BETTER CROPS
WITH PLANT FOOD

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2005 Number 2

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- Renovation of Established Forages with Fertilizer

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BETTER CROPS WITH PLANT FOOD

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Our Cover: Spring planting. Photo courtesy of Case-IH.

Editor: Donald L. Armstrong
Assistant Editor: Katherine P. Griffin
Circulation Manager: Carol Mees
Design: Kathy Hefner

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C O N T E N T S

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The icon shown here is a handy signpost to help you learn more about the various projects, including full annual reports and other publications. The Research Database contains much more detail than can be included in a typical article in this publication.

ONTARIO

Critical Leaf Potassium Is Higher in No-Till Soybeans

By Xinhua Yin and Tony J. Vyn

The critical leaf potassium (K) concentration for maximum yield of conservation-till soybeans was estimated to be 2.4% in nine Ontario trials from 1998 to 2000. This is substantially higher than the critical levels used in Ontario and many states. Critical leaf K levels for the maximum concentrations of oil and isoflavones in soybean seed were estimated to be similar to those for maximum yield. Soils with stratified soil test K appeared to require higher critical levels of leaf K.

Plant analysis for K in soybean leaves at the initial flowering stage (R1) can be a useful tool for identifying K deficiencies. Critical levels ranging from 1.2 to 1.7% have been used in Ontario and many U.S. Corn Belt states. These critical leaf K values were established for traditional production in conventional tillage and primarily in wide row widths, and have not changed with the advent of conservation tillage and narrower rows. These changes in production practices, combined with overall yield improvements, have raised new concerns about the applicability of these critical leaf K concentrations. This concern may be most acute on long-term no-till fields where significant vertical soil test K stratification has occurred.

The objectives of this study were to: 1) determine the critical trifoliate leaf K concentrations of soybean at R1 for maximum yield and seed quality components in conservation-till production systems, and 2) evaluate the influences of vertical soil test K stratification on soybean critical leaf K concentrations.

The investigations were conducted at three sites in Ontario from 1998 through 2000. Each site had a history of at least 5 years of continuous no-till. Soil test K levels in the 0 to 6 in. depth ranged from low (35 parts per million [ppm]) to very high (155 ppm). Soybeans followed winter wheat at two locations and corn at the third. Treatments included both rates and placement (broadcast vs. banded) of K fertilizer at all sites, and fall disk tillage to a depth of 4 in. as a variable at two of the sites. All remaining treatments were grown with no tillage. The investigations involved a total of four varieties; soybean row widths were consistently at 15 or 7.5 in. Further treat-

Low K levels in soybean leaves can lead to deficiency symptoms as the crop matures.

ment details are available in Yin and Vyn (2004).

Composite soil samples were collected from each plot during the spring of each year. Soil probes were divided into depth increments of 0 to 2 in., 2 to 4 in., and 4 to 8 in. to determine the extent of vertical soil test K stratification in each plot. A leaf sample consisting of the most recently fully developed trifoliate leaves, including the petiole, was taken from 20 plants at R1 in mid- to late-July of each year from each plot for the determination of K concentrations.

A quadratic-plateau model was fitted to determine the relationships of leaf K concentration to yield and to concentrations of oil and isoflavones in seed. The critical leaf K value determined by a quadratic-plateau model is the leaf K concentration at which the two portions (quadratic and plateau) of the model join. In order to minimize the influences of year and site (due to soil types, weather conditions, soybean cultivars, etc.), all data of soybean yield and seed quality components were normalized by expressing them as percentages of the highest treatment mean within an individual site-year.

We found the critical leaf K concentration for maximum yield of soybean was 2.4% when all site-years were pooled (**Figure 1**), and 2.6% when only the no-till soybeans were considered. These values are double the critical value of 1.2% which had been used in Ontario soybean production systems for decades. This critical concentration is also remarkably higher than the 2.1% average of the sufficiency leaf K range (1.7 to 2.5%) that was proposed by Small and Ohlrogge (1973) and reported in Georgia (Plank, 1979). It is also greater than the critical leaf K values reported by Sartain et al. (1979) and by deMooy and Pesek (1970) for soybean at developmental stages slightly later than the initial flowering stage.

Critical leaf K concentration for seed oil concentration was estimated to be 2.4%—similar to that for seed isoflavone concentration—when all the data were pooled (**Figures 2 and 3**). Estimations of these critical leaf K concentrations for seed quality components are helpful to producers who aim to produce high-quality soybean for value-added markets. Similar critical values of midseason leaf K for maximum yield and seed quality components suggest that high yield and high seed quality components of soybean can be achieved simultaneously.

