NPK Fertilizer Recommendation Systems for Corn: Decision Aids and Test Kits

Attanandana,T[1]., C. Suwannarat[1], T. Vearasilp[2], S. Kongton[2], R. Meesawat[3], P. Bunampol[3], K. Soitong[4], C. Tipanuka[4] and R.S. Yost[5]

[1]*Department of Soil Science, Kasetsart University, Bangkok, Thailand*
[2]*Land Development Department, Bangkok, Thailand*
[3]*Department of Agriculture, Bangkok, Thailand*
[4]*Department of Agricultural Extension, Bangkok, Thailand*
[5]*Department of Tropical Plant and Soil Sciences, University of Hawaii, USA*

ABSTRACT

A simple and rapid soil test is currently being developed for the field determination of nitrogen, phosphorous and potassium (NPK). Correlation studies were undertaken to select a single extracting solution for NPK determination in soils for routine analysis. A highly significant correlation was obtained between extractable-N (ammonium+nitrate) as determined by colorimetric methods and corn dry weight (CDW) with an R^2 value of 0.74. Extractable-N, determined using colorimetric methods, was also highly significantly correlated with N uptake (R^2 value of 0.77). The highest, significant correlations between extractable-K and both CDW and K uptake were obtained using Mehlich 1. Extractable-P and CDW and extractable-P and P uptake were also significantly correlated with Mehlich 1. Mehlich 1 was selected for use as a universal extractant for NPK.

In field experiments, the actual and predicted yield of corn (*Zea mays,* L.) in seven soil series across four provinces was compared. The N fertilizer requirement was generated by the CERES-Maize model while P and K were calculated by a Mitscherlich-Bray equation. An agreement index of 0.86 between actual and predicted yield was obtained. The PDSS (Phosphorus Decision Support System) was used to predict the P requirement and was tested with an on-farm experiment in Nakorn Ratchasima Province in Thailand. The amount of fertilizer P predicted by PDSS was one-half of the amount obtained by calculation with the Mitscherlich-Bray equation. The yield of the CERES-Maize-PDSS prediction was higher than with the farmer's practice. The economic analysis showed that the PDSS treatment gave a higher benefit than the farmer's practice.

INTRODUCTION

Soil analysis is a widely adopted method for the evaluation of soil fertility and, as a tool for fertilizer recommendations. In developing countries, technology transfer is restricted due to a lack of laboratory infrastructure, specialized training, and essential yet time consuming supportive research. Moreover, soil testing is also costly. Consequently, poor farmers cannot usually afford to have the nutrient status (NPK) of their soils evaluated. Currently, soil testing for NPK requires nutrient-specific chemical extractants and determination methods, expensive instrumentation, and highly trained personnel. Universal extractants for P, K, calcium (Ca), and magnesium (Mg), and other micronutrients have been proposed and are widely used in the United States (Jones, 1985). However, a simple, rapid, and accurate method of soil testing which is applicable for field use has not been developed for the Thai situation. The purpose of this research was to identify a single extracting solution for NPK in soils and to evaluate the determination of extractable-N (NH_4+NO_3), extractable-K and

extractable-P. Stage 1 of the investigation was to compare the effectiveness of various currently adopted standard extraction methods for P to extract N, P, and K in some important soils for growing corn in Thailand, namely Bray 2, citric acid, Mehlich 1, Morgan, Olsen, and sodium lactate (Kamprath and Watson, 1980; Thompson and Pratt, 1954; Page et al., 1982). Stage 2 was to develop the soil test kit for NPK. Stage 3 was to develop the NPK fertilizer recommendation system using a modelling program and employing a soil test kit for initial nutrient evaluation.

