protecting soil and water quality. Maryland Cooperative Extension supports the Maryland Soil Testing Laboratory in order to increase the reliability of crop fertilization recommendations.

Today, numerous public and private-sector soil testing laboratories are sharing the responsibility for quantifying the nutrient status of Maryland's agricultural soil. Commercial soil testing is not well standardized. Different laboratories use different methodologies and report results in a variety of terms and quantitative units. Comparing the analytical report from one soil testing laboratory to another is frequently quite difficult, if not impossible. Reporting discrepancies typically do not result from improper or erroneous laboratory procedure. Instead, numerical discrepancies usually arise from the use of alternative, but appropriate, laboratory methods combined with a multitude of options for quantitative expression of the analytical results. The objective of this project was to develop simple mathematical models for conversion of the analytical results from several regional soil testing laboratories to a common scale. This hopefully will make comparisons between results from regional soil testing laboratories much easier

Methods

In 2000, the Maryland Department of Agriculture, in cooperation with the University of Maryland, Department of Natural Resource Sciences and Landscape Architecture, established a project to study the correlation between soil test results from the Maryland Cooperative Extension Soil Testing Laboratory and soil test results from several other Mid-Atlantic soil testing laboratories. The goal was to develop conversion models for analyses of soil phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and soil acidity (pH). Emphasis was placed on converting soil test values, as expressed by the regional soil testing laboratories, to a common fertility index value (FIV) scale that is currently in use by the Maryland Cooperative Extension Soil Testing Laboratory.

During April and May, 2000, soil samples were collected by Maryland Department of Agriculture personnel from agricultural fields in all twenty-three Maryland counties. All major soil types within each county were sampled. The number of soil samples collected in each county and for each soil type was proportional to the crop and pasture acreage in that county and acreage of a particular soil type within a county. A total of 665 soil samples were collected to represent Maryland's agricultural soils and each soil sample was a composite of multiple soil cores taken from a given field. Soil samples represented commercial fields that were managed for the production of soybeans, corn, small grains, and forages. Soil was collected from the 0 to 8 inch depth. Field moist soil samples were transported to the University of Maryland where they were mixed and dried at ambient air temperature. Soil was crushed with a Dynacrush DC-2 flail-system grinder to pass through a 2 mm sieve and then thoroughly and divided into ten sub-samples.

A complete set of 665 sub-samples was submitted to each of eight regional soil testing laboratories for analysis. Each soil testing laboratory performed the routine analyses for P, K, Ca, Mg and soil pH that were commonly used for determining crop fertility recommendations for Maryland conditions. The eight cooperating soil testing were: 1) A&L Eastern Agricultural Laboratories, 2) AgriAnalysis, Inc., 3) Brookside Laboratories Inc, 4) Agricultural Analytical Services Laboratory, Pennsylvania State University, 5) Spectrum Analytic Inc., 6) Waters Agricultural Laboratories, Inc., 7) University of Delaware Soil Testing Program and 8) Maryland Cooperative Extension Soil Testing Laboratory (Table 1).

Soil test report data from each soil testing laboratory were sent to the University of Maryland, Department of Natural Resource Sciences and Landscape Architecture, where simple linear regression analysis was used to model the relationship between the reported soil test results among the participating laboratories. The conversion models developed use the reported data from the seven regional soil testing laboratories to predict the results that should be generated by the Maryland Soil Testing Laboratory.

Plots of residuals based on analysis of the original data displayed a distinct pattern of increasing variances with increasing predicted means. Weighted least squares regression (SAS/STAT, 1992) was used to resolve this problem. Weighted least squares increased the confidence of the regression line equation for predicting soil test values in the conventional agronomic range (FIV < 100). Regression analysis of soil pH did not require weighted least squares to satisfy the assumption of homogeneity of variance. The regression models constructed predict the expected values of the Maryland Soil Testing Laboratory using Mehlich-1 extraction and molybdate-vanadate colorimetric methods for P, magnesium blue colorimetric methods for Mg, and flame photometric methods for K and Ca. Soil testing methods and instrumentation used by each of the cooperating regional soil testing laboratories are presented in Table 1.