Critical leaf K concentrations for maximum yield...and maximum levels of oil and isoflavone...were higher in the plots with a soil test K stratification index greater than 2, than with an index of 2 or less (**Table 1**). This suggests that the extent of vertical soil K stratification affects the midseason critical leaf K concentrations for soybean. Because soil test K stratification commonly occurs in fields under long-term conservation-till (particu-

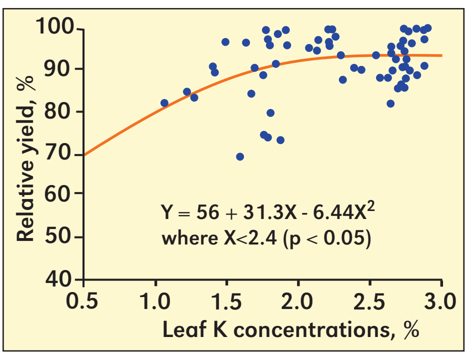

Figure 1. Relative soybean yield vs. leaf K concentration.

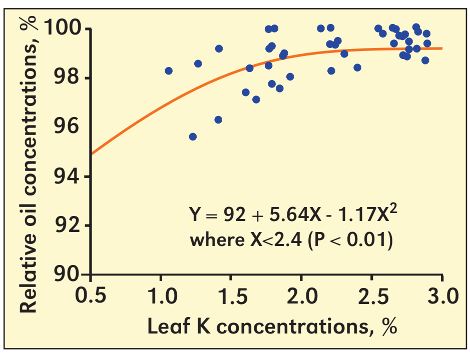

Figure 2. Relative soybean seed oil concentration vs. leaf K concentration.

Table 1. Impact of soil K stratification (KSC) on critical leaf K concentrations.

Dependent variable	KSC[1]	Critical leaf K, %
Yield	>2.00	2.3
	≤2.00	1.9
Oil	>2.00	2.5
	≤2.00	2.2
Isoflavone	>2.00	2.6
	≤2.00	2.2

[1]KSC, vertical soil test K stratification coefficient, is defined as the ratio of soil test K concentration in the 0 to 2 in. layer divided by K concentration at the 4 to 8 in. depth.

larly no-till) management, and the crop acreages under conservation tillage systems have increased rapidly, it will be important to consider the influences of vertical soil test K stratification on critical leaf K values in plant K analysis interpretations.

We also acknowledge that use of narrow row widths (instead of wide rows), and soybean yield improvement with time may have contributed to the higher critical leaf K values in this study compared with those reported previously.

The higher critical leaf K value we observed suggests that K fertilizer application based on the old critical leaf K concentrations may result in yield losses under conservation-till (particularly no-till) soybean production systems.

Increased vertical stratification of soil K may drive critical levels even higher. Based in part on the findings of this study, the optimum leaf K concentration in Ontario's soybean recommendations was raised from 1.2% to 2.0% in 2003. BC

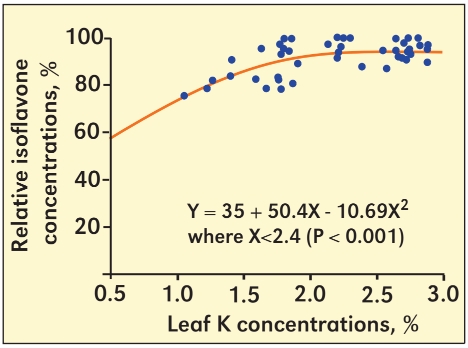

Figure 3. Relative soybean seed isoflavone concentration vs. leaf K concentration.

Dr. Yin is Assistant Professor at the Mid-Columbia Agricultural Research and Extension Center, Oregon State University in Hood River, OR; e-mail: Xinhua.Yin@oregonstate.edu. Dr. Vyn is Professor of Agronomy at Purdue University, West Lafayette, IN; e-mail: tvyn@purdue.edu.

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InfoAg 2005 Scheduled for July 19 to 21

The seventh national/international InfoAg Conference is set for July 19 to 21 in Springfield, Illinois. Co-organized by PPI and the Foundation for Agronomic Research (FAR), the program will focus on a broad range of crop and soil management systems. More details will be available at the website: **>www.infoag.org<**. Or contact Dr. Harold F. Reetz by e-mail at: hreetz@ppi-far.org.

