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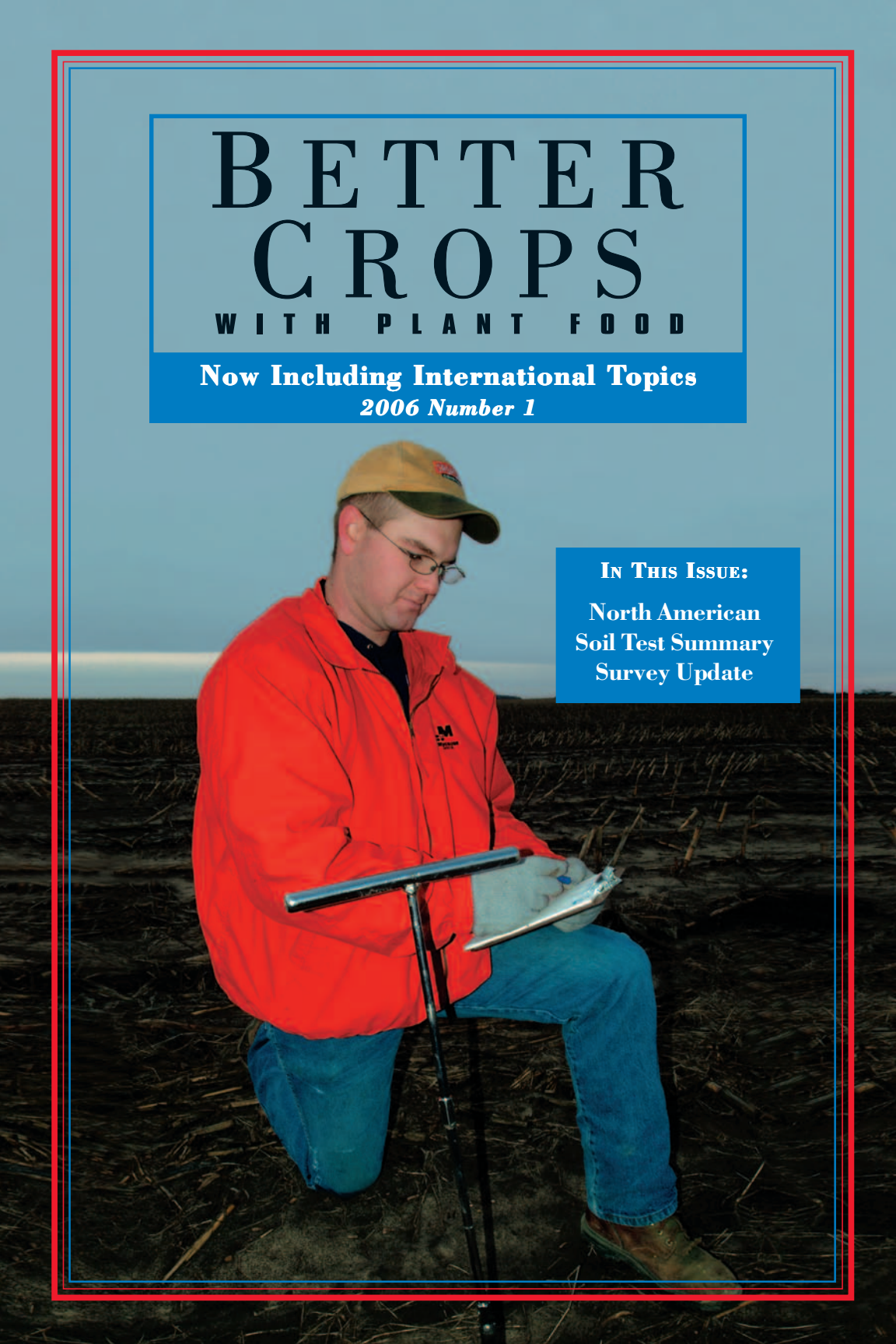

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North American Soil Test Summary Survey Update

BETTER CROPS WITH PLANT FOOD

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Our cover: Matt Henery takes soil samples in Nebraska.
Photo credit: Larry Reichenberger

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Terry L. Roberts Named President of PPI

The Board of Directors of the Potash & Phosphate Institute (PPI) has named Dr. Terry L. Roberts as President of the international agricultural research organization, effective January 1, 2006. The announcement came from Bill Doyle, Chairman of the PPI Board and President and CEO of PotashCorp.

"Terry Roberts is a highly qualified leader, agronomic scientist and also an effective administrator with a wide spectrum of experience. His understanding and insight related to PPI programs, staff, the academic community, and the fertilizer industry will be great assets in the transition to this new responsibility," Mr. Doyle explained. "This is an important time in meeting the challenges of growing more food on limited land, while protecting the environment and using resources wisely. We are pleased that Dr. Roberts is accepting this key position with PPI."

He will be only the sixth president in the 70-year history of the Institute. Dr. David W. Dibb, who had served as President since 1989, announced his retirement effective December 31, 2005.

Dr. Roberts most recently served as Senior Vice President of PPI and the Potash & Phosphate Institute of Canada (PPIC). He also held the title of International Programs Coordinator and had responsibility for member services and communications.

Dr. Roberts previously served as president of the Foundation for Agronomic Research (FAR) and continues as a vice president of that organization.

A native of Alberta, Canada, he grew up in a family fertilizer business. Dr. Roberts received a B.S.A. degree in Crop Science in 1981 and a Ph.D. in Soil Fertility and Plant Nutrition in 1985 from the University of Saskatchewan. He joined the PPI/PPIC staff in 1989 as Western Canada Director, with responsibility for agronomic research and education programs.

In June 1999, Dr. Roberts was transferred to PPI's headquarters in Norcross, Georgia, and was named President of FAR. At the same time, he was appointed Vice President of PPIC for the Latin American Program, and coordinated the Institute's regional programs in Brazil, Northern Latin America, Latin America-Southern Cone, and Mexico/Northern Central America. In February 2002, Dr. Roberts was appointed PPI Vice President, Member Services and Communications. He continues to direct the communications group of the institute, including publication of *Better Crops with Plant Food* magazine, as well as the website and electronic information.

In November 2004, Dr. Roberts was elected Senior Vice President, PPIC, and in January 2005 he became Senior Vice President, PPI, and International Program Coordinator.

An effective communicator and internationally respected as a speaker and writer, Dr. Roberts has given more than 300 invited lectures, seminars, symposia, and other presentations around the world and has written more than 160 technical and non-technical papers. He is a Fellow of the American Society of Agronomy.

Dr. Roberts and his wife, Marianne, have five children and now live near Atlanta, Georgia. BC

Note: Changes in titles and responsibilities of some PPI/PPIC staff members are outlined in an item on page 25.

Soil Test Levels in North America

By P.E. Fixen

With the cooperation of numerous public and private soil testing laboratories, PPI periodically summarizes soil test levels for phosphorus (P), potassium (K), and pH in North America. This 2005 summary is the ninth completed by the Institute.

The 2005 summary includes results of tests performed by more than 70 public and private labs on approximately 3.4 million soil samples collected in the fall of 2004 and spring of 2005. Great appreciation is extended to all the labs cooperating. They were asked to do considerably more work than in the past and it has resulted in what is likely the most comprehensive evaluation of the status of soil fertility in North America ever conducted.

Past summaries reported the percent of samples testing medium or below in P or K or that had pH values less than or equal to 6.0. In general, these were soil test categories where most agronomists would predict a significant yield response in the year of application to P, K, or lime. However, the agronomic definition of medium varies due to differences in philosophical approaches and research results. In other words, the numerical soil test level separating medium and high categories varies substantially. To avoid the confounding which results from geographic and temporal variation in laboratory or state/province definition of medium and actual changes in soil fertility levels, percent medium or below was not estimated in the 2005 summary process. Starting with the 2001 summary, medians will be used to track changes over time in soil fertility levels. The median is the level occurring in the middle when values are arranged in order of magnitude.

Several changes in summary procedures from the past have contributed to a significant improvement in the quality of the 2005 summary. These include an increase in total number of samples, more complete frequency distributions across North America, and the replacement of "medium" with median levels. Despite these improvements, several weaknesses continue in the summary process:

- Quantity of samples remains low in several states and provinces.
- Some samples may have originated outside the state or province indicated.
- Some areas of each state or province are likely under or over-represented.
- It is likely that the better managers soil test and that their soil tests may not be representative of those that do not soil test.
- Due to the requirement of nutrient management plans for many livestock operations, the percent of samples in the summary from manured fields could be higher than in the past for some regions and inflate soil test levels, especially for P.
- Although an attempt was made to define agronomic equivalency for each of the soil test categories among the various procedures, it is likely that error was introduced in this process.

Critical to appropriate use of this information is recognition that nutrient management should occur on a site-specific basis where the needs of individual fields, and in many cases areas within fields, are recognized. **Therefore, a general soil test summary like this one has no value in on-farm nutrient management.** Its value lies in calling attention to broad nutrient needs

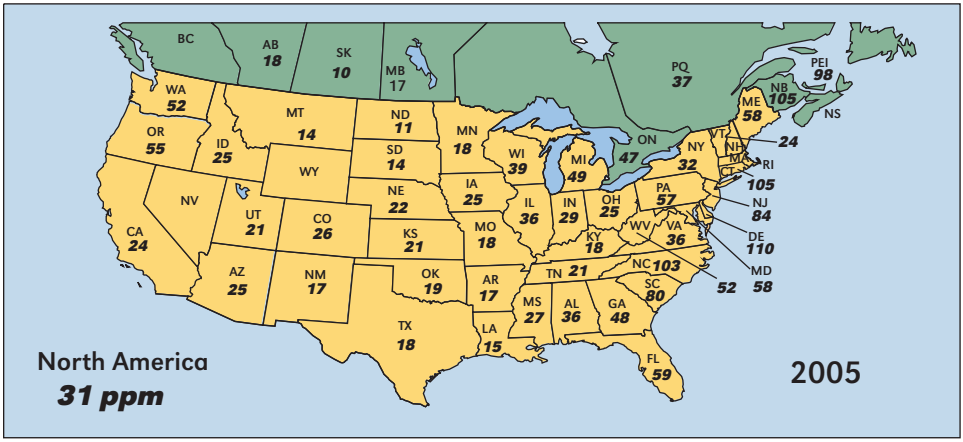

Figure 1. Median Bray P-1 equivalent soil test levels.

and challenges and in motivating educational and action programs.

There are many benefits of high P and K soil test levels. High tests are important in providing plants with needed nutrients to take advantage of optimum growing conditions and reduce the negative effects of stressful conditions. They provide protection against deficiencies induced by nutrient stratification in reduced tillage systems plus offer more options in fertilizer placement, time of application, nutrient application rates, and frequency of soil sampling. High and very high field average soil test levels offer insurance against profit-robbing deficiencies occurring in low testing parts of variable fields. Considering the high frequency of extreme within-field variability revealed by intensive sampling, this factor alone in many cases justifies building soil test levels to at least the high category.

It is important to recognize that these nutrients should be protected from loss to avoid environmental degradation. This can be accomplished through proper management. It should not be assumed that because a soil area or field is high in fertility that it represents a threat to water quality or because it is low in fertility that it offers no threat to water quality. Management relative to watershed characteristics makes the difference.

Critical Bray P-1 equivalent levels for the soils and cropping systems of the Great Plains and western Corn Belt are usually assumed to be around 20 parts per million (ppm) and to increase to 25 or 30 ppm for the eastern U.S. Recent research indicates that critical levels may be higher for high yield management systems. Certain crops, such as potatoes on some soils, will require much higher soil P levels—research shows response in the 100 ppm range. Bottom line…critical levels are site-specific.

Critical ammonium acetate K equivalent levels vary markedly across North America. For the relatively high cation exchange capacity (CEC) soils of western and central North America, calibration research usually indicates critical levels in the 140 to 200 ppm range. Critical levels are usually lower in eastern North America and on low CEC soils may drop to 80 ppm. As with P, specific crops and management systems may have different critical K levels than those indicated above.

The median P level for North America is 31 ppm, with 42% testing less than 25 ppm, a middle-of-the-road critical level. Phosphorus levels continue to vary markedly among states and provinces (**Figure 1**). The northern Great Plains has the lowest P levels with medians in the 10 to 18 ppm range, followed by the Midsouth and western states of the Corn Belt in the

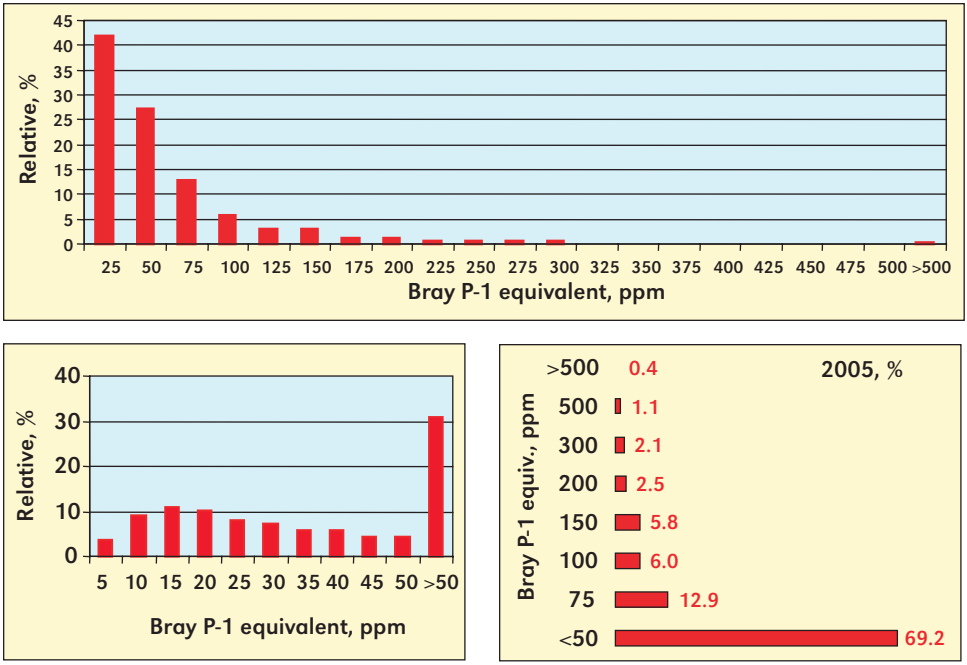

Figure 2. Relative frequencies for soil test P in North America.

