

**Objective 3** Develop auxiliary tools to the integrated knowledge base to enable local agriculturalists to diagnose and solve soil acidity and nutrient problems that predominate within the social, economic and agronomic characteristics of their regional domains

*Output 1* Extensive evaluation network - evaluation of products and capturing knowledge under a variety of location-specific conditions

Within this group we envisage a) individuals with knowledge that should be incorporated into products. b) individuals with field and laboratory data sets that could be used to evaluate products for location-specific conditions, and c) established networks who would be interested and benefit from using our products in their programs. Milestones in activities related to this task are project meetings held in years 1, 2, 4 and 5. Participants would be asked to consider relevance of planned tools to their local needs and suggest potential modifications or additions. In later years we would focus on obtaining feedback on evaluations of NuMaSS and auxiliary tools when applied to their local conditions.

#### Lead Investigators and Contributors

Deanna Osmond provides overall coordination to activities related to the network, but all U.S. project team members participate as they travel overseas and interact with network members. Collaborators from the following institutions (countries/regions) have agreed to participate in the network, contribute their nutrient management knowledge base and evaluate the decision support software prototypes and auxiliary tools under their location specific conditions:

IBSRAM Steepland Network (Asia)

IRRI Rice Consortium (Asia)

CIMMYT Regional Maize Program (Central America)

Potash&Phosphate Institute Andean Program (Central-Latin America)

IBTA (Bolivia)

ICRAF (Peru)

INIAP (Ecuador)

EMBRAPA (Brazil)

University of Viçosa (Brazil)

SRI (Ghana)

ISRA (Senegal)

Cedara Agric. Res. Station (S. Africa)

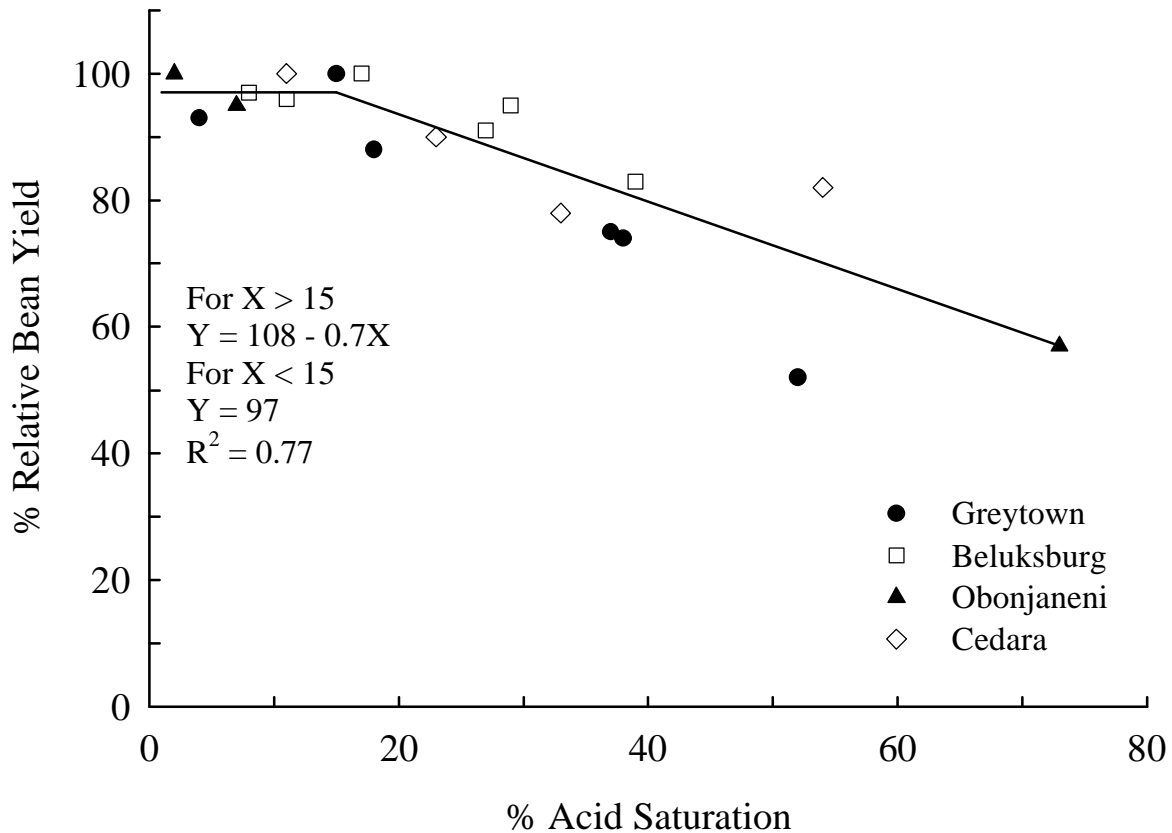
Some of these and many others attended the workshop held in Philippines and are active in the network.

#### Progress

##### *1. Network member site data pertinent to NuMaSS*

Phaseolus bean response to liming in Kwazulu-Natal (contribution from Alan Manson and Guy Thibaud at Cedara Agric. Dev. Inst., Pietermaritzburg, South Africa) collaborators at Cedara have been conducting lime trials at various sites with acid soils to characterize dry bean response to liming. Results for trials at four separate locations are summarized in Figure 1. The critical acid (N KCl-extractable Al + H) saturation of the effective cation exchange capacity across all sites was estimated as 15% by non-linear regression. These trials indicate greater acidity tolerance in dry beans than the default value of 0% acid saturation currently

used in NuMaSS 1.5. Inclusion of these data in the software database will serve to alert users to the range of acidity tolerance among dry bean cultivars and locations.