MATERIALS AND METHODS

Pot Experiment

The experiment was a 15 x 5 factorial in a completely randomized design with, three replications. Five soil series which are representative of soils of the major corn production area of Thailand were used in this study. They were Chai Badan series (Cb), fine, smectitic, isohyperthermic Leptic Haplusterts; Takhli series (TK), loamy-skeletal, carbonatic, isohyperthermic Entic Haplusterts; Lop Buri series (Lb), very fine, smectitic, isohyperthermic Typic Haplusterts; Satuk series (Suk), fine, loamy, siliceous, isohyperthermic Typic (Kandic) Paleustults; and Pak Chong series (Pc), very fine, kaolinitic, isohyperthermic Rhodic Kandiustox. Some chemical properties of these soils are shown in Table 1. Three composite samples of each soil, which differed in P content, were collected. The 15 soil samples were used for greenhouse and laboratory study. The treatments were Control, (PK), (NK), (NP), and NPK. Suwan 5 corn variety was used as the test crop. The dry weight of corn and NPK uptake in the plants were recorded.

Table 1. Physical and chemical properties of soils used in the study.

Soil series	pH[1]	Texture[2]	OM[3] (g kg^{-1})	P[4] (mg kg^{-1})	K[5] (mg kg^{-1})	Ca[5] (mg kg^{-1})	Mg[5] (mg kg^{-1})
Cb – H	8.1	SCL	22	70	280	11,000	340
Cb – M	7.9	C	30	28	140	10,000	260
Cb – L	8.2	CL	22	11	80	13,000	200
Tk – H	8.2	SCL	44	81	200	12,000	210
Tk – M	8.1	C	34	44	130	18,000	220
Tk – L	8.1	C	41	20	210	17,000	260
Lb – H	8.2	C	33	60	280	13,000	350
Lb – M	8.0	C	22	27	90	15,000	520
Lb – L	8.1	C	33	10	90	16,000	530
Suk – H	4.9	LS	04	15	40	160	42
Suk – M	5.2	SCL	11	5	90	520	170
Suk – L	5.4	LS	05	3	40	320	80
Pc – H	7.2	C	35	48	110	3,000	160
Pc – M	5.7	C	32	22	420	3,000	220
Pc – L	6.4	C	18	9	90	3,600	220

[1]1:1 soil:water ratio; [2]hydrometer method; [3]Organic Matter (OM) Walkley-Black method; [4]Bray 2 extraction method; [5]1 M NH_4OAc extraction method.

Extractant Selection

The soils were extracted using 10 different extracting solutions and associated methodologies (Table 2). In each case, the resultant filtrate was analyzed for NH_4, NO_3, P, and K by conventional methods. The N content in the plant was analyzed by the Kjeldahl method, and P and K by double acid digestion (Jones et al., 1991). The uptake of NPK in the corn plants was calculated and the results were correlated with extractable NH_4, NO_3, P, and K in the soils. This was repeated for each extraction method. Each extraction method was assessed by correlating extracted nutrient values with dry matter weight and nutrient uptake of corn in pot experiments. The single extraction and rapid determination methods will be further developed into a soil test kit that can be used in provinces where soil-testing laboratories are not available.

NPK Fertilizer Recommendation Development

The fertilizer recommendation system evaluated in this study was developed using existing decision making aids. The DSSAT-CERES-Maize program version 3.0 was used for N-fertilizer recommendation. Phosphorus requirement was predicted using Phosphorus Decision Support System (PDSS) modelling.

DSSAT-CERES-Maize for determining N-Fertilizer Recommendation

The data from 10 soil series of Petchaboon, Lop Buri, Nakorn Sawan, and Nakorn Ratchasima Provinces were updated and the data of 28 soil series were taken from the database of the Land Development Department. A climatic database including solar radiation, maximum and minimum temperature, rainfall intensity, frequency, and annual distribution was obtained from the Thai Meteorology Department. With the use of the Weatherman program, long-term climatic data were used to predict climatic characteristics for the 1997–2001 period of study. A genetic coefficient study was performed using Suwan 5 and Suwan 3601 corn varieties as the test crops. All necessary data were recorded and calculated to estimate the genetic coefficients of the two corn varieties.