The Maryland Soil Testing Laboratory expresses soil nutrients for P, K, Ca and Mg in terms of fertility index values (FIV). For production of most agronomic crops, the nutrient status of soil for a particular nutrient is considered "low" when soil test values are 0 to 25 FIV, "medium" when values are between 26 to 50 FIV, and "optimum" when values are between 51 to 100 FIV. Soil test nutrient levels greater than 100 FIV are considered "excessive" with respect to crop nutrient requirements. Magnesium soil test values exceeding 114 FIV were not analytically quantified by the Maryland Soil Testing Laboratory. Therefore, the independent variable in the regression was cut in order to delete observations that had Maryland soil test values >114 FIV. Thus, the regression analysis for Mg was performed on a subset of the data that contained approximately 245 observations or about 37% of total observations.

Results and Discussion

Relationships between Maryland Soil Testing Laboratory fertility index values (FIVs) and reported analytical values from seven regional soil testing laboratories are presented in Table 2. Linear regression equations convert the reported level of soil test nutrient, in the form and units shown, to Maryland FIV. For Brookside Laboratories, two conversion equations are given because this soil testing laboratory often reports analytical data in two formats. The significance of the slope and intercept of the regression equations, the coefficient of determination (R^2) of the regression models, the applicable range of reported values from the regional soil testing laboratories, and the number of observations (n) included in each conversion data set are presented in Table 2.

Three examples of 95% confidence intervals for the mean predicted FIV derived from conversion of regional soil testing laboratory data are presented in Table 3. The 95% confidence belts around the predicted mean FIV were relatively narrow, indicating that, on the average, the conversion models are operationally precise and suitable for purposes of soil fertility management and development of crop nutrient recommendations. For instance, for the soils analyzed by Agri Analysis for P and reported in units of P_2O_5 (pounds per acre), and converted to FIV mean of 100, the 95% confidence interval would be between 97 and 103 (Table 3). In the soil test range of expected agronomic response to applied nutrients (FIV < 50), the confidence intervals are very narrow (±1 or ±2) and, on the average, the inter-laboratory conversion indices should be very reliable.

A more concerning impact resulting from the use of conversions of soil analyses is regulatory interpretation of soil test reports. Currently, Maryland nutrient management regulations have established an environmental threshold for soil test P and require, any agricultural field that has a soil test P level greater than 150 FIV to be evaluated with the P Site Index to assess the potential for P losses in field drainage water. If soil test P analyses from regional soil testing laboratories are converted to the Maryland FIV scale and then evaluated for regulatory compliance, errors in compliance targeting may be expected. However, the resulting targeting errors are not large. For example, for the soils analyzed for P by A&L Laboratories and reported in units of Bray P1 (ppm), and converted to FIV mean of 150, the 95% confidence interval would be between 146 and 154 (Table 3).

The soil test laboratory conversion models presented may be reliably used in development of crop fertilization recommendations in the usual range of agronomic response (FIV < 50) and also may be used in higher soil test P situations (FIV > 150) to aid environmental regulation targeting.

Table 1. Participating regional soil testing laboratories, method of soil nutrient extraction used, and instrumentation used to quantify soil nutrient concentrations.