15 to 27 ppm range. Soil P levels in eastern North America from Florida to the Maritime Provinces are generally much higher than for the rest of the region.

Relative frequencies for soil test P in North America are shown in **Figure 2**. Viewing North America as a single frequency distribution with uniform category widths of 25 ppm gives the typical skewed distribution with a long tail to the right. These graphs show why an average is inappropriate for describing most soil P distributions...because it over-estimates the central tendency of the data. It also shows the dominance of the lower categories of soil P in North America.

The median K level for North America is 154 ppm, with 33% of the samples test-

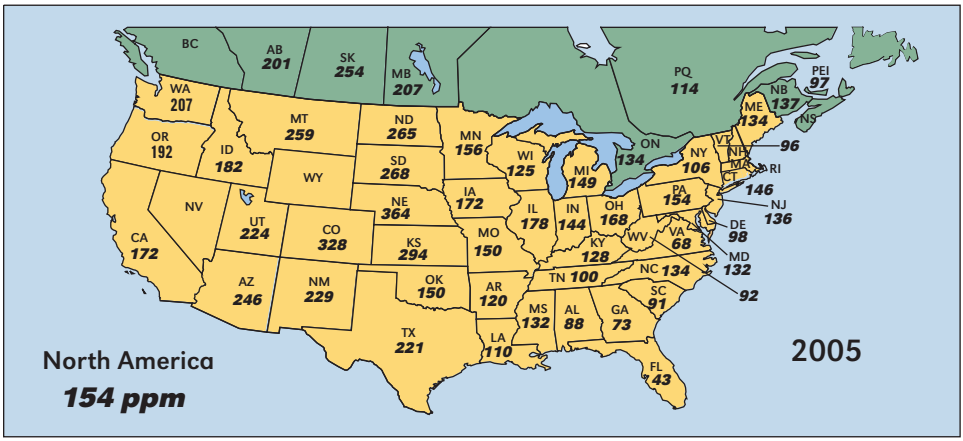

Figure 3. Median ammonium acetate equivalent soil test K levels.

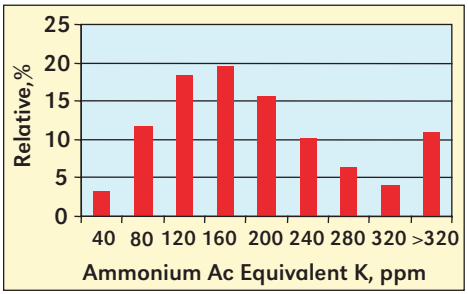

Figure 4. Soil test K frequency distribution for North America in 2005.

ing less than 120 ppm and 53% testing less than 160 ppm (Figures 3, 4). Median K levels in most of the states east of the Mississippi River and in the provinces of eastern Canada are at or below agronomic critical levels, indicating that 50% or more of the fields represented likely require annual K application to avoid yield losses. The higher K levels of the West reflect the less weathered status of western soils. However, in states such as California where 46% of the soils test <160 ppm, crop removal over several decades with limited nutrient addition has significantly reduced soil K levels.

The median pH for the U.S. and Canada is 6.3, with 31% of the samples testing <6.0. A pH of 6.0 is highlighted because a pH above 6.0 is desirable for most cropping systems. Median pH is lowest in the southeastern U.S. and generally increases as you move north and west in North America (**Figure 5**). Historically, soil pH values have tended to be more acid where rainfall is higher and where large amounts of vegetation have helped to acidify the soil. Those conditions have been associated with areas east of the Mississippi River in the U.S. and in the eastern Canadian provinces. But, continued research has revealed that soil acidity problems are not limited to those areas.

Conclusions

Both the P and K results illustrate the importance of regular field-specific soil testing. The wide-ranging distribution of soil test results in nearly all states and provinces points clearly to the need for soil testing to determine fertility needs of specific fields as a guide to fertilizer and manure application. BC

Dr. Fixen is PPI Senior Vice President, Americas Program Coordinator, and Director of Research, located at Brookings, South Dakota; e-mail: pfixen@ppi-far.org.

Note: More detailed information, including comparisons to the 2001 summary, plus magnesium and sulfur soil test information, is included in Technical Bulletin 2005-1 and the accompanying CD, available for purchase from PPI. For more details, see the item on page 24 or go to the website: ***>www.ppi-ppic.org<***

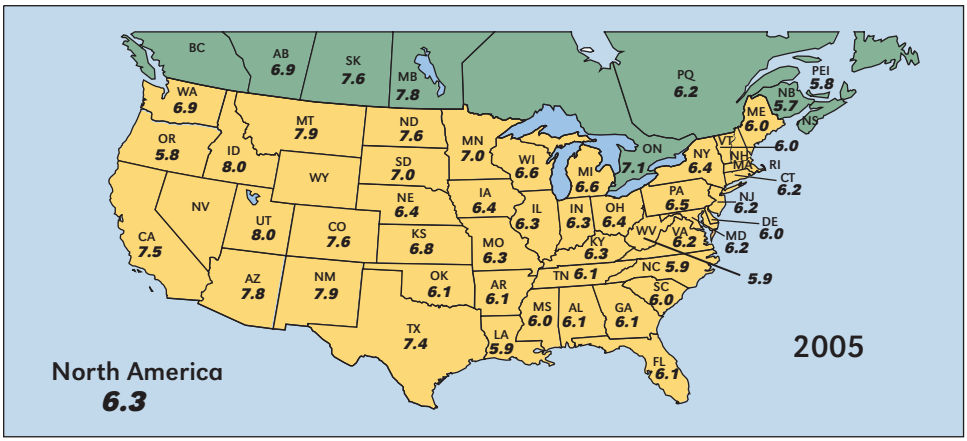

Figure 5. Median soil pH levels.

NORTHEAST

Soil Fertility in the Northeast Region

By T.W. Bruulsema

The fertility of soils in the northeast U.S. and eastern Canada reflects both natural variations in soil and nutrient distribution as influenced by intensive management of all sources. Nutrient management changes—in response to new technologies and regulations—are beginning to be reflected in soil fertility changes.

The Northeast Region is characterized by cool temperatures, high rainfall and humidity, a high density of livestock, and a large human population. Though soils in this region ranged from poor to moderate in fertility a couple of centuries ago, the long history of crop and livestock production has increased fertility levels of many fields through inputs of fertilizers and manures.

The region comprises the six eastern provinces of Canada (Ontario and eastward) and 15 states including and northeast of Michigan, Ohio, and the Virginias.

Interpretation

Interpretation of soil tests is site-specific. Most states and provinces in the region have unique recommendations based on past research linking a specific soil test to crop response. Seven different soil test extractants are used. The equivalencies we use are approximations for the purpose of general comparison of regional soil fertility patterns. They are not adequate for determining fertilizer recommendations for a particular field.

Since critical levels vary across the region, the values chosen in this discussion to distinguish low and high fertility are somewhat arbitrary. Accuracy in making fertilizer recommendations is highest when based on local soil test calibration. Responsible management of high phosphorus (P) soils is best guided using an environmental P Index that assesses the risk of P loss impacting water.

High Phosphorus Soils

The frequency of soils highly enriched in P is substantially greater in the Northeast than in the rest of the continent. Soils testing higher than 50 parts per million (ppm) as a Bray P-1 equivalent comprise 48% of this region (Ohio excluded), compared to only 28% for the rest of North America.

However, a few others outside this region also test high. In British Columbia, Washington, Oregon, the Carolinas, and Florida, more than half the soils test higher than 50 ppm.

Several factors contribute to the high figures for soil test P in the Northeast.

1. The amount of P in manures in comparison to crop removal.
2. Cultivation of crops with high demand for P
3. Regulations mandating soil tests from intensive livestock operations.
4. Inherent soil fertility.

Figure 1 shows that a considerable proportion of the variation among states and provinces in soils testing in this high category is explained by the ratio of crop removal to recoverable manure [data from PPI (2002)]. Where manure P amounts to more than 20% of crop removal (R/M <5), the proportion of soils testing 50 ppm and above often exceeds 50%.

However, one must not be too quick to jump to the conclusion that manure is the cause of high soil test P... "Correlation is not causality." It may be that livestock

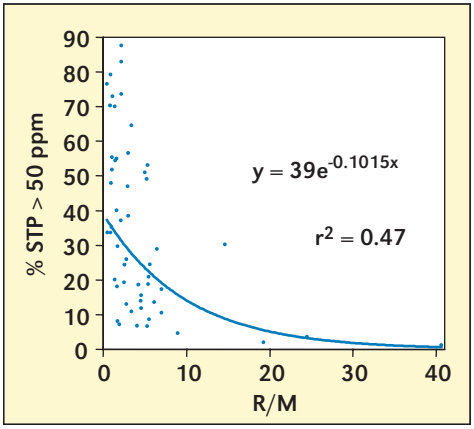

Figure 1. Percentage of soils testing greater than 50 ppm Bray P-1 equivalent as a function of a state or province's ratio of crop removal (R) of P to that applied as manure (M). Each point represents one of 54 provinces and states across North America.

production thrives on the more fertile soils. Also, many states and provinces with relatively large mounts of manure do not have many high testing soils. **Table 1** shows that substantial proportions of both high and low P soils coexist within several states and provinces.

While most field crops do not require soils to be built up in P to over 50 ppm, optimum yield and quality of specialty crops — like potatoes, tobacco, and many vegetables — requires rates of application that build soil tests to well over this level. These crops contribute to the elevated frequency of high P soils in Prince Edward Island, New Brunswick, and Maine **(Table 1)**.

Relative to the 2001 soil test survey, Ontario, Quebec, and New York showed slight declines in median soil test P (-4, -8, and -3 ppm, respectively). In New York, this contrasts with an increasing trend from 1976 to 2000 reported by Ketterings et al. (2005). Generally, where frequencies of high P soils were high in 2001, the changes were slight. This may reflect changes in livestock diets and manure handling in response to active nutrient management programs in the region.

Potassium (K)

More of the soils of the Northeast test lower than 120 ppm K than in the rest of North America **(Table 1)**. The highest frequencies of low K soils occur in the Virginias, Prince Edward Island, Delaware, Vermont, New York and Quebec. Many of these soils may be expected to have low retention capacity for K owing to low clay content and cation exchange capacity.

Considering their elevated frequencies of high P soils, it was surprising to see the substantial proportions of soils in Prince Edward Island, Delaware, and West Virginia that tested below 120 ppm in K. These soils appear to retain P much more than K. One should not presume that P-based manure management will always supply adequate K.

The overall agricultural nutrient balance of eastern Canada indicates a surplus of P (but much smaller than several decades ago) and a deficit of K. Considering this, it is not surprising that soils of the Northeast would show buildup of P even though the frequency of soils low in K is substantial.

Magnesium (Mg)

The Northeast region has fewer soils low in Mg than the rest of North America **(Table 1)**. Low Mg soils occur most often in Virginia, Prince Edward Island, and Delaware. Provinces and states with frequent low K soils tend to show the largest areas low in Mg.

Since K and Mg antagonize each other's uptake, it is important to pay attention to Mg when correcting K deficiencies. While Mg deficiency is often thought to coincide with low soil pH, there was surprisingly little correlation between frequencies of low Mg and low pH.

Soil pH

Acidic soils predominate in the Atlantic provinces, Maine, and West Virginia. However, the Northeast overall has a slightly lower frequency of soils testing

Table 1. Distribution of soil test levels in eastern Canada and northeastern U.S.

Province/State	Number of samples	Bray P-1 equivalent P, ppm %<30	Bray P-1 equivalent P, ppm %>50	Ammonium acetate equivalent K, ppm %<120	Ammonium acetate equivalent Mg, ppm %<75	pH %<6.0
New Brunswick	4,300	17	74	40	18	70
Newfoundland	480	9	83	46	1	90
Ontario	92,100	33	47	40	12	10
Prince Edward Island	5,400	6	88	69	38	66
Quebec	71,600	44	40	53	22	40
CT-MA-NH-RI	6,800	21	73	39	18	34
Delaware	5,700	10	79	67	35	49
Maine	6,400	30	55	44	27	53
Maryland	23,600	28	55	43	16	36
Michigan	98,300	30	49	32	8	18
New Jersey	1,900	26	65	42	13	38
New York	27,000	48	37	58	8	27
Ohio	86,000	57	25	20	1	28
Pennsylvania	62,000	30	54	33	5	21
Vermont	5,500	55	34	61	24	49
Virginia	34,500	42	35	82	46	38
West Virginia	8,200	20	52	67	19	53
Eastern Canada	173,900	36	46	46	18	26
Northeast US	364,900	38	43	39	12	26
NE US & E Canada	538,800	38	44	41	14	26
North America	3,400,000	49	31	33	21	31

lower than pH 6 than the rest of North America.

Much of the variation in soil pH in the region arises from the parent materials of the soils. Cropping systems were long ago adapted to suit the native pH regimes encountered. For example, potatoes dominate crop rotations on the acidic soils of the Atlantic provinces and Maine, while alfalfa, soybeans, and other legumes are favored on the soils derived from limestone parent materials in Michigan, New York, Ohio, and Ontario.

Sulfur (S)

Much of the Northeast receives considerable S by deposition from the atmosphere. As a result, relatively few soils test low. Since S deposition is declining in response to reduced emissions, and since deposition is non-uniform, chances of S limitation are increasing.

Conclusions

Summary results support the need for continued use of soil tests. While nutrient surpluses have built up the fertility of many soils in the Northeast, substantial areas of low fertility soils remain. Soils with a buildup of one nutrient may not necessarily have sufficient levels of all nutrients. BC

Dr. Bruulsema is PPI Northeast Region Director, located at Guelph, Ontario; e-mail: Tom.Bruulsema@ppi-ppic.org.

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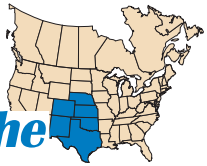
SOUTHERN AND CENTRAL GREAT PLAINS



Soil Test Levels and Changes in the Southern and Central Great Plains Region

By Mike Stewart

The most recent (2005) PPI soil test summary for the six states in the Southern and Central Great Plains Region (SCGP) shows that median soil pH, phosphorus (P, Bray P-1 equivalent), and potassium (K, ammonium acetate) levels range from 6.1 to 7.9, 17 to 26 parts per million (ppm), and 150 to 364 ppm, respectively. Change in median levels of soil P in the region from the 2001 to the 2005 summaries varied from 1 to -5 ppm, while median soil K level decreased for each state except Nebraska. Comparison of frequency distributions between the 2001 and 2005 summaries suggests that for most states there has been some depletion of P in soils around the critical level, with a resulting shift to lower levels. Comparison also indicates that the luxury of naturally high soil K levels in the region is being slowly eroded.