Table 2. The extracting solutions used in the study.

Method	Extracting solutions	Reference
Bray 2	0.03 M NH_4F + 0.1 M HCl, 1:10 soil: solution ratio, shake for 1 minute.	Kamprath and Watson, 1980
Citric acid	1 % citric acid, 1: 20 soil : solution ratio, shake for 30 minutes.	Thompson and Pratt, 1954
Mehlich 1	0.05 M HCl + 0.0125 M H_2SO_4, 1:5 soil: solution ratio, shake for 5 minutes.	Jones, 1985
Modified Mehlich 1	0.05 M HCl + 0.125 M H_2SO_4, 1:5 soil: solution ratio, shake for 5 minutes.	Modified from Jones, 1985
Morgan	0.54 M NH_4OAc + 0.7 M NaOAc pH 4.8, 1: 10] soil: solution ratio, shake for 30 minutes.	Kamprath and Watson, 1980
Olsen	0.5 M $NaHCO_3$, pH 8.5, 1:20 soil: solution ratio, shake for 30 minutes.	Page et al., 1982
Ammonium lactate	0.335 M lactic acid + dil. acetic acid + dil. NH_4OH, 1:20 soil: solution ratio, shake for 4 hrs.	Riehm, 1959
Sodium lactate 1	0.335 M lactic acid + dil. acetic acid + dil. NaOH 1: 20 soil: solution ratio, shake for 30 minutes.	Modified from Riehm, 1959
Sodium lactate 2	0.335 M lactic acid + dil. acetic acid + dil. NaOH 1: 20 soil: solution ratio, shake for 4 hrs.	Modified from Riehm, 1959
Ammonium bicarbonate + DTPA	1 M NH_4HCO_3 + 0.005 M DTPA, pH 7.6, 1: 2 soil: solution ratio, shake for 15 minutes.	Jones, 1985

Phosphorus Decision Support System (PDSS) Program for determining P Requirement
The intended crop, percent clay content, and soil test P of each soil were the only inputs into the program. The program will generate the P requirement for a typical yield. With additional inputs of fertilizer cost, grain price, and interest, estimates of benefit/cost can be calculated.

The On-farm Testing Using the Soil Test Kit and the NPK Fertilizer Recommendation *System*
Farmers' fields were selected to conduct the on-farm test. There were four sites of 1.6, 3.8, 0.8, and 2.1 ha. The soils were Lam Phaya Klang (Lg), Chatturat (Ct), and Lop Buri (Lb) series. Table 3 shows the pH, texture, soil series, and area of the four sites.

Table 3. pH, texture, soil series and area of the four sites, on-farm test.

Farmer	Soil series	pH[1]	Texture[2]	Area (ha)
Saweang	Lg	7.5	C	1.6
Thonglang	Ct	7.0	L	3.8
Oui	Ct	7.0	L	0.8
Perm	Lb	8.0	C	2.1