**Figure 1.** Dry *Phaseolus* relative bean yield as a function of soil acid saturation % of the effective cation exchange capacity in lime trials with four soils in the Kwazulu-Natal region of South Africa. (data provided by Alan Manson and Guy Thibaud, Cedara Agric. Dev. Inst., Pietermaritzburg)

Soil and bean yield data for the trial at Cedara are shown in Table 1. Lime with 86.7% CaCO<sub>3</sub> equivalence was incorporated to a 30-cm depth, whereas soil chemical properties are reported for a 15-cm sampling depth. Rates of lime presented in the table were, therefore, adjusted to half of the actual field applications to coincide with the soil sample data. The lime recommendation by NuMaSS 1.5 to achieve 15% acid saturation in this soil, assuming a bulk density of 1 g cm<sup>-3</sup>, 15-cm depth of incorporation and with the quality of lime used, was 3 ± 0.75 t ha<sup>-1</sup>. However, soil analytical data reveals that 3 t lime ha<sup>-1</sup> only reduced acid saturation to 33%. Further inspection of the data in Table 1 reveals that under-estimation of the lime requirement is due to the lime neutralization factor. In NuMaSS a lime neutralization factor of 1.9 cmol<sub>c</sub> of Ca from lime / cmol<sub>c</sub> of acidity is used, based on lime experiments with Inceptisols, Oxisols and Ultisols in Sitiung, Indonesia (Wade et al., 1987. Liming in transmigration areas. pp. 125-131. In N. Caudle and C.B. McCants (eds.) TropSoils Technical

Report 1985-1986. North Carolina State University, Raleigh, NC). However, soil chemical data for this experiment indicates that the observed lime neutralization factor was 1.74 cmol<sub>c</sub> of Ca from lime / cmol<sub>c</sub> of acidity. Based on numerous experiments in the region, lime recommendations by the Cedara Agric. Dev. Inst. use a higher lime neutralization factor than the default value in NuMaSS. With the help of collaborators throughout the network soil analytical and lime quality data from various experiments are being assembled to compare lime neutralization factors for a variety of soils. Results from this comparison may lead to adjustments in the lime neutralization factor, prior to the release of NuMaSS version 2.0.

Table 1. Soil chemical data and dry *Phaseolus* bean yields for lime treatments on the Hutton soil at Cedara Agric. Dev. Inst. near Pietermaritzburg, South Africa<sup>a</sup>.

<b>Applied</b>	<b>Exchangeable</b>				<b>Acid</b>	<b>pH in</b>	<b>Bean</b>
<b>Lime<sup>b</sup></b>	<b>Ca</b>	<b>Mg</b>	<b>K</b>	<b>Al+H</b>	<b>Sat.</b>	<b>KCl</b>	<b>Yield</b>
t ha <sup>-1</sup>	----- cmol <sub>c</sub> L <sup>-1</sup> -----				%		kg ha <sup>-1</sup>
0	1.40	0.78	0.36	2.94	54.00	4.00	2364
3	2.13	1.46	0.38	1.95	33.00	4.10	2251
5	2.44	1.84	0.36	1.40	23.00	4.30	2582
6.5	3.25	2.63	0.37	0.71	11.00	4.50	2878
LSD <sub>0.05</sub>	0.39	0.41	Ns	0.53	10.00	0.10	

<sup>a</sup> Data contributed by Alan Manson and Guy Thibaud, Cedara Agric. Dev. Inst.

<sup>b</sup> 50% of the lime with 86.7% CaCO<sub>3</sub> equivalence incorporated to a 30-cm depth to coincide with soil data from samples taken to a 15-cm depth.

Immediate and long-term P sorption in Ecuador soils used for potato production -  
(contribution from Jose Espinosa of INPOFOS, Juan Cordova and Franklin Valverde of 'Santa Catalina' Experiment Station, and Francisco Mite of 'Pichilingue' Experiment Station, with analytical support from Fred Cox) Data were collected in Ecuador from two field experiments in which fertilizer P had been applied at various rates and times for a period of three years. The model developed by Cox, et al (1981) was used to determine the immediate and long-term P sorption in these studies. The original model utilized the data from an initial application of P to assess immediate and long-term P sorption, and the results could then be used to compare predicted with actual conditions if re-applications or later applications were made. This was done by solving at various times in a pulsating manner. In the current data sets only four of the 12 treatments had just an initial application, so, to more fully utilize the information, a statistical program in SAS was developed to consider the data from all 12 treatments. That program is as follows:

```
data one; input Site Time Tmt F0 F1 F2 P; peq=5;
  Comment Site is numbered 1 or 2, Time is in years after
```

application, Treatment is the ID number, F0, F1, and F2 are the kg P/ha applied at times 0, 1, 2 yr, P is the Modified Olsen P, and peq is the minimum value of Modified Olsen P allowed for that soil;