Laboratory	Address	Nutrient	Extraction Method extract solution:soil	Instrumentation
A&L	A&L Eastern Agricultural Laboratories 7621 Whitepine Rd. Richmond, VA 23237	P K Ca Mg PH	Bray P1, weak bray (7 ml:0.85 cm^3) 1N amm.acetate (25 ml:4.25 cm^3) 1N amm.acetate (25 ml :4.25 cm^3) 1N amm.acetate (25 ml :4.25 cm^3) Water (10 ml:8.5 cm^3)	ICP ICP ICP ICP Glass Electrode
Agri Analysis	Agri Analysis, Inc. P.O. Box 483 280 Newport Rd. Leola, PA 17540	P K Ca Mg PH	Mehlich-3 (20 ml:1.7 cm^3) Mehlich-3 (20 ml:1.7 cm^3) Mehlich-3 (20 ml:1.7 cm^3) Mehlich-3 (20 ml:1.7 cm^3) Water (5 ml:5 cm^3)	ICP ICP ICP ICP Glass Electrode
Brookside	Brookside Laboratories, Inc. 308 East Main St. New Knoxville, OH 45871	P K Ca Mg PH	Mehlich-3 (20 ml:1.7 cm^3) Mehlich-3 (20 ml:1.7 cm^3) Mehlich-3 (20 ml:1.7 cm^3) Mehlich-3 (20 ml:1.7 cm^3) Water (7 ml:7 cm^3)	ICP ICP ICP ICP Glass Electrode
Pennsylvania State Univ.	Agricultural Analytical Services Laboratory Pennsylvania State University University Park, PA 16802	P K Ca Mg PH	Mehlich-3 (25 ml:2.5 g) Mehlich-3 (25 ml:2.5 g) Mehlich-3 (25 ml:2.5 g) Mehlich-3 (25 ml:2.5 g) Water (5 ml:5 g)	ICP ICP ICP ICP Glass Electrode
Spectrum Analytic	Spectrum Analytic Inc. P.O. Box 639 1087 Jamison Rd. Washington Court House, OH 43160	P K Ca Mg PH	Mehlich-3 (10 ml:1 cm^3) Mehlich-3 (10 ml:1 cm^3) Mehlich-3 (10 ml:1 cm^3) Mehlich-3 (10 ml:1 cm^3) Water (5 ml:5 cm^3)	ICP ICP ICP ICP Glass Electrode
University of Delaware	University of Delaware Soil Testing Program 149 Townsend Hall University of Delaware Newark, DE 19717-1303	P K Ca Mg PH	Mehlich-1 (25 ml:5 cm^3) Mehlich-1 (25 ml:5 cm^3) Mehlich-1 (25 ml:5 cm^3) Mehlich-1 (25 ml:5 cm^3) Water (10 ml:10 cm^3)	ICP ICP ICP ICP Glass Electrode
University of Maryland	University of Maryland Soil Testing Laboratory H.J. Patterson Hall, room 0225 College Park, MD 20742	P K Ca Mg PH	Mehlich-1 (25 ml:5 cm^3) Mehlich-1 (25 ml:5 cm^3) Mehlich-1 (25 ml:5 cm^3) Mehlich-1 (25 ml:5 cm^3) Water (20 ml:20 cm^3)	Colorimeter 420nm Flame Photometer 768nm Flame Photometer 623nm Colorimeter 630nm Glass Electrode
Waters	Waters Agricultural Laboratories, Inc. 257 Newton Highway P.O. Box 382 Camille, GA 31730-0382	P K Ca Mg PH	Mehlich-1 (20 ml:5 cm^3) Mehlich-1 (20 ml:5 cm^3) Mehlich-1 (20 ml:5 cm^3) Mehlich-1 (20 ml:5 cm^3) Water (20 ml:20 cm^3)	ICP ICP ICP ICP Glass Electrode

Table 2. Relationship between Maryland Soil Testing Laboratory fertility index value (FIV) and reported values (x) from seven regional soil testing laboratories. Statistical analyses were performed using weighted-least-squares regression.