[1]1:1 soil:water ratio; [2]hydrometer method

RESULTS AND DISCUSSION

Extractant Selection
The Mehlich 1 extracting solution gave correlation coefficients of 0.74 0.50, and 0.66 for NH_4+NO_3 and CDW, P and CDW and K and CDW respectively. Similarly, correlation coefficients of 0.55, 0.59, and 0.64 were obtained for NH_4+NO_3 and CDW, P and CDW, and K and CDW respectively when using the Morgan extracting solution. In turn, the Sodium Lactate 1 extracting solution was associated with correlation coefficients of 0.77, 0.71, and 0.60 for NH_4+NO_3 and CDW, P and CDW, and K and CDW respectively (Table 4). Similar trends were obtained when NH_4+NO_3, P and K soil-extracted values were correlated with the corn uptake of these nutrients. This is with the exception of extractable K and K uptake as determined by Sodium Lactate 1, which resulted in a non-significant correlation coefficient of 0.48 (Table 5). The correlation results indicate that the Mehlich 1, Morgan, and Sodium Lactate 1 extracting solutions are the most promising for NH_4+NO_3, P, and K extraction. Mehlich 1 was chosen as the single extracting solution due to the highly significant correlation between extractable NH_4 +NO_3, extractable K and CDW, N and K uptake. Correlation coefficients of 0.74 and 0.77 were obtained for NH_4+NO_3 and CDW and N uptake, respectively. Further, correlation coefficients of 0.66 and 0.93 were obtained for extractable K and both CDW and K uptake. In addition, a significant correlation between extractable P and both CDW and P uptake was obtained. A correlation coefficient of 0.50 and 0.56 was obtained between extractable P and both CDW and P uptake (Table 5).

Table 4. Correlation coefficients between NH_4 + NO_3, P, and K extracted by 10 different methods and dry weight of corn.

Method	Dry weight of corn (28 days after planting)		
	$NH^+_4 + NO^-_3$	P	K
Bray 2	-	0.64**	0.62**
Citric acid	0.18	0.22	0.65**
Mehlich 1	0.74**	0.50*	0.66**
Modified Mehlich 1	0.21	0.17	0.63**
Morgan	0.55*	0.59*	0.64**
Olsen	-	0.44	0.63**
Ammonium lactate	-	0.58*	0.46
Sodium Lactate 1	0.77**	0.71**	0.60*
Sodium Lactate 2	0.10	0.65**	0.33
NH_4HCO_3 + DTPA	-	0.49	0.62**

* significant correlation at 95% level ** significant correlation at 99% level

Table 5. Correlation coefficient between NH_4 + NO_3, P, and K extracted by 10 different methods and nutrient uptake of corn.

Method	Nutrient uptake		
	$NH^+_4 + NO^-_3$	P	K
Bray 2	-	0.69**	0.96**
Citric acid	0.17	0.21	0.96**
Mehlich 1	0.77**	0.56*	0.93**
Modified Mehlich 1	0.28	0.13	0.95**
Morgan	0.52*	0.71**	0.95**
Olsen	-	0.51*	0.89**
Ammonium lactate	-	0.73**	0.42
Sodium Lactate 1	0.81**	0.82**	0.48
Sodium Lactate 2	0.19	0.75**	0.41
NH_4HCO_3 + DTPA	-	0.63**	0.93**

* significant correlation at 95% level ** significant correlation at 99% level

Soil Test Kit Development

The colorimetric determination of NH_4, NO_3, and P by a spectrophotometer was modified and developed for use with a standard color chart. Suitable correlations were obtained between the spectrophotometer and color chart for the NH_4 determination. For example, on 244 acid soils the correlation coefficients were 0.54, 0.87, and 0.96 for clayey, loamy, and sandy soils, respectively On 41 alkaline soils the correlation was similarly high for clayey and sandy soils. Similar results were obtained in the case of NO_3 and P (Table 6). In the case of K determinations, a highly significant correlation of NH_4OAc extractable K, determined by A.A., was obtained with the amount extracted by Mehlich 1 and determined by colorimetric methods (Table 7). The process of soil analysis was also simplified, e.g. the soil was scooped instead of weighed. All high-tech equipment was replaced by simple plastic bottles and droppers.

Table 6. Correlation coefficients for Mehlich 1 extractable NH_4, NO_3, and P between spectrophotometer and color chart determinations using 285 soil samples.

	Acid soil			Alkaline soil	
	Sandy (n=51)	Loamy (n=55)	Clayey (n=138)	Sandy (n=8)	Clayey (n=33)
NH_4	r = 0.96**	r = 0.87**	r= 0.54**	r = 0.94**	r = 0.79**
NO_3	r = 0.99**	r = 0.98**	r= 0.80**	r = 0.93**	r = 0.86**
P	r = 0.77**	r = 0.54**	r = 0.48**	r = 0.83**	r = 0.50**

* significant correlation at 95% level ** significant correlation at 99% level

Table 7. Correlation coefficients between extractable-K as determined by the Mehlich 1 and NH_4OAc methods as measured colorimetrically and by Atomic Adsorption Spectrophotometery, respectively..