cards; (data can be provided upon request)

```

title Both Sites;
proc nlin;  parms a=16 b=0.3, c=0.4; bounds b<=1,  c>=0;
if f0>=0 and f1=0 and f2=0 then do;
  model p=(a+b*f0-peq)*exp(-c*time)+peq;
end;
  Comment This is the basic model for an application at Time zero and no
  further applications (Treatments 1 through 4);
  Comment Estimates will be made of "a", the initial Modified Olsen P at
  time zero, "b" the fraction of the fertilizer P that will be present in
  the soil test P, and "c" which indicates the rate of decrease of the
  soil test P in time;
else if f0=0 and f1=0 and f2>0 and time<2 then do;
  model p=(a+b*f0-peq)*exp(-c*time)+peq;
end;
  Comment This statement if for Treatment 5 for periods up until Time 2
  when the fertilizer is applied;
else if f0=0 and f1=0 and f2>0 and time>=2 then do;
  model
p=((a+b*f0-peq)*exp(-c*2)+peq)+b*f2-peq)*exp(-c*(time-2))+peq;
end;
  Comment The first part of this function calculated the "a" at Time
  equals 2 while the remainder solves the function for the period of time
  greater than 2;
else if f0=0 and f1>0 and f2>0 and time<1 then do;
  model p=(a+b*f0-peq)*exp(-c*time)+peq;
end;
  Comment This is the beginning of the functions for Treatment 6, in which
  fertilizer was applied at Times 2 and 3. The same approach and logic as
  used above may be seen in all the following statements;
else if f0=0 and f1>0 and f2>0 and 1<=time<2 then do;
  model
p=((a+b*f0-peq)*exp(-c*1)+peq+b*f1-peq)*exp(-c*(time-1))+peq;
end;
else if f0=0 and f1>0 and f2>0 and time>=2 then do;
  model p=((a+b*f0-peq)*exp(-c*1)+peq+b*f1-peq)*exp(-c*2)+peq
+b*f2-peq)*exp(-c*(time-2))+peq;
end;
else if f0>0 and f1>0 and f2=0 and time<1 then do;
  model p=(a + b*f0-peq)*exp(-c*time)+peq;
end;
else if f0>0 and f1>0 and f2=0 and time>=1 then do;
  model
p=((a+b*f0-peq)*exp(-c*1)+peq)+b*f1-peq)*exp(-c*(time-1))+peq;
end;
else if f0>0 and f1>0 and f2>0 and time<1 then do;
  model p=(a+b*f0-peq)*exp(-c*time)+peq;
end;
else if f0>0 and f1>0 and f2>0 and 1<=time<2 then do;
  model
p=((a+b*f0-peq)*exp(-c*1)+peq)+b*f1-peq)*exp(-c*(time-1))+peq;
end;
else if f0>0 and f1>0 and f2>0 and time>=2 then do;
  model

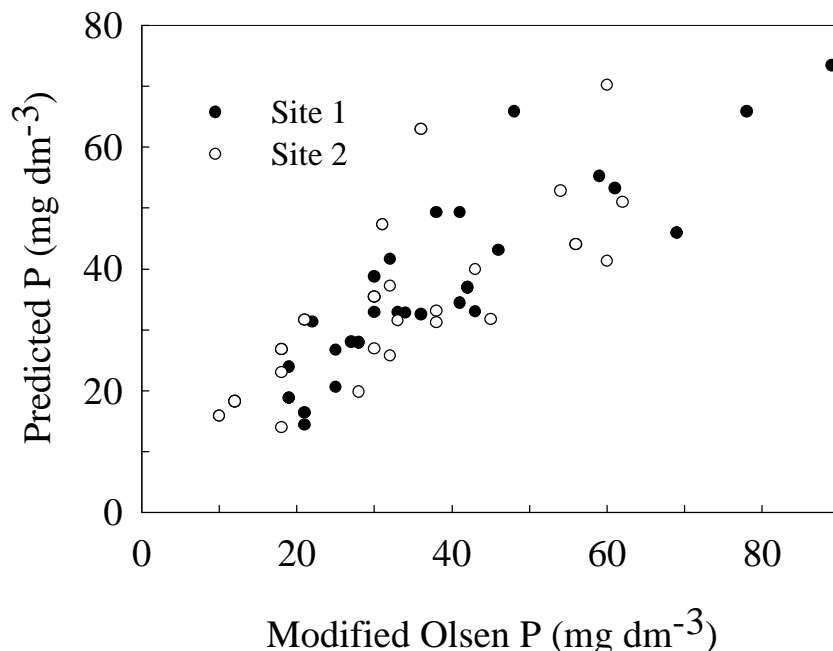
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p=((((((a+b*f0-peq)*exp(-c*1)+peq)+b*f1-peq)*exp(-c*2))+peq)
+b*f2-peq)*exp(-c*(time-2))+peq;
end;
output out=new predicted=py;
proc print;
proc plot; plot py*p/haxis=0 to 100 by 10 vaxis=0 to 100 by 10;
Comment Both the observed and predicted values of Modified Olsen P may
be plotted with Time, but the pulsating nature of the curve makes it
difficult to view well in this case;
run;

```

When the new statistical package was run on the combined data from the two sites, the estimated “a” was 21, “b” was 0.31, and “c” was 0.19. Greater stability is achieved if the coefficients “b” and “c” are combined into one term indicative of P sorption (Cox, 1994). When this is done for the most convenient and practical time of one year, 26% of the applied fertilizer would be in the Modified Olsen P, so 74% of the P had been sorbed to an “unavailable” form. The predicted Modified Olsen P was plotted against the observed Modified Olsen P for the combined data from the two sites and the relationship was reasonably close to the expected 1:1 (Figure 2). However, both the intercept and slope were significant in the relationship  $Y = 11.7 + 0.67X$  and the r-square value was 0.64.



**Figure 2.** Relation between predicted and observed Modified Olsen P for soils under potato production for three years at two sites in Ecuador.

The sites were also analyzed individually and gave markedly different interpretations of P sorption. For Site 1 the a, b, and c values were 24, 0.40, and 0.29, respectively. At one year

30% of the applied P would be shown in the Modified Olsen P. The relationship between PY and P,  $Y = 8.6 + 0.77X$  had an r-square value of 0.76. The data for Site 2 failed to converge in the NLIN program of SAS, but gave a, b, and c coefficients of 16, 0.19, and 0. Thus there was no time effect for long-term sorption and at one year 19% of the P applied would be shown in the Modified Olsen P. In this case the relationship between PY and P,  $Y = 10.9 + 0.66X$  had an r-square value of 0.60.

The reason that the Site 2 data did not converge in NLIN was that the soil test P measured in the check plots increased during the three years. This is not logical as there would naturally be a decrease due to P removal and other P sorption during this time. However, in a biological system there are annual differences affecting the level of P extracted and if this variation is not random, but increases each year, then this can happen. This is less likely to occur in data sets of longer periods.

It is unfortunate that the short terms of these two potato data sets resulted in questionable coefficients for the model. Field data is needed for comparison to coefficients determined in the laboratory to confirm their validity. For the time being, however, the coefficients found with the combined two sets may be used as a first approximation.