Renovation of Established Forages with Fertilizer

By Stewart Brandt, Guy Lafond, Bill May, and Adrian Johnston

Using fertilizers to restore the productivity of established forage crop stands pays major dividends, with the proper balance of nitrogen (N) and phosphorus (P) critical to maximizing yields.

Forage crop fertilization is considered an optional practice for many farmers in the northern Great Plains, especially where dryland conditions limit the forage yields. However, there is a large database to support fertilization of forages as a means of maintaining yield, quality, and stand purity. In fact, the cost of not fertilizing is much higher when stand productivity declines. This project was established to evaluate dry and fluid fertilizer use on old, established stands of grass-legume forages.

Forage crop stands were selected at Scott (Typic Boroll loam soil) and Indian Head (Udic Boroll clay loam soil), Saskatchewan. At Scott, the stand was a mixture of crested wheatgrass, bromegrass, and alfalfa (10%). At Indian Head, it was bromegrass and alfalfa (30%). At Scott, the stand was extensively invaded by fescue and bluegrass species, which are considered less productive when harvested as hay. Both stands were old and nutrient-deficient. However, both were weed-free. Soil tests were taken at the start of the project...N and sulfur (S), 0 to 24 in. deep, P (modified Kelowna) and potassium (K), 0 to 6 in. Results showed 21 lb N/A, 6 lb P/A, >600 lb K/A, and 60 lb S/A at Scott, and 25 lb N/A, 2 lb P/A, >571 lb K/A, and 72 lb S/A at Indian Head.

Fertilizer treatments were applied to the study area in plots 6 ft. by 25 ft. The treatments were 1) unfertilized check, 2) unfertilized check with coulter (12 in. centers) applied in year 1 and coulter applied urea ammonium nitrate (UAN) and ammonium polyphosphate (APP) in year 2 and 3, 3) surface broadcast ammonium nitrate (AN) and monoammonium phosphate (MAP), 4) dribble banded (12 in. centers) UAN and APP, 5) dribble banded UAN and APP with ammonium thio-sulfate (ATS) added at 1% of total solution, 6) coulter injected (12 in. centers) UAN and APP, 7) coulter injected UAN, and 8) coulter injected UAN and APP at three times the annual rate (**Table 1**). Rates of N used at Scott were 53 lb N/A in 2002 and 2004, and 27 lb N/A in 2003. At Indian Head, the rate was 75 lb N/A each year. With the exception of treatment 8, all plots received 30 lb P_2O_5/A each year with the N. Treatment 8 received 90 lb P_2O_5/A in year 1 and then only N each year after. Treatments were applied annually to the same plot area and forage yields were harvested once each year.

Yield response after the first fertilizer application (year 1) was consistent over location years, but in the second and third years of application, there was a significant location by treatment interaction. Most, if not all, the interaction effect could be attributed to a difference in responses to P alone at the 2 locations. At Scott, a small response to N without P was recorded after years 2 and 3, while at Indian Head the N alone treatment yielded the same as the no fertilizer treatment (data not shown).

Dribble banding liquid UAN and APP was an effective means of applying

Table 1. Average yield response to fertilizer N and P additions on established legume-grass forage stands at Scott and Indian Head, SK.

Treatment	Year 1	Year 2	Year 3	Mean
	------ Forage yield, lb/A ------			
1) Check – no fertilizer	1,193	1,210	997	1,130
2) Coulter check – no fertilizer year 1, coulter applied UAN[1] and APP in year 2 and 3	1,059	1,682	2,456	1,736
3) Broadcast AN and MAP	1,771	2,723	3,088	2,528
4) Dribble UAN and APP	1,825	2,706	2,537	2,359
5) Dribble UAN with 10% ATS + APP	1,914	2,581	3,035	2,510
6) Coulter UAN and APP	1,566	2,456	2,830	2,287
7) Coulter UAN	1,406	1,673	1,362	1,477
8) Coulter UAN and 3 X APP[2]	1,914	2,786	3,008	2,572
LSD p=0.05	325	291	354	

[1] UAN = urea-ammonium nitrate; APP = ammonium polyphosphate; ATS = ammonium thiosulfate; AN = ammonium nitrate; MAP = monoammonium phosphate.

N rate was 53 lb N/A in 2002 and 2004, 27 lb N/A in 2003 at Scott; 75 lb N/A in all years at Indian Head. Annual P rate 30 lb P_2O_5/A.