	Acid soil			Alkaline soil	
	Sandy (n=51)	**Loamy (n=55)**	**Clayey (n=138)**	**Sandy (n=8)**	**Clayey (n=33)**
K	r=0.75**	r=0.60**	r=0.73**	r=0.67**	r=0.89**

* significant correlation at 95% level ** significant correlation at 99% level

The accuracy of the Soil Test Kit

The readings for soil NO_3, P, and K of the 15 samples determined by atomic adsorption spectrophotometery and the test kit were compared. The results showed that the test kit and atomic adsorption spectrophotometer (AAS) gave interpretations (low, medium, and high) in 14 of the 15 soils, 13 of the 15 soils, and 13 of the 15 soils for NO_3, P, and K as compared with the spectrophotometer reading (Table 8).

Table 8. Soil test data of the Pioneer Company's plot (before planting) and their interpretations.

No	series	NO_3^- content			P content			K content	
		Spectrophotometer		Test kit	Spectrophotometer		Test kit	Test kit	A.A
		mg N kg^{-1}	Class.		mg P kg^{-1}	Class.		mg K kg^{-1}	mg K kg^{-1}
1	Lb	2.00	VL	VL	4.50	M	H*	M	80
2	Lb	18.00	L	L	0.25	VL	VL	H	130
3	Lb	3.47	VL	VL	3.50	M	H*	M	82
4	Ln	4.38	VL	L	6.75	M	M	M	89
5	Ln	4.37	VL	VL	1.00	L	L	M	71
6	Tk	2.67	VL	L	3.25	L	L	H	277
7	Tk	12.92	L	L	0.56	L	VL	H	174
8	Pc	7.00	VL	L	6.00	M	M	L	39
9	Ct	3.00	VL	VL	2.00	L	L	M*	266
10	Lb	18.00	L	L	19.60	VH	H	H	628
11	Cu	1.25	VL	VL	10.00	VH	H	L	69
12	Lb	1.56	VL	VL	47.50	VH	VH	L*	84
13	Wi	15.00	L	M*	4.41	M	M	H	106
14	Tk	12.00	L	L	1.25	L	VL	H	126
15	Pc	12.00	L	L	9.00	H	H	M	78
			14/15			13/15		13/15	

NB. Class. = Classification

NPK Fertilizer Recommendation using the CERES-Maize Model

The predicted and measured yields of Suwan 3601 hybrid corn on some important soils in the four provinces of the corn belt area using the NPK fertilizer recommendations are shown in Table 9. An agreement index of 0.86 indicated the close agreement between the predicted and actual yield for the seven series (Willmott, 1982). The N fertilizer recommendation was determined by the CERES-Maize algorithm while the P and K fertilizer recommendations came from the Mitscherlich-Bray equation (Dept. of Agriculture, 1966; 1967).

Table 9. Predicted and actual yield of Suwan 3601, tested in the field and the agreement index value.

Soil series	Province	Actual yield	Predicted yield	$N\text{-}P_2O_5\text{-}K_2O$
		kg ha^{-1}		
Cd	Nakorn Sawan	7,225	6,563	94-75-0
Tw	Lop Buri	6,144	6,225	94-75-31
Tk	Lop Buri	5,225	5,475	125-0-31
Wi	Lop Buri	6,469	6,181	125-31-63
Wi	Petchaboon	6,413	6,238	125-75-63
Sat	Petchaboon	6,031	6,194	94-106-63
Suk	Nakorn Ratchasima	5,900	6,513	156-75-63
Ct	Nakorn Ratchasima	7,481	7,000	94-0-31

Mitscherlich-Bray equation = log (100 - y) = log 100 - 0.05419 b - 0.03864 x - P requirement
log (100 - y) = log 100 - 0.00618 b - 0.05132 x - K requirement y = relative yield, b = soil test value, x = fertilizer requirement (Dept. of Agriculture, 1966; 1967).