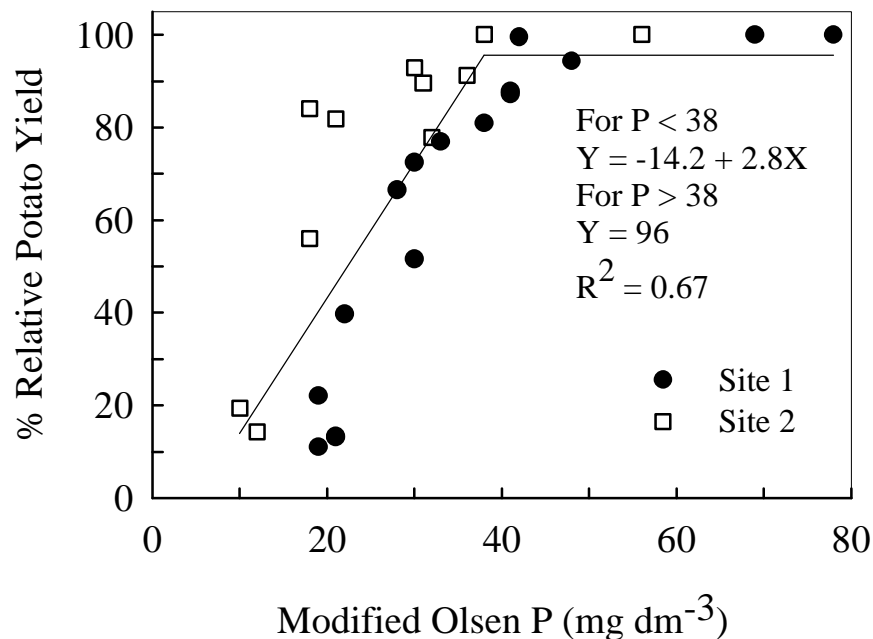
Reference Cited -

Cox, F.R., E.J. Kamprath, and R.E. McCollum. 1981. A descriptive model of soil test nutrient levels following fertilization. *Soil Sci. Soc. Am. J.* 45:529-532.

Critical soil P levels for potato production - (contribution from Jose Espinosa of INPOFOS, Juan Cordova and Franklin Valverde of 'Santa Catalina' Experiment Station, and Francisco Mite of 'Pichilingue' Experiment Station, with analytical support from Fred Cox and Jot Smyth) NuMaSS 1.5 does not contain sufficient information to provide a diagnosis or fertilizer P recommendation for potato. Among the missing pieces of information are critical soil P values from field trials where yield response has been characterized across a broad range of soil P levels. Experiments at the two sites with Andisols in Ecuador provide the desired information for definition of a critical soil P level for potato.

Each site contained three years of potato yield data. In the first year four P treatments of 0, 33, 66 and 99 kg P ha<sup>-1</sup> were established. In subsequent years these plots were sub-divided and residual fertilizer P was compared with fresh applications of the same P rates. There was about a 4-fold variation in Modified Olsen-extractable soil P among P treatments at each site and within each year of the experiment.

Critical soil P levels were first estimated via non-linear regression across crop years for each site. In both sites, however, the relation between relative yield and Mod. Olsen P for the third year deviated considerably from the two initial years. Exclusion of year 3 data changed the critical soil P estimate from 42 to 36 mg P dm<sup>-3</sup> for site 1 and from 38 to 32 mg P dm<sup>-3</sup> for site 2. Due to the small difference in estimated critical soil P values between sites, the two initial years for each Andisol were combined to provide the relation shown in Figure 3 with an estimated critical soil P level of 38 mg P dm<sup>-3</sup>. The resulting critical soil P value from data in Ecuador is similar to the value of 40 mg P dm<sup>-3</sup> used for potato production on Andisols in Costa Rica (Eloy Molina, personal communication). These values are also considerably higher than the Mod. Olsen values of 10 - 15 mg P dm<sup>-3</sup> which are generally used for crops like corn throughout the Central American region.

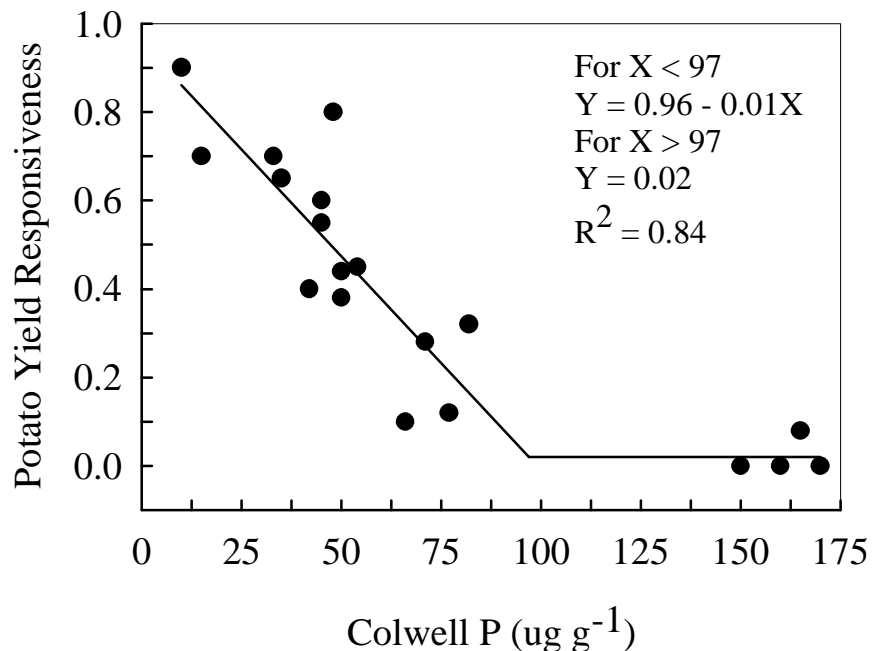


**Figure 3.** Relation between potato yield and Mod. Olsen extractable P for two crop cycles at two separate sites on Andisols in Ecuador.

The critical soil P level for Andisols in Ecuador was compared with data for P fertilization trials with potato on 19 sites in Western Australia (Hegney et al., 2000). Soil classification for these sites was not given but clay content varied from 2 to 9%. For each of these sites, the authors related % relative yield to fertilizer P using regression equations in the form of  $Y=a-be^{-cx}$ . Responsiveness to fertilizer P was assessed as the proportion  $b/a$ , and this yield factor was related to Colwell extractable soil P (Figure 4). There was negligible yield response to fertilizer P above  $97 \text{ ug g}^{-1}$  of Colwell soil P. In their review of P fertilization research in South Australia, Reuter et al. (1995) found that linear regression slopes between Colwell ( $y$ ) and Olsen ( $x$ ) soil P tests for seven regions varied from 1.8 to 2.4 with a mean value of 2.1. Based on this mean value, the critical Colwell soil P value of  $97 \text{ ug g}^{-1}$  would correspond to  $46 \text{ ug g}^{-1}$  with the Modified Olsen extractant.