[2] 3 X APP – ammonium polyphosphate applied at 3 times the annual rate (90 lb P_2O_5/A) in year one only, with N applied each year.

fertilizers to old, established forage stands (**Table 1**). The yield was similar for surface broadcasting granular AN and MAP and the fluid UAN and APP. Adding ATS to liquid UAN appeared to provide a slight (not statistically significant) benefit over UAN alone. If this treatment adds little to fertilizer cost, it may be useful as insurance against N losses under adverse conditions. No advantage was recorded to coulter application of the fluid fertilizer bands in this study (**Table 1**). Dribble band application is a lower cost method than use of coulters, and this research would not support the investment, upkeep, and operational cost of using coulters on forage lands.

Applying a 3-year supply of P at the beginning of the project was as effective as applying equal increments of P annually. In fact, at Indian Head, the application of the 3-year P rate in year 1 was always the highest yielding treatment (data not shown). Only when N and P were applied together was there a yield response at Indian Head, indicating that P was the major limiting nutrient. Applying P only at Scott did increase yield, but was ineffective compared to N plus P treatment (P alone yielded 1,566 lb/A compared to no fertilizer at 1,344, and broadcast N and P at 2,314 lb/A).

The residual effect of repeat fertilizer applications to these plots was dramatic. Check yields remained somewhat static, but fertilized yields tended to increase over time, typically increasing by about 50% in the first year of application. In the second year of application, the most effective fertilizer treatments more than doubled yields. In the third year, yields were tripled. These responses support previous research in the region which showed a progressive improvement in forage response to P additions over a series of years. Where banding without fertilizer was done the first year (treatment 2), followed by fertilizing in each of years 2 and 3, yields continued to be lower than where fertilizer N and P were coulter-banded all 3 years.

Where the productivity of established forages has declined over time due to nutrient deficiencies, fertilizer additions can be an effective means of improving yields. Soil testing to evaluate the level of available nutrients is critical to ensure that all deficient nutrients are applied. Correcting deficiencies in P can be critical to achieving a profitable N response in forage crops.

Mr. Brandt (brandts@agr.gc.ca) is an agronomist with Agriculture and Agri-Food Canada in Scott, SK; Dr. Lafond and Mr. May are agronomists with Agriculture and Agri-Food Canada in Indian Head, SK; Dr. Johnston is PPI/PPIC Northern Great Plains Director, Saskatoon, SK.

PPI/FAR Research Project SK-35

Maximizing Irrigated Corn Yields in the Great Plains

By W.B. Gordon

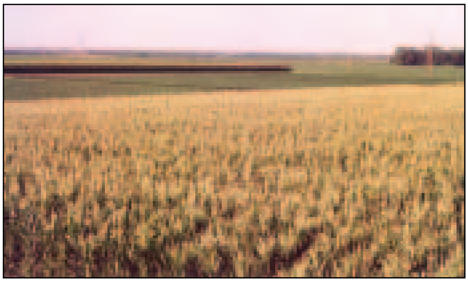
There is a large gap between attainable corn yields and present average yields. The overall objective of this work is to find practical ways of narrowing this gap. Two plant populations and two nutrient input levels were evaluated. With low fertility inputs, yields were decreased when population increased. However, corn produced significantly greater yield at the higher population with additional fertility inputs. One-third of the response to additional nutrient inputs was lost if plant density was not increased. This work further illustrates the importance of using a systems approach when attempting to increase yield levels.

With advances in genetic improvement of corn, yields continue to rise. Modern hybrids suffer less yield reduction under conditions of water and temperature stress. Hybrids no longer suffer major yield loss due to insect, weed, and disease infestations. Furthermore, newer hybrids have the ability to increase yields in response to higher plant populations.

Since 1970, the national average corn yield has increased at a rate of 1.8 bu/A/year. Corn yields reached an all time high of 142 bu/A in 2003, then jumped to a record 160 bu/A in 2004. However, yields obtained in university hybrid performance trials and in state corn grower contests have been even greater. The average corn yield increase during the period 1970-2003 in Republic County, Kansas, was the same as the national average. Meanwhile, yields in the Kansas State University (KSU) Irrigated Corn Hybrid Performance Test increased at the rate of 2.8 bu/A/year. There is a large gap between attainable yields and present average yields. One important aspect of yield advance is that it comes from synergistic interactions between plant breeding efforts and improved agronomic practices. Innovations in each field successively open up opportunities for the other.

The overall objective of this research project is to find practical ways of narrowing the existing gap between average and obtainable yield. This study evaluates more intensive fertility management at standard and high plant populations.