In the process of making fertilizer recommendations using decision support aids, the soil was identified for its soil series and a composite sample was tested for NO_3, P, and K content. The NPK fertilizer recommendation was then prepared according to the initial nutrient contents and soil series in each province.

NPK Fertilizer Recommendations as determined using CERES-Maize and PDSS Models

For this on-farm study, the CERES-Maize model was used for N fertilizer recommendations, the K fertilizer recommendation were derived from a Mitscherlich-Bray equation (Dept. of Agriculture, 1966; 1967), and the P recommendation was developed using the PDSS system. Four on-farm tests were performed comparing: 1) The current farmer practice, 2) NPK fertilizer recommended by CERES-Maize-Mitscherlich-Bray, 3) NPK fertilizer as recommended by CERES-Maize, PDSS, and (4) Mitscherlich-Bray equation. Tables 10 and 11 show the initial nutrient level, fertilizer recommendations, yields of corn and P after harvesting of the on-farm test. The results indicated a higher yield of corn where the NPK fertilizer recommendation was developed using the decision support aids except at one site that was affected by stem borers, which resulted in a yield that was low compared with the farmer's practice. The P content in the soils, after harvest, of the CERES-Maize-PDSS treatment was medium to high resulting from the addition of the recommended amount of fertilizer. In the case of the farmer's field, one site, however, indicated a low content of P after harvesting. Phosphorus fertilizer recommendations by the Mitscherlich-Bray equation were about twice the amounts of P fertilizer recommended by the PDSS decision support aid.

Table 10. Initial nutrient level, fertilizer recommendation, yield of corn, and P after harvest of the farmer's practice and CERES-Maize-PDSS treatments.

Series	pH[1]	Texture[2]	Nutrient Level (NPK)	Farmer's practice			CERES-Maize PDSS		
				Fertilizer applied	Yield kg ha^{-1}	P after harvest	Fertilizer applied	Yield kg ha^{-1}	P after harvest
Lg	7.5	C	VL-VL-H	25-25-0	2769	L	94-44-0	6063	M
Ct	7.0	L	VL-VL-H	13-19-0	4569	H	94-50-0	4138	H
Ct	7.0	L	VL-VL-H	19-25-0	2925	H	94-50-0	4469	H
Lb	8.0	C	VL-VL-H	69-38-0	2706	H	125-69-0	3425	H

[1]1:1 soil:water ratio; [2]hydrometer method

Table 11. Initial nutrient level, fertilizer recommendation, yield of corn and P after harvest of the CERES-Maize-Mitscherlich Bray treatment.

Farmer	Series	pH[1]	Texture[2]	Nutrient Level (NPK)	CERES-Maize Mitscherlich-Bray		
					Fertilizer applied	Yield kg ha^{-1}	P after harvest
Saweang	Lg	7.5	C	VL-VL-H	94-94-0	5913	M
Thong	Ct	7.0	L	VL-VL-H	94-94-0	3650	H
Oui	Ct	7.0	L	VL-VL-H	94-94-0	4944	H
Perm	Lb	8.0	C	VL-VL-H	125-94-0	4394	H

[1]1:1 soil:water ratio; [2]hydrometer method

Economic Analysis

The profit of the four on-farm tests was calculated as the benefit (crop price x the yield increase minus the fertilizer cost, including basic cost). It is clear that the CERES-Maize-Mitscherlich-Bray (CERES-MB) and CERES-PDSS treatments gave higher profits as compared with the current farmer practice (Table 12). The profit would have probably been greater, however, one of the plots was strongly attacked by stem borers and the yield was quite low.