The 2005 PPI soil test summary effort determined the distribution and median values of soil pH, P, and K in the SCGP Region. The majority of samples (54%) analyzed in the region are alkaline (pH ≥ 7).

Figure 1 shows the relative frequency (RF) distribution of soil pH by state. Colorado and New Mexico have the highest proportion of samples above pH 8. They also have the highest median pH values among the states, 7.6 and 7.9, respectively (**Table 1**). The percent of samples testing pH 7 or above is 90% in Colorado and 99% in New Mexico. These are the region's westernmost states and are thus less subject to weathering and the development of acid conditions. The eastern portions of Kansas, Nebraska, Oklahoma, and Texas receive the highest rainfall in the region and consequently have somewhat different RF distributions (**Figure 1**) and lower median soil pH values (**Table 1**). The median pH value for Texas is relatively alkaline (7.4) and the majority of soils tested above pH 7 (68%). Oklahoma has the highest percentage of acid soils…only 36% tested above pH 7.

Soil test P RF distribution among

Table 1. Median values for soil pH, P, and K from the 2001 and 2005 soil test summaries. The last column is the difference or change in median values (2005 minus 2001).

	Median		Change from
	2005	2001	2001 to 2005
	---------- Soil pH ----------		
Colorado	7.6	7.4	0.2
Kansas	6.8	6.8	0
Nebraska	6.4	6.3	0.1
New Mexico	7.9	7.9	0
Oklahoma	6.1	6.1	0
Texas	7.4	7.5	-0.1
	--- Bray P-1 equivalent, ppm P ---		
Colorado	26	25	1
Kansas	21	20	1
Nebraska	22	21	1
New Mexico	17	21	-4
Oklahoma	19	20	-1
Texas	18	23	-5
	- Ammonium acetate equivalent, ppm K -		
Colorado	328	348	-20
Kansas	294	332	-38
Nebraska	364	362	2
New Mexico	229	247	-18
Oklahoma	150	164	-14
Texas	221	232	-11

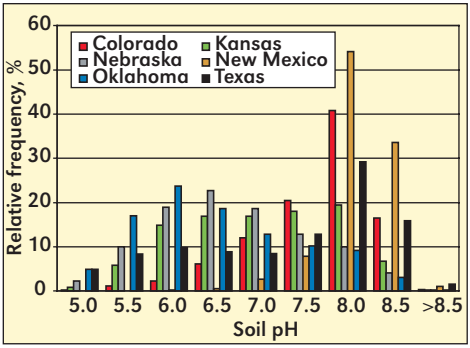


Figure 1. Relative frequency distribution of soil pH from the 2005 PPI soil test summary in the six states of the SCGP.

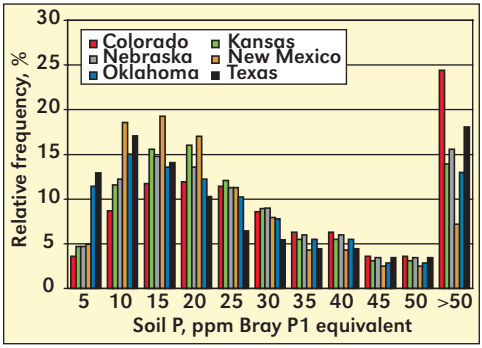


Figure 2. Relative frequency distribution of soil P level from the 2005 PPI soil test summary in the six states of the SCGP.

states in the SCGP generally follows a skewed or log normal distribution (**Figure 2**) that is typical and expected. This distribution is characterized by a peak in the lower ranges with a long "tail" as ranges or values increase. The highest RF range (>50 ppm P) appears to show a large increase. However, this can be misleading since it contains all values above 50 ppm. If the lower range increments (5 ppm P) were maintained through the absolute highest P value measured, we would observe a very long and gradually tapering "tail"...keep this in mind when reviewing the RF figures. Median soil test P values in the SCGP states ranged from 17 to 26 ppm Bray P-1 equivalent **(Table 1)**.

Median soil K levels in the region are relatively high (**Table 1**), with values ranging from 150 to 364 ppm K (ammonium acetate equivalent). More than 60% of soils in all states except Oklahoma test over 160 ppm K (level commonly considered high). Only 46% of samples tested over 160 ppm K in Oklahoma. This is all reflected in the soil K RF distribution shown in **Figure 3**. Depending on crop and conditions, response to P and K fertilizer in the higher soil test ranges is possible and has been demonstrated in recent and ongoing research within the SCGP (see Gordon, BC No. 2, 2005, p. 8-10).

Changes from 2001 Summary

This is the second PPI summary where detailed distributions and medians of soil test pH, P, and K have been evaluated. It is the first summary in the history of our efforts where an evaluation of changes across time in RF distribution is possible.

There was practically no change in median soil pH from 2001 to 2005 among states in the SCGP (**Table 1**). Most of the region is characterized by soils with relatively high buffer capacity.

Change in median levels of soil P in the region varied from 1 to -5 ppm (**Table 1**). Colorado, Kansas, Nebraska, and Oklahoma showed relatively small changes in median soil P level. New Mexico and Texas median P levels changed substantially, by -4 and -5 ppm P, respectively.

To further investigate soil P dynamics in the region from 2001 to the present, sum-

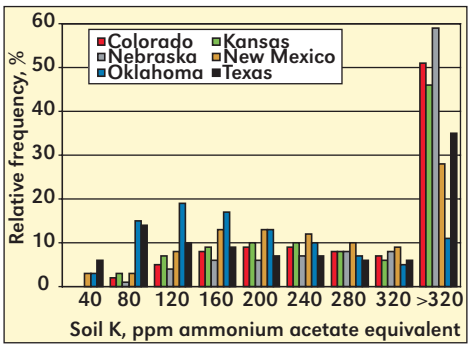


Figure 3. Relative frequency distribution of soil K level from the 2005 PPI soil test summary in the six states of the SCGP.

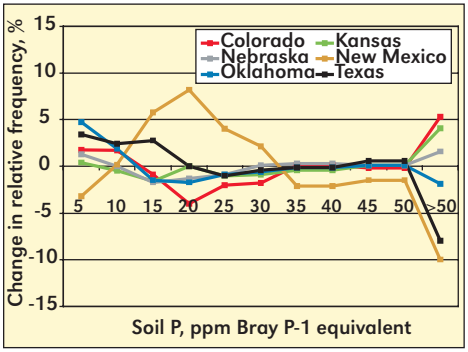


Figure 4. Difference in distribution of soil P level in the six states of the SCGP between the 2001 and 2005 PPI soil test summaries (i.e., 2005 minus 2001).

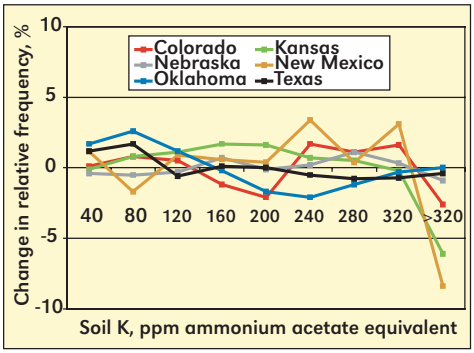


Figure 5. Difference in distribution of soil K level in the six states of the SCGP between the 2001 and 2005 PPI soil test summaries (i.e., 2005 minus 2001).

mary differences in RF within the ranges evaluated have been calculated (**Figure 4**). Notice that the general trend for New Mexico is fairly erratic. This is likely a reflection of the relatively low sample numbers from New Mexico in both summaries. Because of this, statements and conclusions concerning RF trends and differences in New Mexico will be avoided. The remaining five states showed increases in the RF in the lowest soil test P category (<5 ppm P) and decreases in RF around the critical level (20 to 25 ppm) from 2001 to 2005. This suggests that there has been some depletion of P in soils that were around the critical level with a resulting shift to lower levels. Texas had the largest increase in samples below 20 ppm P, which partially explains the large decrease in median P level from 2001 to the current summary. There was very little change in P levels from 30 to 50 ppm P among states between the two summaries. However, above 50 ppm P there was substantial difference among states with Colorado, Kansas, and Nebraska, showing increases in the RF of samples above 50 ppm and Texas and Oklahoma showing decreases. The increase in the highest range in the three states (CO, KS, and NE) is likely attributable to nutrient management planning requirements around confined animal feeding operations. But the reason for the large decrease in Texas is not clear.

Median soil K level decreased for each state except Nebraska (**Table 1**). This is reasonable since all states in the region have negative K budgets (i.e., more K removed than applied as fertilizer). An explanation for the lack of significant change in median K level in Nebraska is not immediately apparent since it is not consistent with the relatively large negative K budget for that state.

The change in RF distribution in soil K is shown in **Figure 5**. New Mexico will again be omitted from this discussion because of low sample numbers. There was very little change in RF distribution of K in Nebraska. The remainder of the states (CO, KS, OK, and TX) showed increases in the RF of samples below 160 ppm and corresponding decreases in those above. Much of the production area in the SCGP receives relatively little K fertilizer because of inherently high soil K levels. The change in RF distribution between summaries and the median value declines suggest that the luxury of naturally high K levels is being slowly eroded, and provides further evidence that the historic negative K budgets for the states in the region are not sustainable over the long-term. BC

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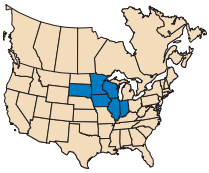
NORTHCENTRAL



Northcentral Soil Test Summary: Changes in Phosphorus and Potassium

By Scott Murrell

Shifts in median soil test levels for phosphorus (P) and potassium (K) in the Northcentral states from 2001 to 2005 were minor, even though most state nutrient budgets were negative.

Median soil test P and K levels and their changes from 2001 to 2005 are shown in **Table 1**. Across the region, little change occurred in soil test P. Median levels in 2005 were -4 to +3 parts per million (ppm) of what they were in 2001. Frequency distributions of soil test P trended downward in Indiana and upward in South Dakota. Median levels of soil test K tended to be higher in 2005 for the four eastern-most states in the region, but only the Illinois shift was significant.

To aid in the interpretation of changing soil test levels from 2001 to 2005, cumulative nutrient budgets were calculated from 2001 to 2004 for each state (**Table 2**). Yields of field crops, vegetable crops, and fruit and nut crops reported by the USDA National Agricultural Statistics Service were converted to nutrient removal rates, based on published sources. All crops were considered for each state. Manure additions reported by the USDA Natural Resources Conservation Service (Kellogg et al., 2000) were used for the 2001-2004 time period. Fertilizer use was that reported by the Association of American Plant Food Control Officials and The Fertilizer Institute (TFI). Budgets were calculated by subtracting nutrient additions from nutrient removal. Negative budgets therefore indicate that removal rates exceed those of nutrient additions. In addition, removal to use ratios were calculated.

Phosphorus budgets for the 2001-2004 time period were negative for all states, whether or not manure additions were considered (**Table 2**). The negative budgets were not correlated to changes in soil test P levels from 2001 to 2005 (**Table 3**).

Potassium budgets during the years 2001 to 2004 were negative for all states except Indiana and, when manure was considered, Illinois (**Table 2**).

Across the six states in the Northcentral Region, median soil test K levels generally went up when K budgets were positive or not as greatly negative (**Table 3** and **Figure 1**). Averaged across states in the Northcentral Region, the data in **Figure 1** show that balanced nutrient

Table 1. Comparing results from the 2001 and 2005 summaries: shifts in median soil test levels and statistical significance of the shift in soil test distributions.

State	Number of samples	Median P, ppm 2005	Median P, ppm Change	Median K, ppm 2005	Median K, ppm Change	Sign. of dist. change[1] P	Sign. of dist. change[1] K
IL	509,000	36	0	178	29	NS	0.08
IN	163,000	29	-4	144	16	0.25	NS
IA	356,000	25	0	172	20	NS	NS
MN	104,000	18	2	156	-2	NS	NS
SD	34,000	14	3	268	-10	0.11	NS
WI	131,000	39	-2	125	14	NS	NS

[1] Based on Chi Square analysis; NS = probability of years being the same >0.25.

Table 2. Cumulative nutrient budgets for 2001 to 2004.

State	Fertilizer – removal P_2O_5	Fertilizer – removal K_2O	Fertilizer + manure – removal P_2O_5	Fertilizer + manure – removal K_2O
	million lb			
IL	-1,831	-291	-1,523	101
IN	-664	370	-300	742
IA	-2,143	-1,785	-1,207	-625
MN	-1,302	-3,328	-522	-2,432
SD	-352	-2,577	-124	-2,289
WI	-1,059	-1,839	-543	-951

budgets tended to produce increases in state median soil test levels while negative budgets were needed to maintain them. However, both Wisconsin and Iowa showed numerical increases in median soil test K levels with negative K budgets. These findings, like those for P, indicate that negative budgets don't necessarily result in measurable decreases in median soil test K levels in the short term.

Soil test K levels, more than those for P, are sensitive to environmental conditions during sampling. How soil test levels change depends on many factors, some of the most important of which are soil mineralogy and wetting and drying cycles. For this reason, precipitation data from the National Oceanographic and Atmospheric Association were examined. During the fall sampling period (September through November) of 2000, moisture was near normal, with only two states, Indiana and South Dakota, being above normal. In the fall of 2004, Wisconsin and Iowa had near-normal precipitation, but all other states were above or much above normal, indicating that the fall in 2004 was generally

Table 3. Correlation between cumulative nutrient budgets and changes in median soil test levels, 2001 to 2004.

	P change	Sign.*	K change	Sign.*
Fertilizer - removal	-0.013	NS	0.737	0.10
(Fertilizer + manure) - removal	0.024	NS	0.845	0.03

*Probability that the correlation is due to chance alone; NS = probability >0.25.