References Cited -

- Hegney, M.A., I.R. McPharlin and R.J. Jeffery. 2000. Using soil testing and petiole analysis to determine phosphorus requirements for potatoes (*Solanum tuberosum* L. cv. Delaware) in the Manjimup-Pemberton region of Western Australia. *Aust. J. Exp. Agric.* 40:107-117.
- Reuter, D.J., C.B. Dyson, D.E. Elliott, D.C. Lewis and C.L. Rudd. 1995. An appraisal of soil phosphorus testing data for crops and pastures in South Australia. *Aust. J. Exp. Agric.* 35:979-995.



**Figure 4.** Relation between potato yield responsiveness to applied fertilizer P and Colwell-extractable soil P for 19 field trials in Western Australia. (adapted from Hegney et al., 2000).

2. *On-farm testing of the PDSS module in Thailand* - (T. Attanandana, T. Vearasilp, K Kukiet, S. Kongton and R. Yost) Phase one results of the Thailand Research Fund project have indicated that suitable predictions of N requirements were predicted for each of the major soil series used for the growing of maize in central Thailand (Attanandana et al., 1999). The phase two objectives of the project were to identify P needs and to attempt to predict responses using the PDSS nutrient management software. The results presented here evaluate the first season's comparisons among ways to estimate the P fertilizer requirements in the maize-growing soils of Central Thailand. Two groups of fields were prepared by TRF project staff, including Pioneer and CP companies. Because PDSS and NuMaSS represent four components of nutrient management information processing (diagnosis, prediction, economic analysis, and recommendations), we analyze the results successively for the diagnosis and prediction components in this report.

Diagnosis component - In order to assess the success of the on-farm tests with respect to diagnosis we first look at the data, usually observational, historical, but also the soil and plant analysis data available for each site.

The PDSS diagnostic module will analyze as many as seven criteria in making a diagnosis, however we only are checking the soil P levels as extracted by Mehlich1 and Olsen extractants in this comparison. The data indicate that there was a good range of soil test P levels – from less than 1 to nearly 20 mg kg<sup>-1</sup> (Table 2). Such a wide range in values should be excellent for testing the ability of the software to diagnose P responsive and unresponsive conditions. The

first important conclusion from these data was that there was excellent agreement between the test kits and the laboratory determined intervals of P availability (Table 2, last line). In terms of class comparisons, 8 of the 10 classes matched for the two approaches to measure soil test P. There was, in fact, closer agreement between the test kit and the laboratory than there was between the two extractants Mehlich 1 and Olsen. We suspect that this might be due to the neutralization of the acidic Mehlich extractant by the free calcium carbonate in several of the maize soils. Comparisons among the laboratory and kit determined nitrate and potassium were also indicated good agreement. Results from the five CP company fields was apparently more successful, however, indicating that the diagnostic methods accurately detected fertilizer responsive conditions (Table 3).

Table 2. Soil test data of the pioneer company's plot (before planting)

Series	NO <sub>3</sub> <sup>-</sup> content		P content				K content			Response			
	Spectrophotometer		Spectro(Mehlich)		Spectro(Olsen)		Test Kit		A.A	Pred ict	Obse rv		
	mg/kg N	level	mg/kg P	level	mg/k g P	level	mg/k g K	mg/kg K	level				
Lb	2.00	VL	VL	4.50	M	H*	8	L	M	80	M	-	-
Lb	18.00	L	L	0.25	VL	VL	6	L	H	130	H	+	-
Lb	3.47	VL	VL	3.50	M	M	4	L	M	82	M	-	+
Ln	4.38	VL	L	6.75	M	H*	11	M	M	89	M	-	+
Ln	4.37	VL	VL	1.00	L	L	5	L	M	71	M	+	+
Tk	2.67	VL	L	3.25	L	L	17	M	H	277	H	+	-
Tk	12.92	L	L	0.56	L	VL	6	L	H	174	H	+	+
Pc	7.00	VL	L	6.00	M	M	6	L	L	39	L	-	-
Ct	3.00	VL	VL	2.00	L	L	4	L	M*	266	H	+	+
Lb	18.00	L	L	19.60	VH	H	22	H	H	628	H	-	-
		<b>10/10</b>		<b>8/10</b>				<b>9/10</b>			<b>6 = 0.2</b>		

Table 3. Soil test data of the CP company's plot (before planting)

No	series	NO <sub>3</sub> <sup>-</sup> content		P content				K content			Response		
		Spectro		Test Kit	Spectro (Mehlich)		Test Kit	Spectro (Olsen)		Test Kit	A.A	Pred	Obs
		ppm N	level		ppm P	level		ppm P	level		ppm K		
1	Cu	1.25	VL	VL	10.00	VH	H	8.0	L	L	69	-	-
2	Lb	1.56	VL	VL	47.50	VH	VH	26.0	H	L*	84	-	-
3	Wi	15.00	L	M	4.41	M	M	9.0	L	H	106	-	-
4	Tk	12.00	L	L	1.25	L	VL	8.0	L	H	126	+	+
5	Pc	12.00	L	L	9.00	H	H	11.0	M	M	78	-	-
<b>Agreement:</b>		<b>4/5</b>		<b>5/5</b>				<b>4/5</b>			<b>6 = 1.0</b>		

Olsen's: 0-9=L, 10-20=M, >21=H

The second test of the diagnosis phase is to determine if the soil tests correctly identified P responsive soils to which P applications would result in increased yields (Cai et al., 1996).

This can be done by forming a matrix similar to that in Table 4, and calculating the coefficient kappa, which expresses the agreement between the diagnosis and the field-determined results..