Soil Testing Laboratory & extraction method	Nutrient (x) & units	Regression equation †	R^2	Range of reported x values Min	Max	n
A&L						
Bray P1 (weak bray)	P1 (ppm)	FIV = 1.685 x + 6.26	0.83	4	592	649
1*N* NH_4OAc, pH 7	K (ppm)	FIV = 0.626 x + 0.77^{ns}	0.91	25	895	648
1*N* NH_4OAc, pH 7	Ca (ppm)	FIV = 0.134 x - 18.43	0.88	240	3400	643
1*N* NH_4OAc, pH 7	Mg (ppm)	FIV = 0.669 x + 21.40	0.64	18	111	243
H_2O	Soil pH	pH = 0.894 x + 0.77	0.97	4.3	7.8	652
Agri Analysis						
Mehlich-3	P_2O_5 (lb/a)	FIV = 0.224 x + 7.17	0.82	21	3984	655
Mehlich-3	K_2O (lb/a)	FIV = 0.268 x - 2.50	0.92	76	2573	660
Mehlich-3	Ca (lb/a)	FIV = 0.061 x - 21.54	0.94	318	8937	652
Mehlich-3	MgO (lb/a)	FIV = 0.232 x - 0.70^{ns}	0.76	104	443	244
H_2O	Soil pH	pH = 0.886 x + 0.82	0.95	4.4	7.9	645
Brookside						
Mehlich-3 (easily extractable)	P (ppm)	FIV = 1.196 x + 3.48	0.86	8	929	657
Mehlich-3	K (ppm)	FIV = 0.718 x - 2.79	0.94	25	896	655
Mehlich-3	Ca (ppm)	FIV = 0.135 x - 22.85	0.94	221	3406	651
Mehlich-3	Mg (ppm)	FIV = 0.787 x + 11.48	0.75	26	113	241
Mehlich-3 (easily extractable)	P_2O_5 (lb/a)	FIV = 0.260 x + 3.46	0.87	37	4255	653
Mehlich-3	K (lb/a)	FIV = 0.359 x - 2.79	0.94	50	1792	655
Mehlich-3	Ca (lb/a)	FIV = 0.068 x - 22.85	0.94	442	6812	651
Mehlich-3	Mg (lb/a)	FIV = 0.392 x + 11.62	0.75	52	228	248
H_2O	pH (H_2O 1:1)	pH = 0.855 x + 0.97	0.95	4.2	8.0	644
Pennsylvania State Univ.						
Mehlich-3	P (ppm)	FIV = 1.1148 x + 6.87	0.88	5	790	651
Mehlich-3	K (ppm)	FIV = 0.597 x + 0.07^{ns}	0.97	25	1059	653
Mehlich-3	Ca (ppm)	FIV = 0.117 x - 21.33	0.94	186	4489	646
Mehlich-3	Mg (ppm)	FIV = 0.756 x - 1.08^{ns}	0.80	31	134	249
H_2O	Soil pH	pH = 0.932 x + 0.42	0.95	4.6	7.8	657
Spectrum Analytic						
Mehlich-3	P (lb/a)	FIV = 0.754 x + 9.13	0.87	5	1150	653
Mehlich-3	K (lb/a)	FIV = 0.332 x - 1.49	0.94	47	2066	653
Mehlich-3	Ca (lb/a)	FIV = 0.076 x - 15.93	0.97	239	6301	644
Mehlich-3	Mg (lb/a)	FIV = 0.427 x + 8.49	0.76	46	214	244
H_2O	Soil pH	pH = 0.926 x + 0.54	0.93	4.5	7.9	654

(continued)

Table 2 (continued). Relationship between Maryland Soil Testing Laboratory fertility index value (FIV) and reported values (x) from seven regional soil testing laboratories. Statistical analyses were performed using weighted-least-squares regression.

Soil Testing Laboratory & extraction method	Nutrient (x) & units	Regression equation	R^2	Range of Reported x values Min	Max	n
University of Delaware						
Mehlich-1	P (index)	FIV = 1.009 x + 6.85	0.97	6	1090	651
Mehlich-1	K (index)	FIV = 1.096 x + 0.90	0.98	14	619	656
Mehlich-1	Ca (index)	FIV = 1.055 x - 8.62	0.95	10	597	647
Mehlich-1	Mg (index)	FIV = 0.968 x + 9.63	0.81	11	95	246
H_2O	pH	pH = 0.954 x + 0.30	0.90	4.5	7.9	644
Waters						
Mehlich-1	P (lb/a)	FIV = 1.179 x + 4.11	0.95	8	1023	454
Mehlich-1	K (lb/a)	FIV = 0.380 x - 1.50	0.96	48	1477	651
Mehlich-1	Ca (lb/a)	FIV = 0.058 x - 12.10	0.95	231	8802	650
Mehlich-1	Mg (lb/a)	FIV = 0.426 x + 3.61*	0.79	40	230	247
H_2O	Soil pH	pH = 0.863 x + 0.96	0.97	4.2	8.1	654