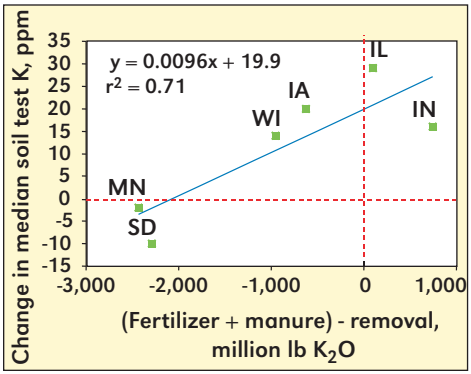


Figure 1. Relationship between cumulative K budgets and changes in median K levels from 2001 to 2004.

wetter than that in 2000. During the 2001 spring sampling season (March through May), Indiana and Illinois were drier than normal, but all other states in the Northcentral region were above and much above normal. During the same time period in 2005, Illinois, Indiana, and Wisconsin were much drier than normal, Iowa was near normal, and Minnesota and South Dakota were above normal. Thus, the spring of 2005 was generally drier than that of 2001 in the Northcentral region. How these precipitation differences affect soil test K is not well known, but it should be recognized that significant differences did exist in precipitation between the two soil test monitoring years.

In addition to weather-induced changes in soil test levels, crop roots can access non-soil test extractable forms of P and K in surface soils and subsoils that lead to short-term buffering of soil test levels. Shifts in sampling times, tillage systems, and cultural practices may also cloud the relationship between nutrient budgets and soil test level changes. BC

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Reference

Kellogg, R.L., C.H. Lander, D.C. Moffitt, and N. Gollehon. 2000. Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: Spatial and temporal trends for the United States. USDA-NRCS-ERS Publication No. nps00-0579.

NORTHERN GREAT PLAINS

Little Change in Soil Phosphorus and Potassium in the Northern Great Plains

By Adrian Johnston

Soil test phosphorus (P) and potassium (K) levels have shown little change in the provincial/state summaries prepared between 2001 and 2005 for the Northern Great Plains Region. Minor increases in soil test P were recorded, reflecting improved fertilizer P management on all lands and manure use in isolated areas. Soil test K levels have shown little change...with the exception of Manitoba where the growth of the potato industry on coarse textured soils has increased the number of fields that fall below the sufficient range.

Like people, soils need to be checked regularly to determine how they are doing as far as their nutrient status, and what we might need to do to improve their productivity. Well, 2005 marked the ninth summary of North American soil test levels by PPI/PPIC. Samples analyzed by public and private laboratories in the fall of 2004 and spring of 2005 were tabulated to assess the nutrient status of soils and any changes in nutrient levels.

In the Northern Great Plains Region there were very few changes in soil test levels to report from this summary. Sample numbers collected by province or state showed a general increase…with the exception of Saskatchewan, where the number of P and K samples considered decreased **(Table 1)**. The northern portions of the prairie provinces were affected by frost and delayed harvest in the fall of 2004, delaying soil sampling activities and reducing the numbers of samples submitted. A substantial increase in sample numbers was recorded in Manitoba, Montana, and North Dakota. In the case of Manitoba, we saw the inclusion of samples from a new laboratory in 2005 and a rapid expansion in the area seeded to potatoes, an intensively managed crop. In Montana, we had more labs submitting sample information in 2005 relative to 2001, and in North Dakota we had a large increase in sample numbers reflecting a much improved fall for sampling in 2004 than in 2000.

In evaluating soil test P in this sum-

Table 1. Soil test P frequencies (relative %) and median levels for 2001 and 2005.

Prov/State and year	Samples	Bray P-1 equivalent, ppm									Median P, ppm
		0-5	6-10	11-15	16-20	21-25	26-30	31-40	41-50	>50	
Alberta'01	37,437	4	17	21	18	12	11	7	3	8	17
Alberta'05	36,967	5	14	20	17	11	10	8	8	7	18
Saskatchewan'01	24,627	17	36	22	11	7	4	2	1	0.1	10
Saskatchewan'05	20,713	20	28	18	14	7	6	4	2	2	10
Manitoba'01	14,999	2	23	26	17	11	6	6	3	6	15
Manitoba'05	36,155	4	17	21	16	11	8	8	6	11	17
Montana'01	4,349	10	30	22	16	8	5	5	2	2	12
Montana'05	9,649	11	23	22	16	10	7	6	2	4	14
North Dakota'01	38,450	6	43	29	12	5	2	1	1	1	10
North Dakota'05	66,887	4	39	30	14	6	3	2	0	1	11

mary, we consider all samples with a Bray P-1 equivalence of 20 parts per million (ppm) or less to have potential to show a response to fertilizer P additions. In all states and provinces the soil test P levels of 20 ppm or less declined between the 2001 and 2005 summary reports, with the largest decline in Manitoba and the smallest decline in North Dakota **(Table 1)**. As a result of these changes, the median P concentration in the soil either stayed the same, or showed a minor increase. One interesting observation from these data is the increase in samples testing >50 ppm P in some provinces, while little or no change was observed in others. Soil testing to maintain compliance with provincial or state regulations where livestock manure is being used may be reflected in the large increase in high testing soils in provinces like Saskatchewan and Manitoba. While soil test P is currently not a requirement for evaluating soils with regard to manure application, it has been proposed in Manitoba. One major consistency from past soil test summaries was that the Northern Great Plains Region continues to have the lowest testing soils for P concentration in all of North America.

While our regional soils may be low in P, that is not the case for soil test K levels **(Table 2)**. Median K levels are high in all states and provinces of the region, with little change observed between the results in 2001 and 2005. The number of samples considered for soil test K increased in all areas between 2001 and 2005, with the exception of Saskatchewan. Sample numbers more than doubled in Manitoba and Montana, and increased by 75% in North Dakota. Using 160 ppm of ammonium acetate equivalent soil test K as a division between medium and sufficient soil K levels, we observed an increase in medium and lower testing soils in both Manitoba and Montana. The increase is likely a reflection of the increase in samples collected between the two surveys, generally a reflection of shifting cropping practices in an area. In the case of Manitoba, the large increase in soils testing less than 160 ppm K, and decrease in median soil test K levels, reflects the rapid expansion of the potato industry in that province. Most of these potatoes

Table 2. Soil test K frequencies (relative %) and median levels for 2001 and 2005.

Prov/State and year	Samples	Ammonium acetate equivalent K, ppm 0-40	41-80	81-120	121-160	161-200	201-240	241-280	281-320	>320	Median K, ppm
Alberta'01	28,858	1	4	12	17	17	14	16	12	9	201
Alberta'05	39,091	1	6	14	15	14	12	14	8	17	201
Saskatchewan'01	24,029	0	2	4	9	14	16	21	20	14	251
Saskatchewan'05	21,517	0	2	6	10	12	11	20	7	30	254
Manitoba'01	12,624	1	3	6	10	9	11	11	10	41	282
Manitoba'05	26,824	1	8	12	13	13	11	11	7	23	207
Montana'01	4,128	0	0	1	8	13	14	15	14	35	276
Montana'05	9,177	0	1	6	13	12	12	13	12	31	259
North Dakota'01	36,698	0	0	4	10	10	13	15	14	34	274
North Dakota'05	65,173	0	1	4	8	13	14	15	14	30	265

are being grown on coarse textured soils, fields which have been brought into production after growing forages, and are typically low in soil test K. The results from Manitoba, when considered by soil test K category, show a general shift in the distribution of data to lower available soil K levels.

The soil test summary also considered soil pH. Very little change was observed in the soil pH values between 2001 and 2005, with the 2005 medians for Alberta at 6.9, Manitoba at 7.8, Montana at 7.9, and North Dakota and Saskatchewan at 7.6. The lower pH in Alberta is commonly due to the increased number of soils in the 5.6 to 6.5 range, common for soils in the forested regions of the province.

The minor improvements in soil test P…and lack of change in soil K…indicate that we are doing fairly well in holding our own with regard to the fertility of soils in the Northern Great Plains. Soil test P levels are low, and continued improvements with managing fertilizer and manure P inputs to balance crop removal will be critical to prevent a decline in soil nutrient status. These overview pictures for each province or state provide us with some insight into how soil fertility status is changing over time. At the individual field level, each grower can make the same assessment by evaluating soil test results collected over a similar time frame. In both instances, we receive the necessary insight for making nutrient management decisions that will help us with profitable crop production decisions. BC

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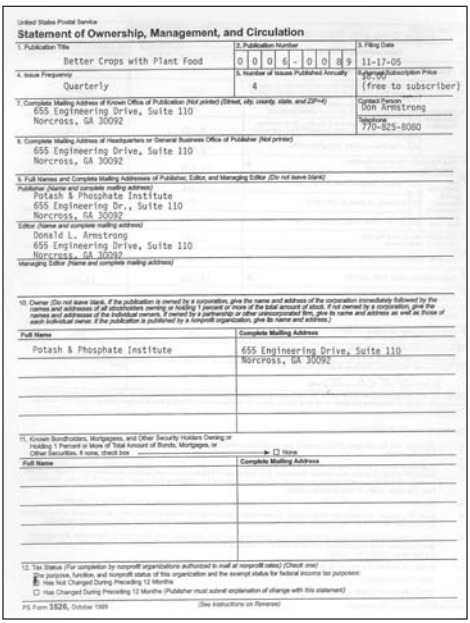

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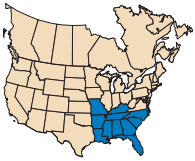

Phosphorus and Potassium Budgets and Soil Test Levels in the Mississippi-Atchafalaya River Basin

By Cliff Snyder

The Mississippi-Atchafalaya River Basin (MARB) includes 41% of the contiguous United States (U.S.), 55% of U.S. agricultural land, and 27% of the U.S. population. It encompasses about 80% of the U.S. corn and soybean acreage, and much of the cotton, rice, sorghum, wheat, and forage acreage. Thus, it is easy to understand the importance of the MARB to the fertilizer industry, the animal industry, and to environmental authorities with interest in non-point source pollution.

The public perception is that excessive loss of nitrogen (N) from farm fields...principally in the upper Midwestern states...and delivery to the Gulf of Mexico causes hypoxia (low dissolved oxygen levels, <2 mg/L). Discharge of soluble phosphorus (P) has been recently considered as another possible contributor to excessive algal/phytoplankton growth, which leads to the abundant deposition of organic matter in the shallow Gulf waters and the subsequent depletion of oxygen in the water column as bacteria decompose the organic matter.

The current scientific thought is that N concentrations in the Mississippi and Atchafalaya rivers and the shallow Gulf are large enough that even a 70% reduction will not affect the development of hypoxia. There is a growing hypothesis that any increase in P (dissolved inorganic P or phosphate) discharge, and especially a narrowing of the dissolved inorganic N to dissolved inorganic P (DIN:DIP) ratio, will stimulate a worsening of the hypoxia condition.

There is also a perception that farmers are using excessive amounts of fertilizer P. The U.S. Geological Survey (USGS) has reported that nutrient use and discharge from the 20 major MARB states has the dominant influence on the load of nutrients delivered from the MARB to the Gulf, because these states include the majority of the agricultural land in the MARB (Goolsby et al., 1999). An evaluation of the recent balance of P inputs as fertilizer and manure and the removal of P in harvested crops in the 20 major states shows that overall, the crop harvest removal of P exceeds fertilizer plus recoverable manure P inputs (from *Plant Nutrient Use in North American Agriculture*, PPI/PPIC/FAR Technical Bulletin 2002-1, Appendix Table 4.1). The crop harvest removal of P exceeds fertilizer plus recoverable P inputs in 11 of the 20 major MARB states.

Mississippi-Atchafalaya River Drainage Basin.

The results of the 2005 PPI soil test summary also indicate that 40% of these 20 major states have experienced a decline in soil test P (based on median values) since 2001 (**Table 1**). The average decline in the median soil test P levels exceeds the average increase in soil test P since the 2001 PPI soil test summary.

Table 1. Median changes in soil test P in the 20 major Mississippi-Atchafalaya River Basin states.

State	Median soil test P, 2001	Median soil test P, 2005	Change since 2001
	---------- ppm-	----------	
AR	21	17	-4
CO	25	26	1
IL	36	36	0
IN	33	29	-4
IA	25	25	0
KS	20	21	1
KY	21	18	-3
LA	16	15	-1
MN	16	18	2
MS	32	27	-5
MO	17	18	1
MT	12	14	2
NE	21	22	1
OH	23	25	2
OK	20	19	-1
SD	11	14	3
TN	15	21	6
WV	-	52	-
WI	41	39	-2
WY	19	15	-4
% of states with lower median P levels		40	
Average decrease in states with decreased median P level, ppm		3	
% of states with same median P levels		10	
% of states with higher median P level		45	
Average increase in states with increased median P level, ppm		2.1	

Table 2. Median changes in soil test K in the 20 major Mississippi-Atchafalaya River Basin states.

State	Median soil test K, 2001	Median soil test K, 2005	Change since 2001
	---------- ppm-	----------	
AR	156	120	-36
CO	348	328	-20
IL	149	178	29
IN	128	144	16
IA	152	172	20
KS	332	294	-38
KY	135	128	-7
LA	114	110	-4
MN	158	156	-2
MS	158	132	-26
MO	147	150	3
MT	276	259	-17
NE	362	364	2
OH	150	168	18
OK	164	150	-14
SD	278	268	-10
TN	99	100	1
WV	-	92	-
WI	111	125	14
WY	188	145	-43
% of states with lower median K levels		55	
Average decrease in states with decreased median K level, ppm		19.7	
% of states with same median K levels		0	
% of states with higher median K level		40	
Average increase in states with increased median K level, ppm		12.9	

The potassium (K) budget in the 20 major MARB states and the 2005 soil test summary results both show that significantly less K is being applied than is being removed in crop harvests (**Table 2**). The median soil test K levels in 50% of the 20 major MARB states has declined since the 2001 PPI soil test summary. Just as was observed with soil test P, the rate of decline in the median soil test K levels exceeds the rate of soil test increase among these states.

Contrary to popular belief, there are more soil samples with soil P testing in the agronomically responsive range than in the non-responsive range (**Figures 1a** and **1 b**). More than 78% of the soil samples tested below 50 parts per million (ppm) in Bray 1 equivalent-extractable P and 94% tested 100 ppm or below. Clearly, elevated soil test P is a relatively minor issue in most of these MARB states.