Table 4. Diagnosis accuracy assessment: Pioneer Company

	No response	Response
No diagnosis (not deficient)	3	2
Diagnosis (deficient)	2	3
Kappa coefficient = 0.20, n=10		

The matrix is composed of the Diagnostic test (in this case soil tests) on the left and the actual response in the columns on the top. The kappa statistic summarizes the extent to which “No response” situations were detected by the diagnostic test, soil analyses in this case. Kappa values of 1 indicate perfect prediction, i.e. there was no response to fertilizer P when the soil test P was in the Medium or High categories and there was always a response when the soil tests were less than Medium, i.e. Low or Very Low. Kappa values of 0 indicate that there was just as many incorrect diagnoses as correct ones or that the diagnostic test was no better than chance alone. The kappa analyses of the Pioneer experiments indicated that the soil tests were useful in identifying P or fertilizer responsive situations (Table 4). Kappa analyses of the CP company’s results, however, gave higher values than those from the Pioneer experiments (K = 1.0 versus K = 0.2) (Table 5). There were, however, slight differences in the amounts of K and N applied so it is possible that some of the responses were not, in fact, due solely to P. We suggest that future on-farm tests seek to vary only one nutrient so that comparisons / updates of the critical level can be obtained from such studies.

Table 5. Diagnosis accuracy assessment: CP Company

	No response	Response
No diagnosis (not deficient)	4	0
Diagnosis (deficient)	0	1
Kappa coefficient = 1.0, n=5		

Table 6. Diagnosis accuracy assessment: Pioneer Company & CP Company

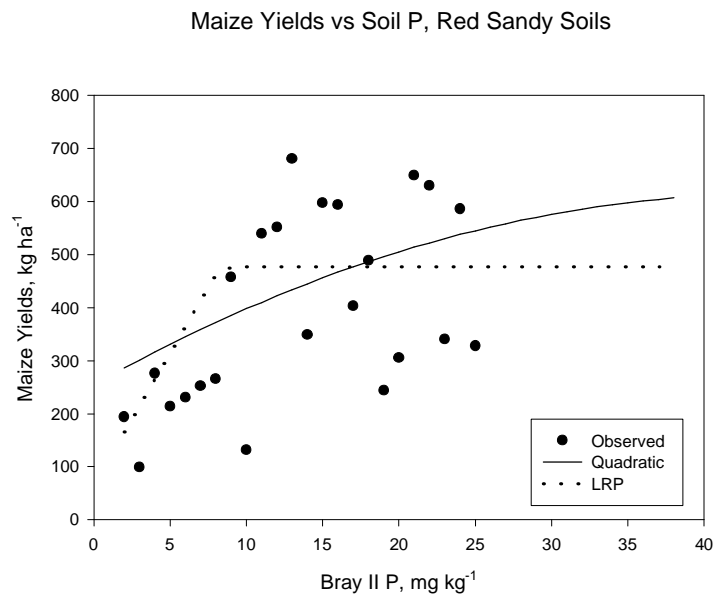
	No response	Response
No diagnosis (not deficient)	7	2
Diagnosis (deficient)	2	4
Kappa coefficient = 0.44, n=15		

Prediction component: estimating P critical levels - Prediction of P requirements is heavily influenced by the target critical levels, therefore we also compared the PDSS prediction of soil

P critical levels with local estimates. The estimates of P critical level used in PDSS are based on % clay using results largely developed on highly weathered soils of Brazil (Lins and Cox, 1989). Our hypothesis was that the prediction of critical level based on clay percentage alone may not apply to the mix of weathered soils of Thailand, sandy, red soils and the black smectitic soils.

It is likely these two categories of soils contain different amounts of P and will require different amounts in order to restore their productivity to the potential as estimated from the DSSAT maize model (Attanandana et al., 2000). Project data were analyzed according to the LRP fitting routine developed by X. Shuai (2000, unpublished data) with PROC NLIN of SAS v. 8.0.

Results of the plotting and estimation of the critical levels of the red, sandy soils are given in Figure 5. The LRP equation was estimated as  $Yield = 66.87 + 49.568 * (\text{Min}(X, 8.26))$ , which indicates a critical level of Bray II of 8.26, approximately 2.4 mg P kg<sup>-1</sup> (Attanandana, personal communication). This graph also shows the common occurrence that quadratic equations of critical level, yield response, and other functions, often over-estimate the critical levels and x values – a point long emphasized in Anderson and Nelson (1975).

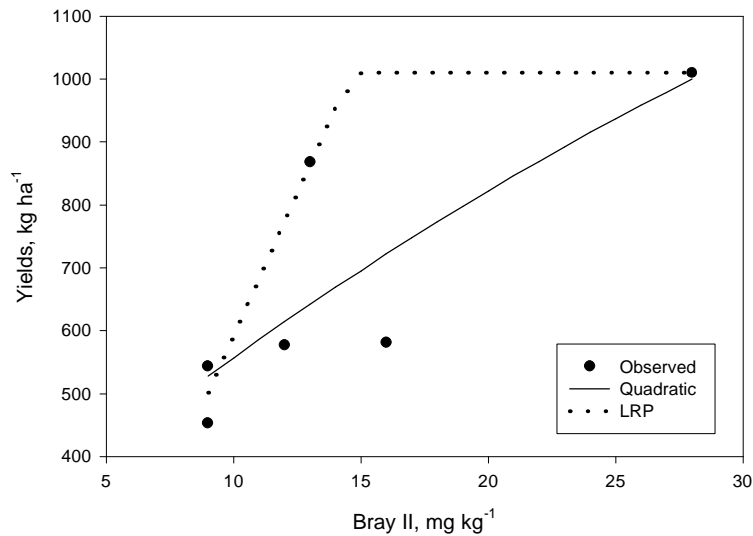


**Figure 5.** Estimated critical level, red, sandy soils.

An attempt to estimate the critical level for the black soils is shown in Figure 6, but indicates that the data are scarce. A best estimate, however, is that the level is approximately 14.6, which corresponds roughly to a Mehlich1 of 4 mg kg<sup>-1</sup>.