The experiment was conducted in 2000 through 2002 on a producer's field located in the Republican River Valley near the North Central Kansas Experiment Field at Scandia, on a Carr sandy loam soil. In 2003-2004, the study was conducted at the Experiment Field on a Crete silt loam soil. On the Carr sandy loam site, analysis by the KSU Soil Testing Laboratory showed that the initial soil pH was 6.8, organic matter was 2%, Bray-1 P was 20 parts per



More intensive fertility management at higher plant populations may be one approach to narrowing the yield gap between average and obtainable corn yields.

million (ppm [high]), exchangeable K was 240 ppm (very high), and sulfate-sulfur (SO_4-S) was 6 ppm. Soil test values for the Crete silt loam site were: pH, 6.5; organic matter, 2.6%; Bray-1 P, 25 ppm (very high); exchangeable K, 170 ppm (very high); and SO_4-S, 15 ppm. Both sites were in continuous corn and ridge-tilled. The experiment was fully irrigated. Irrigation was scheduled using neutron attenuation methods. Irrigation water was applied when 30% of the available water in the top 36 in. of soil was depleted. Treatments included two plant populations (28,000 and 42,000 plants/A) and nine fertility treatments.

Fertility treatments consisted of three nitrogen (N) rates (160, 230, and 300 lb/A) applied in two split applications (half preplant and half at V4) in combination with 1) current soil test recommendations for P, K, and S (this would consist of 30 lb/A P_2O_5 at these two sites); 2) 100 lb P_2O_5 + 80 lb K_2O + 40 lb SO_4-S/A applied preplant, and the three N rates applied in two split applications (half preplant and half at V4 stage); and 3) 100 lb P_2O_5 + 80 lb K_2O + 40 lb SO_4-S/A applied preplant with N applied in four split applications (preplant, V4, V8, and tassel). In 2001, treatments were included in order to determine which elements were providing yield increases. Additional treatments included an unfertilized check, 300 lb N/A alone, 300 lb N + 100 lb P_2O_5 /A, 300 lb N + 100 lb/ P_2O_5 + 80 lb K_2O/A, and 300 lb N + 100 lb P_2O_5 + 80 lb K_2O + 40 lb SO_4-S/A. Preplant applications were made 14 to 20 days before planting each year. Fertilizer sources were ammonium nitrate, monoammonium phosphate (MAP), ammonium sulfate, and potassium chloride (KCl).

Table 1. Interaction of plant population and fertilizer rates on irrigated corn yield. Carr sandy loam soil, 2000-2002.

Population, plants/A	P_2O_5 + K_2O + S, lb/A[1]: 30 + 0 + 0	100 + 80 + 40	Response
	- - - - - - - - - Grain yield, bu/A - - - - - - - - -		
28,000	162	205	43
42,000	159	223	64
Response	-3	18	

[1]Plus 230 lb N/A (half preplant; half at V4).

The results from the 3-year study on the Carr sandy loam soil clearly illustrate the interaction between plant density and fertility management (**Table 1**). Increasing plant density had no effect on yield unless fertility was increased simultaneously and one-third of the fertility response was lost if plant density was not increased. Fertility levels must be adequate in order to take advantage of the added yield potential of modern hybrids grown at high plant populations. Treatments added in 2001 and 2002 show that all three elements contributed to the yield response (**Table 2**). The addition of P, K, and S increased yield by 88 bu/A over the N alone treatment.

Table 2. Response of irrigated corn yields to application of N, P, K, and S. Carr sandy loam soil, 2001-2002. Rates of fertilization were 300 lb N/A, 100 lb P_2O_5/A, 80 lb K_2O/A, and 40 lb S/A.

Treatment	Grain yield	Response to inputs
	- - - - - - - - - - bu/A - - - - - - - - - -	
Unfertilized check	80	—
N	151	71
N + P	179	99
N + P + K	221	141
N + P + K + S	239	159
LSD ($p<0.05$)	10	

Results from the 2-year study on the Crete silt loam study were similar (**Table 3**). At the low fertility treatment yields were decreased when population was increased. When additional fertility was added, corn yield responded to higher plant populations. As in the experiment on the Carr soil, one-third of the fertility response was lost if plant population was not increased. Addition of P to the N increased yield by 56 bu/A (**Table 4**). Addition of K further increased yield by 13 bu/A, and adding S to the mix further increased yield by 9 bu/A. With both soils, yield increased with increasing N rate up to the 230 lb N/A rate. Increas-

Table 3. Interaction of plant population and fertilizer rates on irrigated corn yields. Crete silt loam soil, 2003-2004.