The frequency distribution of soil test K levels for the 20 major MARB states also

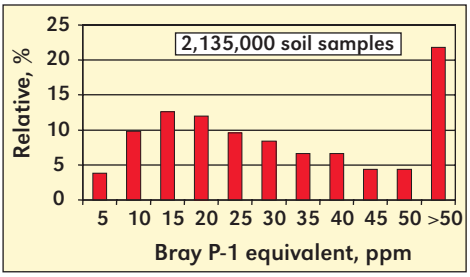

Figure 1a. Soil test P frequency distribution for the 20 major MARB states in 2005.

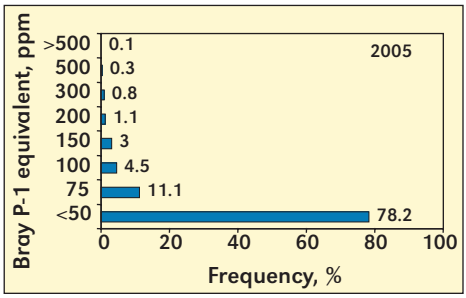

Figure 1b. Soil test P frequency distribution for the 20 major MARB states in 2005.

reflects the K balance, and it shows the strong need for continued and increased K fertilization (**Figure 2**). The bulk of the soil samples test below 200 ppm, levels at which an agronomic response to K may be expected by corn and soybeans in Iowa (Mallarino et al., 2003).

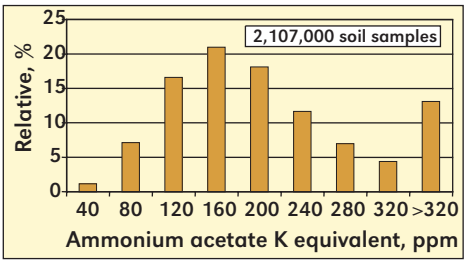

Figure 2. Soil test K frequency distribution for the 20 major MARB states in 2005.

Summary

These data for fertilizer and recoverable manure use, nutrient balance estimates, and soil test P and K results in the 20 major MARB states indicate:

- there is a strong need for P and K fertilization to sustain soil productivity;
- almost 80% of the sampled soils have extractable P in the agronomic range;
- few soil test P levels have been raised to levels that would appear to present a direct threat to water quality;
- P and K removal from farm fields in crop harvests is out-stripping fertilizer plus recoverable manure in 40 to 50% of the 20 major MARB states;
- farmers, crop advisers, and fertilizer dealers should pay close attention to individual field and farm nutrient budgets to ensure that P and K are not limiting N use efficiency and farm profitability;
- continued soil testing, evaluation of trends, and estimates of nutrient balance can contribute to a better understanding of agronomic opportunities and potential environmental challenges. BC

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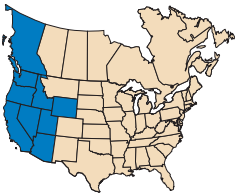
WEST REGION



A Check-Up on Nutrients in the West

By Rob Mikkelsen

Many soils in the West Region continue to test medium or low in phosphorus (P) and potassium (K). A notable exception is the jump in P concentrations in the Pacific Northwest, likely due to the greater analysis of waste-application fields. Balance between K imports and exports remains negative for all the western states. Monitoring soil nutrient concentrations is essential for making the most of applied fertilizers and manures.

Maintaining soil fertility depends on managing complex biological, chemical, and physical properties of the soil. Some of these properties are difficult to alter or change, but maintaining adequate plant nutrition is somewhat easier. The value of adding essential plant nutrients has been known for thousands of years, but the science of soil fertility and modern fertilizer has been developed mostly during the last century. A primary mission of PPI continues to be providing the best information available to get the most value from plant nutrients.

With ready access to modern soil testing, constantly improving crop nutrient recommendations, and the ability to carefully blend the required fertilizers, there is no longer any reason for having crop nutrition limit yields or harvest quality. But the results of the most recent summary of soil test information from the West indicate that there is still room for improvement and there are a significant number of growers who continue to underfertilize their crops. Although these latest results provide only an average look at soil test conditions, there are a number of emerging trends that are noteworthy.

Potassium Status of Western Soils

It is frequently assumed that there is less need for K fertilization in western soils due to their mineralogy and younger geologic age, compared with soils in other parts of North America. However, recent estimates of the balance between K fertilization and crop K removal show that many areas are drawing down the K reserve in the soil. Decades of harvesting high yields continue to deplete native soil fertility unless the nutrient supply is eventually replenished. While this nutrient drawdown may be acceptable for a time in soils that have a high nutrient status, such negative nutrient budgets are not sustainable over the long term.

One surprising result of this survey is the relatively high number of California soils that are now low in K. Almost half of the soils tested medium or lower in 2005. This finding requires a closer look at current fertilization trends and supports the conclusions drawn from state-wide nutrient balances. For example, it was recently reported that California crops remove over twice as much K as added back to the soil in fertilizer and animal wastes. All other western states also have a similarly negative K budget, where more is removed in crops than is replenished in the soil… clearly not a trend that can be maintained over the long-term.

Soil K concentrations generally remained steady or declined between 1997

and 2001. The 2005 survey shows similar trends in overall soil K status in the West. Special attention should be given to particular regional differences, such as the high-K fixing soils and their need for careful management to meet the unusual K requirement in these areas. **Figure 1** shows percentage of samples testing <120 parts per million (ppm) ammonium acetate extractable K or >160 ppm in the western states and in North America.

The primary potash source used in the West Region is potassium chloride (KCl), but a number of other excellent materials are also available and commonly used. Generally, KCl is the least expensive K source and also supplies Cl, which is regularly shown to boost yield and quality of several important crops in the region. Other excellent K sources include potassium magnesium sulfate ($K_2SO_4 \bullet 2MgSO_4$) potassium sulfate (K_2SO_4), and a variety of other materials well suited to more specialized applications. Potassium contained in organic wastes and crop residues is rapidly released and returned to the soil, but the harvested portion of the crop accounts for nutrients exported from the farm. For example, alfalfa removes over 60 lb K_2O/A in each ton of hay. Declining soil test K values are frequently observed after multiple years of hay production without replacing the harvested nutrients.

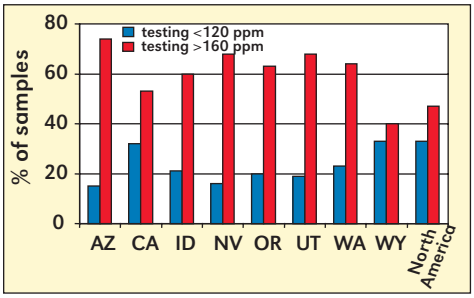


Figure 1. The percentage of soil samples testing <120 ppm ammonium acetate extractable K or >160 ppm K in the West region and the percentage in North America.

Phosphorus Status of Western Soils

The soil P concentrations for most of the West Region remained relatively unchanged… with the exception of the Pacific Northwest states…where apparent P concentrations are higher than in previous surveys. This survey, similar to those conducted previously, indicates that there are many soils that need additional P for crops to meet their growth potential.

The number of samples in the very high category…>50 ppm P…increased in every state compared with the 2001 survey. This increase likely represents a greater number of samples taken from fields receiving regular applications of organic wastes. Much of this sampling is legally required for waste management plans and these soil samples cannot be separated in the survey from the more traditional samples receiving fertilizer. Since there is seldom an agronomic justification for increasing P concentrations to these high levels, it is very unlikely that a farmer would squander resources to apply unnecessary fertilizer where no crop response is expected. A regular program of soil testing is needed to track the depletion or accumulation of nutrients in a cropping system to avoid such high soil P concentrations. **Figure 2** shows percentage of samples testing <30 ppm Bray P equivalent or >50 ppm in the western states and in North America.

Where organic materials are applied to meet the nitrogen (N) requirement of a growing crop, it is common that 3 to 10 times more P is simultaneously added than the crop will take up and remove in the harvested portion. This nutrient imbalance between N and P in organic wastes requires careful management to prevent excessive concentrations of nutrients and potentially undesirable consequences. Manures should be applied only to fields that can benefit from the additional nutrients, and not to fields that are already very high in nutrients or with a high loss potential.

Although high P soils may get more attention because of potential environmental concerns, a large number of fields remain low in P. In several western states, from 40% to over 60% of all fields sampled

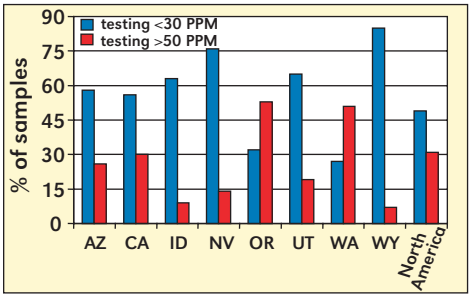


Figure 2. The percentage of soil samples testing <30 ppm Bray P equivalent or >50 ppm Bray P equivalent in the West region and the percentage in North America.

continue to remain low or medium in soil P concentrations. Crops grown in these soils will generally respond to fertilization with higher yields and plant health compared with crops growing in fields with nutrient-deficient conditions. Given the high yield potential and profitability of most crops grown in the West, it surprising that so many growers continue to allow a lack of adequate plant nutrition to drag down profitability.

Overall, the results from this most recent soil testing survey correspond well with a study released from the University of California showing that soil quality has generally improved over the past 50 to 60 years of intensive management and cropping. Does that mean that the status quo is fine? No, continued efforts must be made to continue to protect and improve our soils that are vital for food and fiber production for the world's population.

We know that soils cannot be continually cropped and nutrients removed without depleting their native fertility and quality. Efforts to maintain high yields and soil quality are essential for long-term sustainability. Careful management and utilization of modern technology accomplish this. The technology available in 2005 is beyond the wildest dreams of the farmers not too many years ago. Let's continue the progress that has been made to improve the soil nutrient status of soil through regular testing and monitoring. Replacement of essential nutrients when needed is a key factor in profitable and sustainable farming. A healthy and fertile soil is in everyone's best interest. BC

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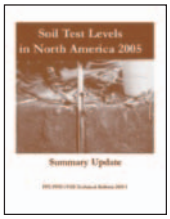
Soil Test Levels in North America, 2005



A new publication from PPI/PPIC summarizes soil test levels for phosphorus (P), potassium (K), and pH…plus magnesium (Mg) and sulfur (S)…in North America. The summary was prepared with the cooperation of numerous public and private soil testing laboratories.

The 45-page publication—titled *Soil Test Levels in North America, 2005*—offers a snapshot view of soil test levels in the U.S. and Canada in 2005, but also provides a comparison to the previous summary which was completed in 2001.

The 8 l/2 x 11-in. coil-bound booklet is available for purchase at US$25.00 each. An optional CD-ROM is available for US$10.00 each. It contains a PDF file showing the pages of the report, a PowerPoint file of all figures (graphs) in the report, and an Excel workbook of the major tables to facilitate construction of custom graphs for regions of interest. The combination package of the printed publication plus the CD-ROM is available for US$30.00. Shipping cost is additional.

An order form is available as a PDF file at the website: >**www.ppi-ppic.org**<. Or contact Circulation Department, PPI, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone: 770-825-8082. Fax: 770-448-0439.

Changes in PPI/PPIC Staff Responsibilities

Incoming PPI President Dr. Terry Roberts has announced new responsibilities and titles for some staff members of the Institute, effective January 2006.

Dr. Paul Fixen of Brookings, South Dakota**,** now has oversight responsibilities for Latin America Programs, in addition to North America. His new title will be Senior Vice President, Americas Program Coordinator, and Director of Research. The Latin America Program includes offices in Brazil, Ecuador, and Argentina.

Dr. Adrian Johnston of Saskatoon, Saskatchewan, is Northern Great Plains Region Director and President of the Potash & Phosphate Institute of Canada (PPIC). He will continue in those roles, with the added title of Asia Program Coordinator, having oversight duties for Institute programs in China, India, and Southeast Asia.

Steven J. Couch of Norcross, Georgia, is now Director, Information Technology and Member Programs/Conferences. He has served as Manager of Information Technology at PPI for several years and will now have added responsibilities related to meetings and other assignments. BC

Rob Mikkelsen Honored as Fellow of ASA

Dr. Robert L. Mikkelsen, PPI West Region Director, was recognized as a Fellow of the American Society of Agronomy (ASA) at the recent annual meetings in Salt Lake City. Fellow is the highest honor bestowed by the Society, and only 0.3% of the Active and Emeritus members may be elected to Fellowship.

Dr. Mikkelsen joined the staff of PPI in 2002 and is based at Davis, California. Previously, he was on the faculty of the Soil Science Department of North Carolina State University (NCSU), where he was very active in graduate education. He received the College Excellence in Teaching Award. His research at NCSU focused on managing fertilizers and manures in cropping systems to maximize nutrient efficiency and productivity.

After earning his B.S. degree at Brigham Young University in Utah, Dr. Mikkelsen went on to complete his Ph.D. at the University of California-Riverside in 1985. He later worked as a Research Scientist with the National Fertilizer Development Center of the Tennessee Valley Authority. Dr. Mikkelsen was responsible for nutrient management issues involving fertilizers and irrigation and received a patent for new fertilizer innovations.

Dr. Mikkelsen has been active in many national professional societies and served on editorial boards of numerous international journals. He was Associate Editor for *Agronomy Journal* and the *Journal of Environmental Quality*, and currently serves as Associate Editor of the *Soil Science Society of America Journal*. BC

NORTH AMERICA

A Western Evaluation of Soil Testing Laboratory Performance

By Robert O. Miller

Researchers have reported on the variability in soil testing lab results by submitting a split sample to several different labs. Some of this variation can be explained by the use of different extraction procedures, but some is apparently due to lab error. Proficiency testing and performance verification are becoming increasingly important because of heightened nutrient management accountability, government programs, and environmental litigation.

With expanding utilization of nutrient management plans (NMPs) there is an increasing emphasis on soil sampling and testing. Variation in soil testing laboratory results have been documented through the submission of duplicate, blended samples to laboratories in the west (Davis et al., 1999; Lorbeer et al., 1999; Koenig, 2003). Although in specific instances this variation can be attributed to differences in extraction methodologies, variation among labs using identical procedures does exist (Miller and Kotuby-Amacher, 1997).