These results contrasted with the results suggested in Lins and Cox (1989) and Cox (1994), who found that as the % clay increased the critical levels decreased. They also found that as the % clay increased the buffer coefficient (defined as the change in extractable P / unit of applied P, decreased (data not shown).

Maize Yields vs soil P, Black clayey soils



**Figure 6.** Estimated critical level, black soils.

Prediction component: estimating the amounts of P needed - In this component we try to analyze the question were the correct amounts of P recommended by PDSS? In order to answer this question precisely expensive factorial experiments should be conducted at each site, obviously costing a great deal of time and money. Another way to answer this question, however, is to compare soil tests before and after the application of fertilizer and growth of the crop to determine whether the additions did bring the soil test levels up to the critical level as predicted by the PDSS software.

The Pioneer and CP studies can also provide some information on this question. Fortunately, there were measures of soil test P taken after harvest, which makes it possible to check to see if the application of the recommended amounts of fertilizer did, indeed, result in soil test levels at or above the critical levels (Table 7). The results according to the Mehlich 1 test were that for the most part the extractable P was increased to the M or H levels by the addition of the recommended amounts of fertilizer. In a couple of cases, Lb1 and Lb2, according to the Mehlich extractant, too much P was added, however, according to the Olsen results the right amounts were added resulting in levels of M in both cases. In some cases it appears that the recommended amounts were too low, i.e. the extractable P did not increase to sufficiency level: Ln1, Ln2, and Tk2.

Table 7. Soil test data of the pioneer company's plot, a comparison before planting with after planting.

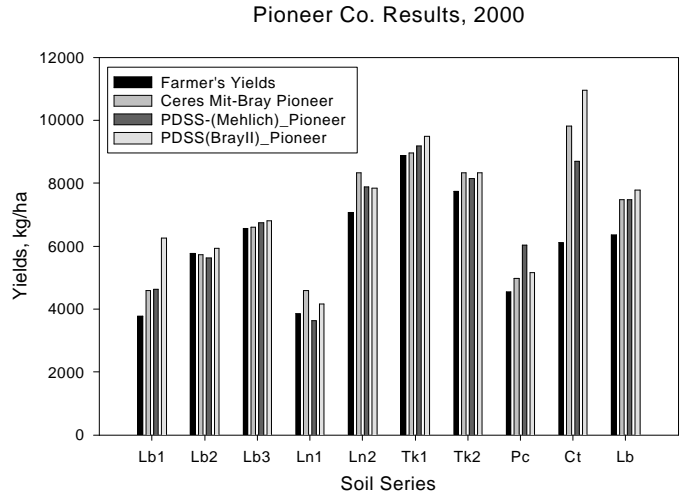
No	series	Before cropping			After cropping			Before cropping		After cropping	
		Spectro (Mehlich)		Test Kit	P added*, kg/ha	Spectro (Mehlich) level	Spectro level	Spectro (Olsen)		Spectro (Olsen)	
mg/kg P	level			mg/kg P				level	mg/kg P	level	mg/kg P
1	Lb	4.50	M	H*	13	17.5	VH	8	L	16	M
2	Lb	0.25	VL	VL	20.2	12.0	VH	6	L	14	M
3	Lb	3.50	M	M	14.6	7.0	H	4	L	6	L
4	Ln	6.75	M	H*	9.1	2.0	L	11	M	6	L
5	Ln	1.00	L	L	17.9	2.0	L	5	L	8	L
6	Tk	3.25	L	L	16.3	3.5	M	17	M	15	M
7	Tk	0.56	L	VL	22.1	0.6	VL	6	L	4	L
8	Pc	6.00	M	M	10.4	10.0	VH	6	L	6	L
9	Ct	2.00	L	L	17.6	5.0	M	4	L	4	L
10	Lb	19.60	VH	H	0	13.3	VH	22	H	34	H

\* Estimated from a 10cm wide x 10cm depth in 75cm rows.

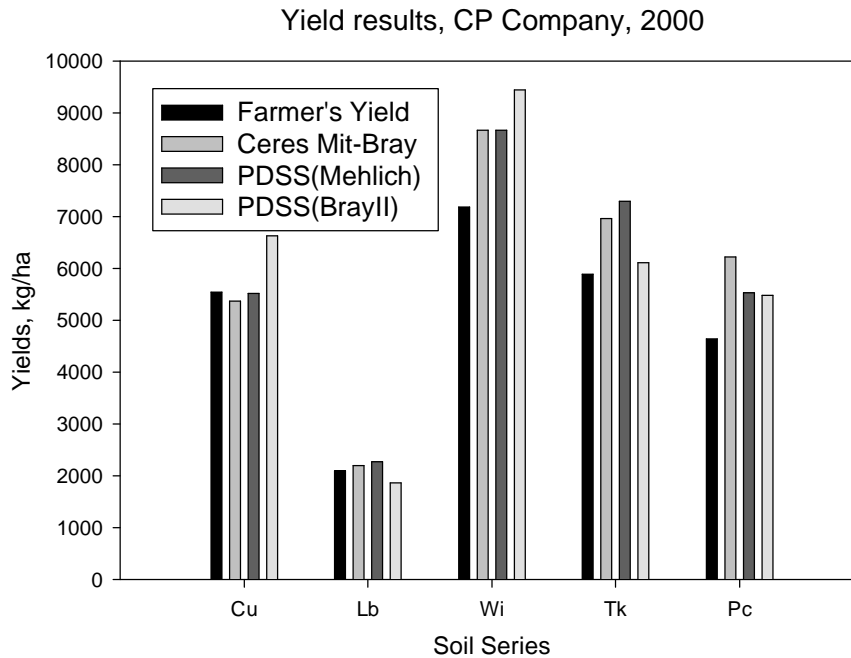
Next we can test for differences in yields where different approaches were used to estimate the P requirements. Those results, shown in Table 8 and Figures 7, 8 indicate that there was generally a significantly greater yield where the decision-aids were used to estimate fertilizer requirement. A limitation of this sort of analysis is that if the soils already have sufficient P there will be no yield advantage to the use of the decision-aids to estimate P requirement. A more accurate evaluation would be to assess whether the application of P where recommended, was profitable. This means asking the question was there a yield increase where the P was recommended or not. In other words, did the soil tests correctly diagnose nutrient responsive conditions and was the correct amounts of fertilizer recommended in order to meet crop needs?