† Slope and intercept terms were significantly significant ($p < 0.01$) for all regression equations except as follows:
* intercept significant at $p<0.10$; ns intercept not significant ($p>0.25$)

Table 3. Confidence interval (C.I.) for the mean predicted FIV and individual predicted FIV at three levels (50, 100, 150) for seven regional soil testing laboratories. FIV is fertility index value used by the Maryland Cooperative Extension Soil Testing Laboratory.

Soil Testing Laboratory extraction method	Nutrient (x) & units	95% C.I. for mean FIV at		
		50	100	150
A&L				
Bray P1, weak bray	P1 (ppm)	± 1†	± 2	± 4
1*N* HN_4OAc, pH7	K (ppm)	± 1	± 1	± 2
1*N* HN_4OAc, pH7	Ca (ppm)	± 1	± 2	± 3
1*N* HN_4OAc, pH7	Mg (ppm)	± 2	± 4	‡
Agri Analysis				
Mehlich-3	P_2O_5 (lb/a)	± 1	± 3	± 4
Mehlich-3	K_2O (lb/a)	± 1	± 1	± 2
Mehlich-3	Ca (lb/a)	± 1	± 2	± 3
Mehlich-3	MgO (lb/a)	± 2	± 3	‡
Brookside				
Mehlich-3 easily extractable	P (ppm)	± 1	± 2	± 4
Mehlich-3	K (ppm)	± 1	± 1	± 2
Mehlich-3	Ca (ppm)	± 1	± 2	± 3
Mehlich-3	Mg (ppm)	± 2	± 3	‡
Mehlich-3 easily extractable	P_2O_5 (lb/a)	± 1	± 1	± 3
Mehlich-3	K (lb/a)	± 1	± 1	± 2
Mehlich-3	Ca (lb/a)	± 1	± 2	± 3
Mehlich-3	Mg (lb/a)	± 2	± 3	‡
Pennsylvania State Univ.				
Mehlich-3	P (ppm)	± 1	± 2	± 3
Mehlich-3	K (ppm)	± 0	± 1	± 1
Mehlich-3	Ca (ppm)	± 1	± 1	± 2
Mehlich-3	Mg (ppm)	± 1	± 3	‡
Spectrum Analytic				
Mehlich-3	P (lb/a)	± 1	± 2	± 4
Mehlich-3	K (lb/a)	± 1	± 1	± 2
Mehlich-3	Ca (lb/a)	± 1	± 1	± 2
Mehlich-3	Mg (lb/a)	± 2	± 3	‡
University of Delaware				
Mehlich-1	P (index)	± 0	± 1	± 1
Mehlich-1	K (index)	± 0	± 1	± 1
Mehlich-1	Ca (index)	± 1	± 1	± 2
Mehlich-1	Mg (index)	± 1	± 3	‡
Waters				
Mehlich-1	P (lb/a)	± 1	± 1	± 2
Mehlich-1	K (lb/a)	± 0	± 1	± 2
Mehlich-1	Ca (lb/a)	± 1	± 2	± 2
Mehlich-1	Mg (lb/a)	± 2	± 3	‡

† All confidence intervals (C.I.) rounded to unit values.

‡ The range for Mg was not applicable because colorimetric procedures for the determination of Mg in Mehlich-1 soil extracts at the Maryland Soil Testing Laboratory were not designed to quantify Mg soil test levels greater than 114 FIV.