In 1998, as a membership activity of the Soil Science Society of America (SSSA), the North American Proficiency Testing (NAPT) Program was developed as a tool to assist soil testing laboratories across North America with the quality of their analysis. Guidelines for the NAPT program were developed by groups familiar with standardizing methods for soil and plant analysis and developing recommendations within the U.S. and Canada including: Regional Soil and Plant Analysis Workgroups; state/provincial Departments of Agriculture; the Soil and Plant Analysis Council, SSSA; the Canadian Society of Soil Science; and private and public soil and plant analysis laboratories. Participation in the program is voluntary. Annually, NAPT participating labs receive soil, plant, and water samples on a quarterly basis, and they subsequently provide a report on their soil testing proficiency. The NAPT program provides an opportunity for laboratories to under-go self improvement and make modifications to correct analysis problems. The NAPT Program offers to work with labs to resolve any problems and also offers workshops to improve the quality and precision of testing lab results.

The voluntary nature of the NAPT Program means that not all labs participate. In addition, submitted samples are analyzed by the labs as single-blind samples, in that the participating lab knows the samples are for proficiency testing and only the soil test value is unknown. Although many labs participate, not all provide results, and of the labs that do provide results, some have analysis values falling outside acceptable ranges.

Proficiency testing and performance assessment of soil testing labs is becoming even more important.

In Utah, it was reported that paired soil samples submitted by livestock producers to two laboratories gave contrasting results (Koenig, 2003). A survey of consultants and labs in the western region indicated that some form of laboratory certification program was needed for NMPs. In July of 2003, representatives of the USDA Natural Resources Conservation Service (NRCS) from the western U.S. and the NAPT Oversight Committee reviewed issues involving lab quality. It was agreed that a double-blind evaluation of the labs using standard reference soils would be the most cost effective means of assessing the performance of soil testing laboratories. Double-blind in this instance means soils of known values would be submitted by surrogate clients, such that the lab would not know the analytical value or the real source of the soils being tested. This program, the NAPT Performance Assessment Program (PAP), was endorsed by the NRCS in 2004. It was implemented as a pilot program for labs in the western U.S. which provide soil testing for NRCS-approved NMPs.

Participating labs in the 2004 PAP pilot were required to: 1) enroll in the NAPT program; 2) provide quarterly analysis of pH_{water}, electrical conductivity (EC), nitrate-nitrogen (NO_3-N), phosphorus (P), potassium (K), and soil organic matter (SOM) results; 3) provide soil method information on all client reports; 4) agree to a double-blind evaluation of their analytical performance; and 5) agree to a code of ethics. The program was based on seven soil analyses:

- pH, saturated paste or 1:1 (soil:water ratio)
- EC, saturated paste or 1:1 (soil:water ratio)
- NO_3-N, cadmium (Cd) reduction, ISE or CTA
- Ammonium (NH_4-N), all methods
- Phosphate (PO_4-P), Olsen (1:20) colorimetric
- K, ammonium acetate or Olsen extractable
- Organic matter, Walkely Black or Loss on Ignition (LOI)

Five soil samples were selected from the NAPT 2003 and 2004 program archives for use in the PAP (**Table 1**). One soil was duplicated in the program to evaluate laboratory reproducibility on double-blind samples. Soils were prepared and aggregated to resemble "real world" lab samples. Surrogate lab clients were contacted and engaged in shipping and submitting samples to the participating lab.

Twenty-one labs enrolled in the 2004 pilot PAP program from the states of Washington, Oregon, California, Idaho, Utah, Montana, Wyoming, Colorado, North Dakota, Nebraska, Kansas, and Tennessee. Results were obtained from 20 labs. A review of the reports provided indicated that only two of the participating labs had provided method information, and in specific cases the unit information was not provided. Laboratory analytical performance was evaluated based on the median and median absolute deviation (MAD) of the double-blind database, using 90% (2.5xMAD) confidence interval for the 20 labs providing data.

A comparison of NAPT and PAP median and MAD values and those of the 20 PAP labs is shown in **Table 2** for soil 2003-120. A majority of the analyses in PAP had MAD values significantly higher than those observed in the NAPT program. This was potentially associated with additional variability introduced as a result of additional sample handling within the participating lab (drying and grinding). However, as the increased MAD values were strongly

Table 1. Chemical properties of soils utilized in the 2004 NAPT-PAP Program.

Soil	pH, 1:1 H_2O	NO_3-N, Cd red	P, Olsen	K (Am. acetate)	SOM (LOI)
		mg/kg[1]	mg/kg	mg/kg	%
2003-108	5.50	189	69	294	3.30
2003-119	6.43	7.3	45	122	1.20
2003-120	6.00	42.5	30	1,130	2.25
2004-102	8.52	45.0	115	482	1.89
2004-104	7.90	61.0	166	435	3.20

[1]mg/kg is equivalent to parts per million (ppm)

Table 2. A comparison of NAPT and PAP median and MAD values for soil 2003-120.

Soil 2003-120 Platner	NAPT statistics		PAP statistics	
	Median	MAD	Median	MAD
pH, 1:1 H_2O	6.10	0.10	6.20	0.20
EC, 1:1 H_2O, dS/m	0.44	0.10	1.1	0.51
NO_3-N, mg/kg	42	5	51	8
NH_4-N, mg/kg	1	1	7	3
P - Olsen, mg/kg	30	3.0	38.3	3.4
K -Am. acetate, mg/kg	1,100	94	992	175
SOM, %	1.68	0.20	2.00	0.20

associated with P and K analyses, lab analytical bias was likely a factor.

Performance of individual labs was based on a weighting of individual analyses (pH 5%; EC, 5%; NO_3-N, 30%; PO_4-P, 40%; K, 10%; and SOM, 5%) to determine the total proficiency score. Successful labs were those that met an overall proficiency score of 80%. This proficiency value was selected based on standard scores utilized in the Iowa and Minnesota soil lab registration programs.

A comparison of results for NAPT soil ID 2003-120 is listed in **Table 3**. Overall, 11 of 12 labs provided pH (1:1 H_2O) results within 0.25 units (2.5 x MAD) of the median. Labs #7, #8, #12, #14, #15, #16, and #17 provided pH by the saturated paste method. For NO_3-N, 5 of 18 reporting labs were flagged as exceeding the 90% confidence interval.

For Olsen P, 6 of the 17 reporting labs had results exceeding the 90% confidence interval of 38.0 ± 8.7 mg/kg. It is important to note that the majority of soil samples used in these evaluations had

Table 3. Results for soil 2003-120 from the PAP program.

2003-120 Platner	PAP values		Lab number									
	Median	MAD	1	2	3	4	5	6	7	8	9	10
pH, 1:1 H_2O	6.20	0.16	6.61*	6.00	6.40	6.10	5.80	6.20		6.10		6.40
EC, 1:1 H_2O, dS/m	1.1	0.41	0.2	1.2	1.8*		1.1			0.9		
NO_3-N, mg/kg	51	8.5	35	41	29*		48	167 *	51	59	51	51
NH_4-N, mg/kg	7	3	11	4								
P - Olsen, mg/kg	38	3.5	26*	35	23*	32	74*		41		34	39
K -Am. acetate, mg/kg	992	175	825	990	670		1,260	1,343	1,020	1,280	1,175	930
SOM, %	2.00	0.20	3.50*	1.80	1.62		2.3	2.00	1.58	2.00	1.60	2.10
	Median	MAD	11	12	13	14	15	16	17	18	19	20
pH, 1:1 H_2O	6.20	0.16	6.50							6.00	6.00	6.4
EC, 1:1 H_2O, dS/m	1.1	0.41	0.4	68					1.2	0.6		1.9
NO_3-N, mg/kg	51	8.5	210*		43	68	185*	49	64	44	61	29*
NH_4-N, mg/kg	7	3	10						7	4		
P - Olsen, mg/kg	38	3.5	43	200*	38	200 *	37	14.6 *	39	38		46
K -Am. acetate, mg/kg	992	175	971	332*	1,249	332*	400*	907	860	994	1,040	
SOM, %	2.00	0.20	2.20	3.10*	2.10	3.1*		1.80	1.93	1.80	2.00	1.95

* Lab values exceeding warning limit (2.5 x MAD) of PAP median.

Table 4. Comparison of PAP median and MAD duplicate soil submissions.

Analyses	2003-108 Thorndike - 1 Median	2003-108 Thorndike - 1 MAD	2003-108 Thorndike - 2 Median	2003-108 Thorndike - 2 MAD
pH, 1:1 H_2O	5.80	0.15	5.60	0.10
EC 1:1 H_2O, dS/m	3.13	1.86	2.22	1.24
NO_3-N, mg/kg	203	36	216	27
NH_4-N, mg/kg	32	7	37	15
P – Olsen, mg/kg	71	12	69	11
K –Am. acetate, mg/kg	266	22	274	26
SOM, %	2.46	0.50	2.36	0.44

Olsen extractable PO_4-P and NO_3-N levels above what is considered the normal agronomic range (see **Table 1**) which has traditionally been the range of greatest interest to users of soil testing. However, today the range of interest extends to much higher levels and failing to adjust calibration protocols can introduce additional error. For ammonium acetate K, 3 of the 19 reporting labs exceeded the 90% confidence interval of 992 ± 437 mg/kg.

Results of the PAP duplicate soil, NAPT 2003-108 Thorndike, generally indicated good reproducibility for the median values for all soil analysis methods (**Table 4**). The exception was soil pH (1:1 H_2O) which showed a 0.20 unit shift in the median values and soil EC (1:1) which showed a 0.91 dS/m shift. Since these samples were prepared and randomly selected, we can only conclude that this error is either linked to within-lab handling problems or method variability.

Based on an evaluation of laboratory performance using median and MAD values of the 20 participating labs and the method-weighting factors listed, the preliminary results of the PAP program indicate an overall median proficiency score for the 20 labs of 91%, with 5 labs failing to achieve a proficiency score of 80%. Those labs (5 of 20) not meeting the 80% proficiency score are being retested in 2005. Those which meet the PAP performance standards have been listed on the program website as soil analysis labs approved for NRCS-NMP. Visit the website at: >www.NAPT-PAP.org<.

Overall, the PAP program has identified that the majority of testing labs doing business in the western U.S. are capable of providing soil test results within 25% of the actual value. There are a few labs that currently are not meeting that standard. Since the PAP program assessed performance using known standards and defined methods, these variations can only be attributed to individual lab bias. BC

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Acknowledgment

The author expresses special thanks to soil testing labs which funded this pilot project and representation of the NRCS for assistance in development.

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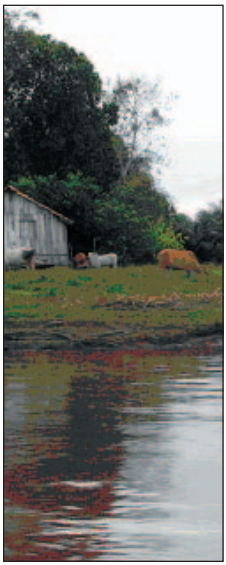
International Section

BRAZIL

Available Phosphorus and Potassium Status of Soils of Amazonas State

By Adônis Moreira and José Ricardo Pupo Gonçalves



Amazonas State in Brazil does not have significant fertilizer consumption at present, but the area has great potential for production of oil palm and other crops. Researchers recently compiled results from over 3,000 soil samples taken during the last 30 years. They identified large areas of phosphorus (P) and potassium (K) deficiency in soils.

Subsistence agriculture producing cassava, beans, rice, and bananas currently prevails in Amazonas State. The climate and other conditions are favorable for industrial crops such as palm oil, rubber, tropical fruits, and possibly even beef cattle. Agroforestry systems with a crop mix of cacao and rubber or Brazil nut and cacao are being considered.

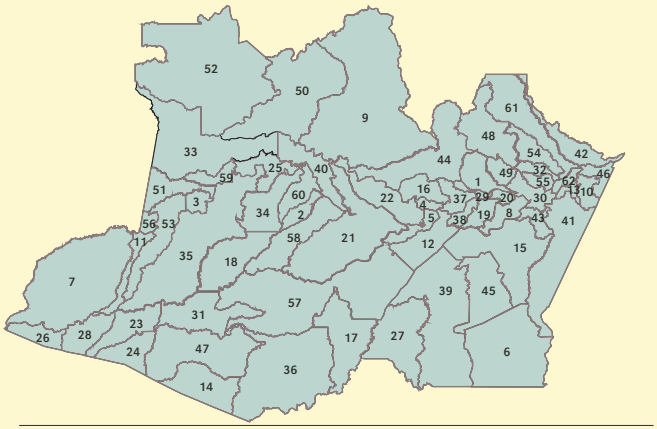
However, the region has serious limitations with regard to soil fertility. Even where river access to transportation and commercial trade is readily available, fertilizer use is still in its infancy. The slow development can be attributed to lack of affordable crop inputs as well as to inconsistent support for programs designed to promote efficient use of fertilizers and soil amendments. The current low literacy level and difficulty in financing agricultural production are other drawbacks.

About 75% of soils in the tropical Amazon region are either Oxisols or Ultisols. Both soil types are found in the uplands, "Terra Firme", and the floodplains, "Várzea", which comprise the two principle landscapes. The upland topography undulates moderately, having flat and dissected areas, small hills, and narrow valleys located beyond reach of river floods. Soils are acidic and aluminum (Al) toxicity occurs in about 80% of the region. The floodplains encompass 60,000 km^2 and have variable fertility and soil composition due to inconsistent deposition of sediments with varied mineralogical origin, organic composition, and particle size distribution, derived from the Andes Mountains and river bank erosion.

Despite this diversity, soils are predominantly dystrophic, with exchangeable calcium (Ca) and magnesium (Mg) lower than 1.5 cmol$_c$/dm^3 (Moreira and Malavolta, 2002).

Overview of the Amazonas area in Brazil.

Malavolta (1987) and Lehmann et al. (2001) estimate 90% of soils in the Amazonian area have poor fertility. Soil testing commonly finds K, Ca, Mg, and available P to be below critical levels. Available soil P and K are primary yield-limiting factors as judged by the frequency of Mehlich 1 samples testing less than 5 mg/dm^3 for available P and 0.1 cmol$_c$/dm^3 for available K. This is clearly limiting agricultural activity in the central Amazon. Most soils have higher than 50% Al saturation and lower than 50% base saturation. These conditions present a large obstacle for healthy root growth and plant development (Demattê, 1988).