Table 12. Economic analysis of the four on-farm tests.

	Sawaeng	Thonglang	Oui	Perm	Average
	Baht ha^{-1}				
Farmer's practice	34.8	7,743.0	755.5	-1091.9	1,860
CERES-MB	10,524.8	1,201.2*	6,532.5	3,863.5	5,531
CERES-PDSS	12,277.8	4,210.6*	5,574.3	438.7	5,623

* The profit was low due to the corn plants being attacked by stem borers.

CONCLUSIONS

The Mehlich 1 extracting solution is proposed as a single extracting solution for NH_4, NO_3, P, and K in soils of Thailand. Standard color charts for NH_4, NO_3, P and K were developed and used with a soil test kit for field-based NPK determination. Nutrient interpretations obtained by the soil test kit were comparable to values obtained in the laboratory. The results showed an agreement of 14/15, 13/15, and 13/15 for NO_3, P, and K between the soil test kit and AAS interpretations. The predicted and actual yield of NPK fertilizer recommendations using the CERES-Maize program and the Mitscherlich-Bray equation was performed in the field and an agreement index of 0.86 was obtained. In the case of P requirement, PDSS showed that P fertilizer can be reduced by about one-half the amount obtained from the calculation of the Mitscherlich-Bray equation. Using fertilizer recommendation with decision support aids and test kits, higher profit was obtained as compared to the amount used by the farmers, which did not take the initial amount of nutrients and the sustainability of the soils into account.

Recommendations for further study

The on-farm test has to be further expanded for a larger area of corn production. Adequate amounts of nutrients applied to the soil for corn production and in sufficient quantities for sustainable agriculture should be investigated. Moreover, the economic analysis should be focused and highlighted. The simplified program for NPK fertilizer recommendation should be loaded into laptop computers as an aid for extension workers and agricultural advisors.

ACKNOWLEDGEMENT

The authors would like to express their sincere thanks to the Thailand Research Fund (TRF) for the financial support of this study.

REFERENCES

Department of Agriculture. 1966. Annual Report 1966. Bangkok, Thailand.

Department of Agriculture. 1967. Annual Report 1967. Bangkok, Thailand.

Jones, Jr. J.B. 1985. Soil testing and plant analysis: Guide to the fertilization of horticultural crops. *Horticulture reviews*. Vol. 7. A.V. Publishing Co. 68 p.

Jones, Jr. J.B.; Wolf, B.; and Mills, H.A. 1991. *Plant analysis handbook, a practical sampling, preparation, analysis, and interpretation guide.* Micro-Macro Publishing, Inc. 213 p.

Kamprath, E.J.; and Watson, M.E. 1980. Conventional soil and tissue tests for assessing the phosphorus status of soils. In Khasawneh, F.E., Sample, E.C. and Kamprath, E.J. (Eds.), *The role of phosphorus in agriculture.* Madison, Wisconsin: ASA-CSSA-SSSA. pp 910.

Page, A.L.; Miller, R.H.; and Keeney, D.R. 1982. Methods of soil analysis. part 2. Chemical and microbiological properties. Second edition. Madison, Wisconsin: American. Society of Agronomy, Inc., Soil Science Society of America, Inc.. pp 1159.

Riehm, H. 1959. Die Ammoniumlaktat-Essigsaure-Methode zur Bestimmung der leicht loslichen Phosphorsaure in karbonathaltigen Boden. *Agrochemica* 3: 49–65.

Thompson, L.F.; and Pratt, P.F. 1954. Solubility of phosphorus in chemical extractants as indexes to available phosphorus in Ohio soils. *Soil Sci. Soc. Amer. Proc.,* 18 (4): 467–470.

Willmott, C.J. 1982. Some comments on the evaluation of model performance. *American Meteorological Society,* 63:1309–1313.