Table 8. Maize yields associated with the various methods of estimating fertilizer requirement, Pioneer and CP company experiments, 2000 season.

Method	Yields, kg rai <sup>-1</sup> (n=15)	Significance
Farmer's method	918	a
Mitscherlich-Bray	1054	b
Mehlich 1	1038	b
Bray II	1090	b



**Figure 7.** Corn yields, 2000 on-farm experiments testing P recommendations of PDSS.



**Figure 8.** On-farm (2000 season) tests of PDSS diagnosis and recommendations.

Economics component - As indicated above, the economics component is the third component of nutrient management that is implemented in PDSS. There are two ways that use of soil tests and decision-aids built on them can benefit the grower economically: 1) they can save the grower from spending money for fertilizer that is not needed, and 2) they can indicate when fertilizer responsive conditions are likely. In the studies on Pioneer and CP there were

cases where a simple soil test could have saved the grower money. In the case of Pioneer, there were two clear cases where the soil test indicated no need to apply fertilizer. This saved the grower an average of about 3.7 kg P<sub>2</sub>O<sub>5</sub>/rai or 94 Bt / rai. In the case of CP there were four of the five farms that tested medium or high in soil P and in this case by testing the grower would have been able to save his investment of about 100 Bt/ rai. As indicated in Table 9, there was surprisingly similar average amounts of P applied using the farmer's methods as in the PDSS recommendations, but it was not applied where responses occurred. Actual yields were somewhat higher using the decision-aids methods, but the most significant difference was that following the decision-aids, the P was applied where responses in terms of increased maize yields occurred (Table 9). Although the data are sparse there were several cases where there was a clear trend of a significant response to the addition of P fertilizer. These were in soils Ln1, where there was an approximate 13.7 kg/rai increase in yield for each kg of P<sub>2</sub>O<sub>5</sub> added, the other series were respectively: Ln2 at 14.4, Tk2 at 5.6, Ct at 42 until about 8 kg P<sub>2</sub>O<sub>5</sub>, Cu (CP) at 11.6, and Tk (CP) at 11.8 kg/rai yield / kg P<sub>2</sub>O<sub>5</sub>. The purpose of a good decision-aid is to detect such cases so that the farmer can take advantage of such opportunities to increase yield and increase profitability.

Table 9. Economic analysis results of various methods of recommending fertilizer P.

Method	Average P <sub>2</sub> O <sub>5</sub> recommended	Average Yield	Average Benefit* - Cost
	kg rai <sup>-1</sup>	kg rai <sup>-1</sup>	Baht rai <sup>-1</sup>
Farmer's Practice	4.2	918	-5.32
Ceres (Mitscherlich - Bray)	9.4	1054	7.59
PDSS-Mehlich1	3.8	1038	45.2
PDSS-Bray2	4.6	1091	64.7

\*Benefit: Maize yield calculated at 4Baht kg<sup>-1</sup>, Cost: P calculated as DAP at 21.7Baht kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>. Yield response was estimated from the four levels of added P with yield maxima estimated from the approximate response curves for each soil. Baht is about 43/\$US. 6.25 rai = hectare.

**Conclusions** - In summary, the phase two experiments illustrate several important evaluations of current nutrient management and suggest some areas for improvement.

- In terms of diagnosing nutrient responsive conditions, the rapid, low cost, field test kits gave results that essentially matched those obtained when the soils were packaged, mailed to a central laboratory, analyzed, and the results mailed back to the grower. This may open an alternative for on-site diagnosis of nutrient responsive conditions and savings in time and money. In terms of diagnostic accuracy, the soil tests' accuracy could be improved. Because there were differences in the amounts of N and K applied, it wasn't certain that the responses were due to P alone.
- Based on comparisons of before and after soil P analyses, the P additions, generally speaking, addressed the deficiencies identified by the soil tests. After-harvest soil P levels

were much improved over the before harvest values, and were close to expected values based on PDSS predictions.

- The economic analysis indicated the true value of the improved management information provided by the decision-aids. While the amounts of purchased and applied P were very similar between the farmer's methods and those using PDSS, it was clear that using the information provided by PDSS the fertilizers were applied where there would be response. Thus while yields were not greatly improved with the decision-aids, the profitability was increased from an average loss of about 5 baht to a profit of 40 or so. This illustrates the need to include economic analyses in the evaluation of fertilization strategy as implemented in the PDSS system.

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- Thailand Research Fund, \$25,000.
- Access to data provided by network collaborators fills important information gaps in the NuMaSS database, as illustrated in this report. Although it is difficult to put a \$ value on these data, it is safe to assume that the robustness of the NuMaSS database and its performance would suffer significantly in the absence of the information provided.

#### Travel and Meetings Attended

- Fred Cox - travel to Costa Rica to work with collaborators on laboratory and field trials related to P management for peach palm; travel to Ecuador to review and discuss soil P management data with Dr. Espinosa (PPI-Potaphos). September 17-18.
- Travel to Thailand to review, analyze, and interpret results from the 2000 maize experiments of the Thailand Research Fund project.

Relevant Publications, Reports and Presentations at Meetings

- Ares, A., N.P. Falcao, R.S. Yost, K. Yuyama, E. Molina and C.R. Clement. Soil and foliar nutrient analysis as diagnostic and predictive tools in perennial tree crops. *Agron. Abstr.* p. 353.
- Attanandana, Tasnee, Chairerk Suwannarat, Taweesak Vearsilp, Kukiet Soitong and R.S. Yost 2001. Soil test kits for NPK diagnosis and recommendation (manuscript in preparation)
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- Cox, F. 2000. Report on travel to Costa Rica and Ecuador. Decision Aids for Integrated Soil Nutrient Management Project. 12p.  
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