1 - Manaus
2 - Alvarães
3 - Amaturá
4 - Anamã
5 - Anori
6 - Apuí
7 - Atalaia do Norte
8 - Autazes
9 - Barcelos
10 - Barreirinha
11 - Benjamin Constant
12 - Beruri
13 - Boa Vista dos Ramos
14 - Boca do Acre
15 - Borba
16 - Caapiranga
17 - Canutama
18 - Carauari
19 - Castanho
20 - Careiro da Várzea
21 - Coari
22 - Codajás
23 - Eirunepé
24 - Envira
25 - Fonte Boa
26 - Guajará
27 - Humaitá
28 - Ipixuna
29 - Iranduba
30 - Itacoatiara
31 - Itamarati
32 - Itapiranga
33 - Japurá
34 - Juruá
35 - Jutaí
36 - Lábrea
37 - Manacapuru
38 - Manaquiri
39 - Manicoré
40 - Maraã
41 - Maués
42 - Nhamundá
43 - Nova Olinda do Norte
44 - Novo Airão
45 - Novo Aripuanã
46 - Parintins
47 - Pauini
48 - Presidente Figueiredo
49 - Rio Preto da Eva
50 - Santa Isabel do Rio Negro
51 - Santo Antônio do Içá
52 - São Gabriel da Cachoeira
53 - São Paulo de Olivença
54 - São Sebastião di Uatumã
55 - Silves
56 - Tabatinga
57 - Tapauá
58 - Tefé
59 - Tonantins
60 - Uarini
61 - Urucará
62 - Urucurituba

Figure 1. Counties in Amazonas State of Brazil.

With the objective of presenting more substantial data, results from 3,340 soil samples collected during the past 30 years were compiled by the Laboratory of Soil Fertility of the Brazilian Agricultural Research Enterprise (Embrapa Western Amazon—Manaus). Samples were collected from all 62 counties of Amazonas…the largest state in Brazil…with approximately 1.5 million km^2, representing 30% of the Brazilian Amazon area (**Figure 1**). In the absence of geographical coordinates, it was assumed that sample points were uniformly scattered over each county. Soil fertility data were assembled as three intervals of percent frequency with 0 to 40%, 40 to 80%, and 80 to 100% of occurrences below 5 mg/dm^3 for available P, and 0.1 cmol$_c$/dm^3 for available K.

Results of the Survey

Western and central counties with large areas near sediment-filled rivers, or lakes flooded by these rivers, had the lowest occurrence of soil P deficiency (**Figure 2a**). A few soils in the central region were identified as isolated areas of higher P fertility. Given their location (i.e., Anori, Careiro da Várzea, Alvaraes, Uarini, and Juruá counties), they are most likely examples of floodplain or anthropogenic soils. The loamy plains in the eastern and western part of central Amazonas had intermediate P fertility.

Counties located inside a wide arch extending north to south had more than 80% of samples testing low in available P. The low values observed in

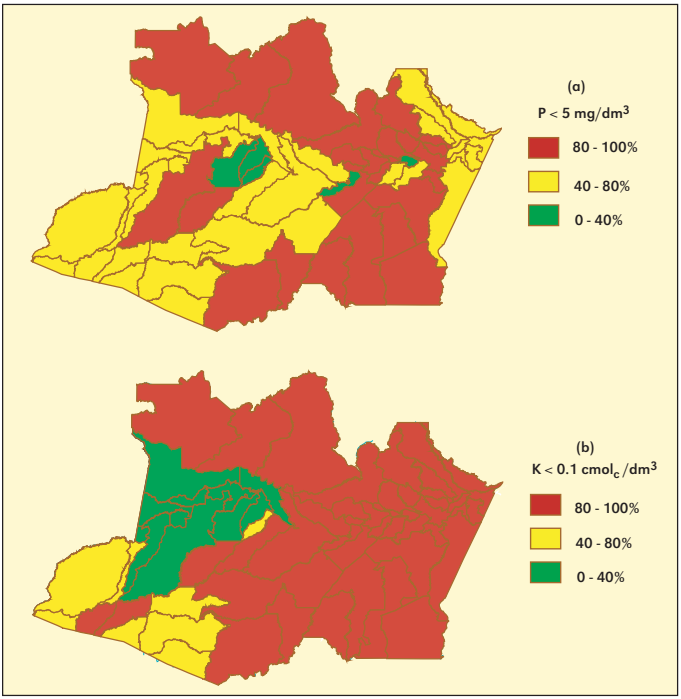


Figure 2. For Amazonas State, frequency of highly P-available deficient soils (< 5 mg/dm^3) is illustrated at top (a). Frequency of highly K-available deficient soils (< 0,1 cmol$_c$/dm^3) is illustrated in (b). Mehlich 1-extractable P and K (N = 3,340 samples).

the northern reaches of the state are a result of extensive plateau areas covered by higher weathered sediments of the cretaceous-quaternary period, and of crystalline shield uplands located around the basin of blackwater rivers (i.e., Negro, Japurá, and Branco Rivers) characterized by an absence of sediment. The counties of this area (Barcelos, Santa Isabel do Rio Negro, São Gabriel da Cachoeira), together with the entire east and a large part of central Amazonas (Carauari and Jutai), represent 70% of the state wherein 80 to 100% of soil test P values were less than 5 mg/dm^3.

With regards to available soil K, the western reaches had the lowest occurrence of samples testing below 0.1 cmol$_c$/dm^3 (**Figure 2b**). These relatively high K contents are mainly a result of an appreciable presence of primary minerals such as feldspars, chlorite, and micas (Marques et al., 2002). In the extreme west and southwest, 40 to 80% of samples tested below 0.1 cmol$_c$/dm^3. It was verified that the central and eastern areas of the state represent a large block of K deficiency. This area along with the equally K-deficient northern counties (Barcelos, Santa Isabel do Rio Negro, São Gabriel da Cachoeira) combine to represent 70% of the state wherein a vast majority of samples (80 to 100%) tested less than 0.1 cmol$_c$/dm^3. BC

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Effect of Iron Chelate Application on Citrus in the Three Gorges Area

By Fang Chen and Jianwei Lu

Researchers examined methods to correct iron (Fe) chlorosis and deficiency in citrus grown on calcareous soils. Soil application of an Fe-chelate was most effective at reducing symptoms of poor Fe supply and provided a boost in fruit yield and quality.

Iron chlorosis is a major yield-limiting concern for citrus trees grown on calcareous soils. The southern provinces of Chongqing and Hubei contain a citrus production belt along the Yangtze River within the Three Gorges Area. This region plays a significant part in China's total citrus production, yet its mountainous slopes are mainly comprised of calcareous soils. The recent extension of high productivity citrus cultivars is removing more soil nitrogen (N), phosphorus (P) and potassium (K), as well as micronutrients from these soils. Thus, among other problems, Fe deficiency is becoming increasingly more common. For example, a recent survey of orchard soils in Hubei indicates that 34% are deficient (<10 mg/kg) in Fe (Lu et al., 2002).

SPAD meter readings helped determine green index value of citrus leaves.

Most micronutrient deficiencies have a significant effect on citrus yield and quality. Iron plays a highly important role in plant chlorophyll synthesis and numerous enzymatic systems. Iron chlorosis and deficiency is usually corrected through application of inorganic Fe fertilizers such as ferrous sulfate ($FeSO_4$) and/or soluble organic compounds, or chelates, which can bind Fe and other metals within their complexes.

In calcareous soils, soil pH levels above neutrality lower Fe solubility, resulting in a high degree of 'fixation'. Lime-induced Fe chlorosis is another concern wherein sufficient Fe concentrations exist in leaf tissues. However, excessive uptake of bicarbonate ions (HCO_3) immobilizes plant Fe, thus rendering it unavailable.

Calcareous soils under citrus in Hubei require special attention to micronutrient deficiencies, including Fe.

Citrus response to inorganic Fe is often poor in these soils and high rates are often required. Many turn to foliar applications in these cases, although translocation can be poor and care must be taken not to cause fruit or leaf burn. Similar care must be taken with Fe-chelates, but they are not as susceptible to soil adsorption and are more effective at lower rates.

The authors compared methods of application for a Fe-chelate [Fe-EDDHA, (Fe content 6%)] for correction of deficiency symptoms in established (8 to 10 years old) navel orange (*Citrus sinensis L.*) tree orchards in Yichang, Zigui, and Yidu Counties in Hubei Province. All sites had purple soils, which are derived

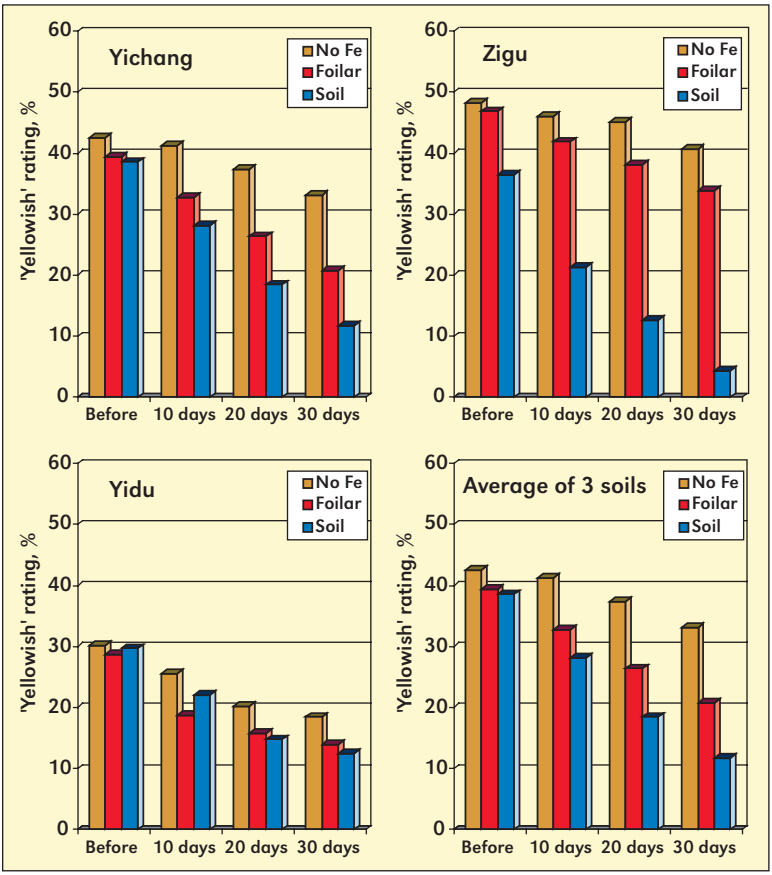

Figure 1. Effect of Fe-chelate application method on 'yellowish' rating of citrus leaves. Observations were taken prior to treatment as well as 10, 20, and 30 days after application, Hubei.

from parent materials high in calcium carbonate. Soils were sampled at three layers: 0 to 20, 21 to 40, and 41 to 60 cm. Micronutrients were analyzed by DTPA extraction and atomic absorption spectrometry.

The trials consisted of randomized blocks with four replications. There were three treatments in each block and five uniform trees were selected for each treatment. Along with N, P, and K fertilizers, treatments provided: 1) common practice with no Fe fertilizer); 2) foliar application of Fe-chelate at 50 g per tree at 1% concentration applied during budding, early flowering, and early fruiting; 3) soil application of Fe-chelate at 50 g per tree with 2.5 kg water applied during budding.

A leaf 'yellowish' rating was estimated 3 to 5 days before Fe fertilization and 10, 20, and 30 days after Fe fertilization. Chlorophyll concentration was expressed as a green index value determined with a Minolta SPAD 502 meter before fruit harvest. Fruiting ratio, normal fruit ratio, and single fruit weight was also measured during the growing season (data not provided). Fruit sugar content, acid content, and vitamin C (Vc) contents were analyzed to evaluate fruit quality. Results found the following.

Chelate applied either directly to soil or as a foliar dressing reduced the 'yellowish' rating for citrus leaves (**Figure 1**). Soil application proved especially effective at Zigui because of particularly low soil available Fe content (**Table 1**) and out-performed the foliar treatment significantly. By averaging observations over the three study sites, it is apparent that the soil-applied treatment was most effective. SPAD meter readings taken at Yichang and Zigui concurred with these results. The foliar treatment significantly increased leaf chlorophyll concentration

Symptoms of deficiency can be reduced soon after Fe-chelate application.

Table 1. Soil pH and micronutrient analysis (mg/kg), Hubei.

	Soil layer, cm	Yichang	Zigui	Yidu
pH (soil:water=1:1)	0-20	8.0	8.2	8.2
	21-40	8.1	8.2	8.2
	41-60	8.2	8.2	8.2
Fe	0-20	3.78	1.05	1.80
	21-40	1.61	0.41	1.95
	41-60	4.36	0.42	1.28

over common practice, but the soil-applied treatment provided even higher green leaf index values. (**Table 2**).

Foliar or soil-applied Fe chelate, along with adequate N, P, and K, produced better fruit yields (**Table 3**). However, the soil treatment was more effective than the foliar dressing, no matter if Fe chelate was applied at low or high yielding citrus trees sites.

Citrus quality, as measured by carbohydrate, sugar, acid, and Vc content, was consistently better than common practice under the basal dressing. The foliar dressing provided intermediate improvements for a selected number of these parameters (**Table 4**).

Iron deficiency symptoms of citrus were significantly reduced in one or two weeks by chelate application. Citrus fruit yield and quality can be improved by either soil or foliar treatments. However, the clear advantage of soil application over foliar treatment at these sites, especially in terms of fruit yield and quality, is valuable information for growers managing citrus on calcareous soils. The authors are interested in expanding their study of soil applied Fe-chelates and the mechanisms contributing to the agronomic effectiveness demonstrated. BC

Table 2. Effect of Fe-chelate application on green index value of citrus leaf, Hubei.

Treatment	Yichang (n=60)	Zigui (n=27)	Average	Increase, %
No Fe	30.2	31.0	30.6	
Foliar	44.8	52.1	48.5	58.5*
Soil	56.5	54.4	55.5	81.4**

* indicates significant at p = 0.05
** indicates significant at p = 0.01

Table 3. Effect of Fe-chelate application on citrus yield (t/ha), Hubei.

Location	Treatment	Zigui	Yield diff., %	Yidu	Yield diff., %
Site 1	No Fe	9.6		28.5	
	Foliar	12.4	30.7	29.9	5.0
	Soil	15.4	63.0	32.1	12.9
Site 2	No Fe	25.4		43.7	
	Foliar	30.9	21.9	47.7	13.7
	Soil	37.7	48.5	54.2	33.0

Table 4. Effect of Fe-chelate application on citrus quality, Hubei.

Treatment	Carbohydrates, g/100g	Sugar, g/100g	Acid, g/100g	Sugar-to-acid	Vc, mg/100g
No Fe	9.00	9.06	1.27	5.8	27.3
Foliar	9.90	11.62	1.27	6.6	27.7
Soil	10.03	11.84	1.06	8.7	30.1

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Reference

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GIS-Based Site-Specific Management of Cocoa

By José Espinosa, Francisco Mite, Sergio Cedeño, Sandra Barriga, and Javier Andino

Two goals of site-specific management are to describe the spatial variability of nutrients at the field-scale and design management practices most suited to that landscape. The characteristics of established cocoa plantations often make this a challenging task.

Mapping nutrient variability requires intensive soil sampling across fields. Soil testing has not been properly calibrated for many tropical crops and soils. Remote sensing imagery is also costly and access has been limited in tropical areas. A different approach, at least initially, may be needed to design appropriate nutrient recommendations. Interpretation of nutrient removal data could be an effective alternative until soil test calibrations are developed from data generated locally. Meanwhile, soil testing can still be employed as a monitor of other important physical and chemical characteristics.

Cocoa is a widespread plantation crop, but several historical factors have contributed to poor development. Depressed international markets have traditionally characterized the crop as a low user of technology and inputs. Higher quality cocoa varieties having the distinctive cocoa flavor and aroma used in fine chocolates suffer from high susceptibility to disease. Yields are low...only about 900 kg dry beans/ha...even under optimal conditions. A newer clonal variety (CCN51) developed in Ecuador has high yield potential and resistance to common fungal diseases, making it an acceptable alternative to produce cocoa for bulk use in most cocoa products and chocolate formulas. The clone can also compete in higher quality markets with careful post harvest care and fermentation. Under full solar exposure and high plant density, CCN51 can reach yields over 4,000 kg of dry beans/ha. That productivity level has sparked interest in rejuvenating established cocoa plantations.

The Cañas Cocoa Enterprise initiated activities with CCN51 in 1991 at Naranjal, Guayas Province, Ecuador. The prospect of high yields provoked a fast and disorganized development wherein only approximate field sizes and shapes were known and no accurate record of field area existed. Four different planting densities were laid out from 1991 to 1993 to identify the yield potential of the site. New fields were also planted during 2000 to 2003. Establishment of a geographic information system (GIS) would be the only way to accurately determine size and distribution of fields...a crucial first step.

At Cañas, yields were relatively

CCN51 cocoa clonal material has high-yield potential under complete solar exposure and high planting density.

Figure 1. Relative size and shape of fields at Canas, obtained with the help of aerial photograph (layer below) and GPS measurements.

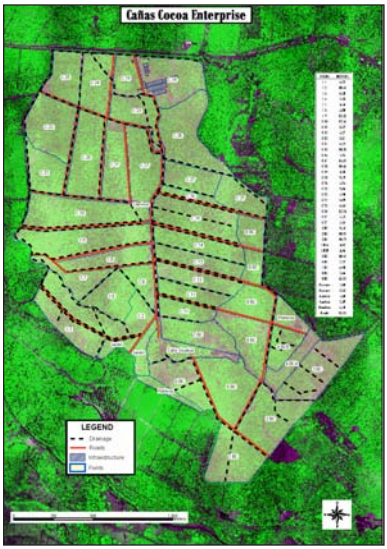
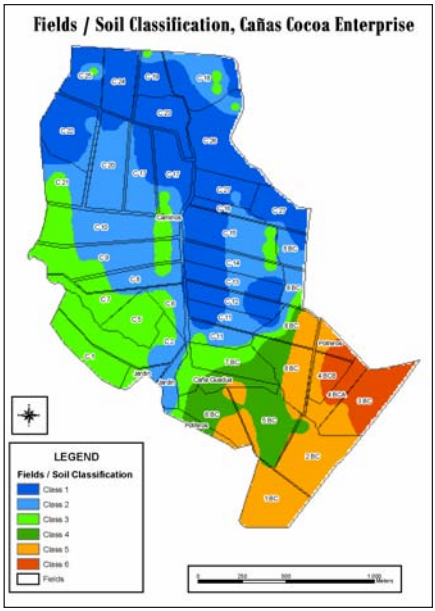


Figure 2. Layer of actual field size over a layer of soil classes.



high during the early 1990s, but were short-lived under conditions of full sun exposure, high plant densities, and poor plant nutrition. Management evolved to include a generalized soil testing program in 1999 which improved yields. Sustained improvement in international markets from 2003 onwards created the resources needed to establish a regularly maintained agronomic database capable of providing real unit area yields built on exact field measurements. Geo-referenced and ortho-rectified aerial photographs had recently become readily available. Global positioning system (GPS) field measurements defined actual field sizes along with the existing drainage pattern, thus comprising the basic platform to integrate any further accumulated data (**Figure 1**).

When the map layer of actual field boundaries was superimposed over the soil class map layer, it became obvious that little regard had been given to potential productivity of the site (**Figure 2**). Soil suitability classes were initially determined by soil texture of the first 90 cm and depth of the water table. Unfortunately, an excellent opportunity had been missed to properly organize the plantation's fields. The map layer representing depth of the water table alone (**Figure 3**) was now most useful at this stage of the plantation's development since it is possible to modify drainage patterns to eliminate this limiting factor from affected fields.

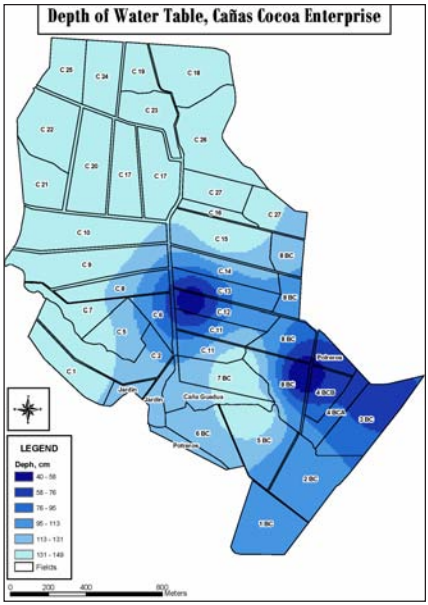


Figure 3. Layer of actual field size over a layer of soil drainage.

Figure 4. Normalized yield history of cocoa field by plant density.

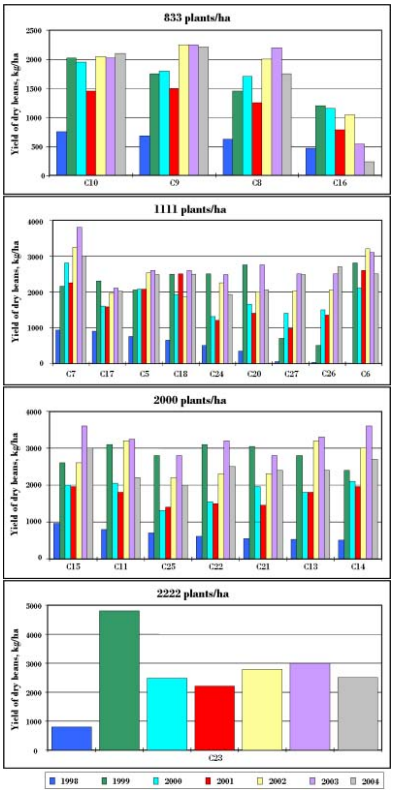
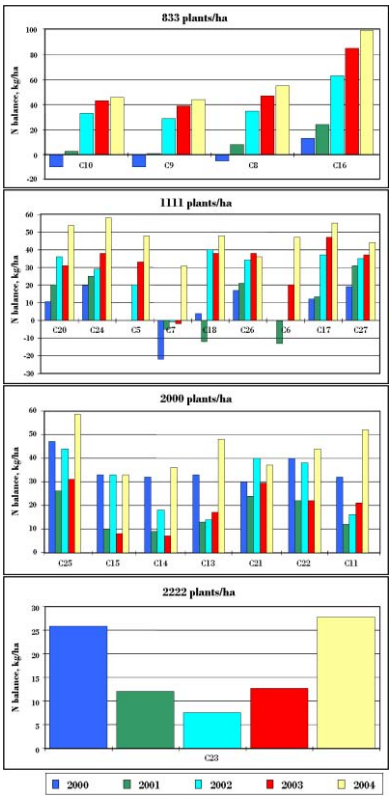


Figure 5. Nitrogen balance history of cocoa field by plant density.



Once the correct field measurements were determined, all accumulated yield data were normalized to reflect this fact. A history (1998 to 2004) of field-specific cocoa yields, arranged by planting density, is presented in **Figure 4**. Yield was positively correlated with high plant densities under full sun. The first attempt at soil testing and controlled fertilizer applications is evident as all fields produced excellent responses to applied nutrients in 1999. However, yield declines were evident for several fields in the following 2 years. This yield reduction indicates that the soil testing system was failing to provide an accurate indication of crop nutrient requirement. Managers were relying on established critical levels since no calibration data for P and K response existed. Nutrient applications were increased every year to cope with yield losses caused by apparent lack of adequate nutrition.

Table 1. Total nutrient uptake of CCN51 clonal material, Cañas Cocoa Enterprise Naranjal, Guayas, Ecuador (2005).

N	P_2O_5	K_2O	MgO	S
---- kg/t of dry cocoa beans ----				
28.5	13.2	57.7	12.0	3.4

In 2005, after the completion of a nutrient uptake study for CCN51, managers initiated a different approach to designing fertilizer recommendations based on total crop nutrient uptake (**Table 1**) and removal. The data allowed managers to estimate nutrient balances for each field based on fruit pod harvests (**Figures 5 and 6**). The balances considered leaf litter and pruned branch recycling within each field. Empty pods are also returned to the field. Nutrient balances also assumed 50% use efficiency for N and 70% use efficiency for K.

Figure 6. Potassium balance history of cocoa field by plant density.

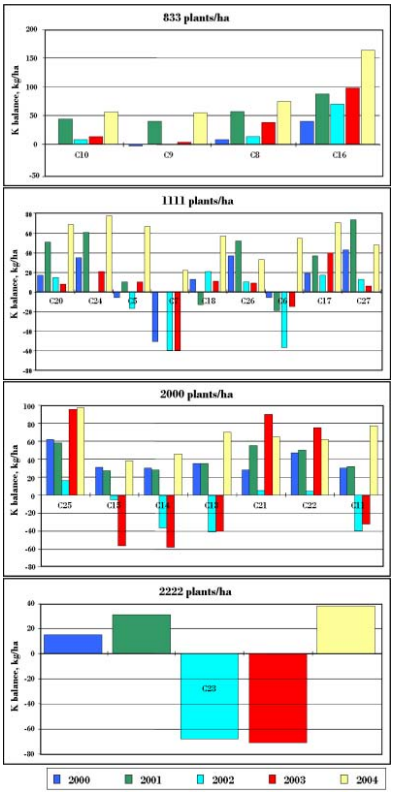
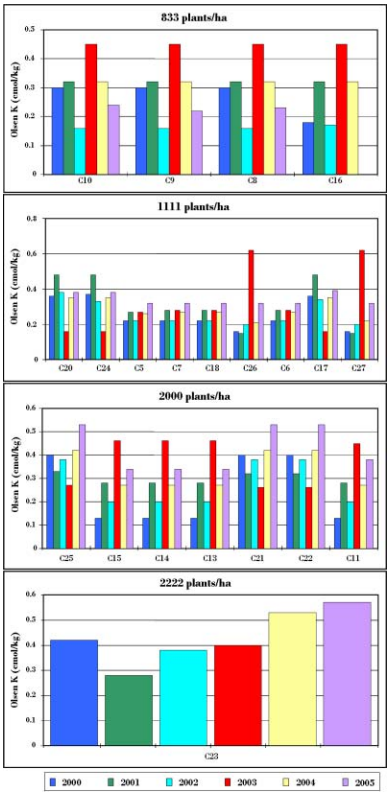


Figure 7. Soil K history of cocoa fields by plant density.



Nitrogen balances suggest that excessive amounts of N were used over the years, particularly in 2004. Potassium data indicate negative balances at higher plant densities, although amounts used in 2004 appeared to be in excess. Lack of balance between N and K could help explain yield reductions observed after the first yield response to fertilizer in 1999. This is also evident from accumulated soil K data (**Figure 7**).

Management of information using GIS-based site-specific management has allowed the Cañas Cocoa Enterprise to compile exact field measurements in relation to yield, soil testing, nutrient removal, and any other production factor deemed worthwhile monitoring. One especially useful example allowed managers to track the severity and dynamics of the fungal disease *Monilla* sp. The enterprise can now manage variability within fields, and if desired, even reorganize its fields to minimize impact on production. Eventually, yield and nutrient removal information can be correlated to obtain soil critical levels for all nutrients except N. In this way, soil testing can be a reliable diagnostic tool. BC

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Out of Season

I love strawberries. I really do. Growing up in rural America in the 1960s and '70s, I ate a lot of food from our family garden. I use the term "family garden" loosely. Mom and Dad did most of the work. My brother and I helped too, just in a different way: "Don't step on the runners" and "Can't you find a different place to play?" are a couple of prime examples.

Our garden produced a lot. Some things I liked, and some things evidently tasted better once you got older. But the strawberries I loved — picked fresh in our own back yard.

Well, I should qualify that a little. I loved them for about the first 3 or 4 days. After that, the 9th serving of shortcake began to lose its luster. So did the smell of the third batch of strawberries boiled on the stove to make strawberry jam. But the strawberries kept coming. Pretty soon, we were all glad that strawberries only came once a year. It would get so bad that Mom called strawberries names that weren't in the botany books. And it was that way with everything the garden produced – corn, squash, green beans – good at first, plentiful when they were in season, then gone for another year.

I remember those times as I walk through the grocery store in our neighborhood. I sometimes think of these mammoth temples of food as the true modern marvels of our era. Often, my daughter and I will take a trip to the supermarket to get her favorite fruit – strawberries. But this time, we're getting them in January…a little out of season in Minnesota. And we're getting a quart…just enough to enjoy, but not so much that we start calling them unbotanical names.

We may not want strawberries for another month, but they'll be there when we do…thanks to the network of modern agriculture and the science of crop nutrition, including the critical role of soil testing.

T. Scott Murrell

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