Population, plants/A	$P_2O_5 + K_2O + S$, lb/A[1] 30 + 0 + 0	100 + 80 + 40	Response
	- - - - - - - - - Grain yield, bu/A	- - - - - - - - -	
28,000	202	225	23
42000	196	262	66
Response	-6	37	

[1]Plus 230 lb N/A (half preplant; half at V4)

Table 4. Response of irrigated corn yields to application of N,P, K, and S. Crete silt loam soil, 2003-2004. Rates of fertilization were 300 lb N/A, 100 lb P_2O_5/A, 80 lb K_2O/A, and 40 lb S/A.

Treatment	Grain yield	Response to inputs
	- - - - - - - - - - bu/A	- - - - - - - - - -
Unfertilized check	137	—
N	187	50
N + P	243	106
N + P + K	256	119
N + P + K + S	265	128
LSD (p<0.05)	7	

ing the number of N applications from 2 to 4 did not increase yields on either soil in any year of the experiment.

Results of this experiment have shown a clear interaction between plant density and fertility management, thus illustrating the importance of using a systems approach when attempting to increase yield levels.

This 5-year study also points out the need for soil test calibration and fertility management research that is conducted at high yield levels. Standard soil test recommendations on these two soils would not have produced maximum yield. BC

Dr. Gordon is Professor, Department of Agronomy, Kansas State University, North Central Kansas Experiment Field; e-mail: bgordon@oznet.ksu.edu.

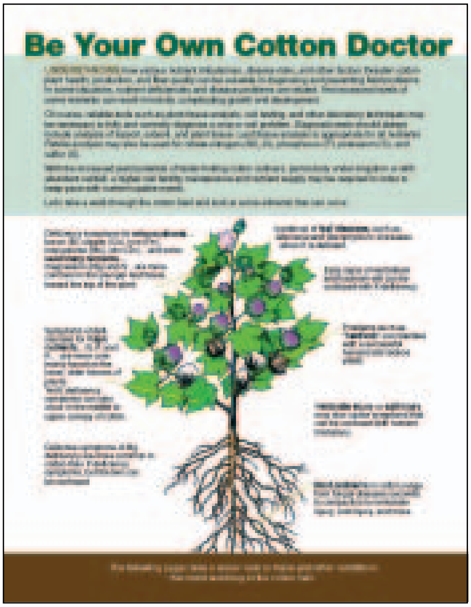
PPI/FAR Research Project KS-33F

Introducing: Be Your Own Cotton Doctor

A new publication from PPI titled *Be Your Own Cotton Doctor* offers cotton growers and their advisers and consultants a new tool. The 8-page booklet features 40 color illustrations showing typical symptoms of nutrient deficiencies, toxicities, diseases, and other disorders in cotton production. While it does not substitute for diagnostic tools such as plant tissue analysis and soil testing, this publication can help distinguish and identify various field problems.

The 8 ½ x 11-in. guide is patterned after the classic publication *Be Your Own Corn Doctor*, which has been widely used for over 50 years. *Be Your Own Cotton Doctor* is available for US$0.50 per copy, plus shipping. Discount on quantities.

Contact: Circulation Department, PPI, phone (770) 825-8082; fax (770) 448-0439, or e-mail: circulation@ppi-far.org. BC



IDAHO

The Nature of Phosphorus in Calcareous Soils

By A.B. Leytem and R.L. Mikkelsen

Calcareous soils (containing free lime) are common in many arid and semi-arid regions of North America and occur as inclusions in more humid regions. Phosphorus (P) is very reactive with lime. Following fertilizer application, P undergoes a series of reactions that gradually reduce its solubility. In most calcareous soils, there does not appear to be a strong agronomic advantage of any particular P source when managed properly. Organic matter can inhibit P fixation reactions to some extent. Some fertilizer recommendations call for additional P to be added when the soil contains high amounts of free lime.

Calcareous soils are common in arid and semi-arid climates and occur as inclusions in more humid regions, affecting over 1.5 billion acres of soil worldwide and comprising more than 17% of the soils in the U.S. Calcareous soils are identified by the presence of the mineral calcium carbonate ($CaCO_3$ or lime) in the parent material and an accumulation of lime. This is most easily recognized by the effervescence (fizzing) that occurs when these soils are treated with dilute acid. The pH of these soils is usually above 7 and may be as high as 8.5. When these soils contain sodium carbonate, the pH may exceed 9. In some soils, $CaCO_3$ can concentrate into very hard layers, termed caliche, that are impermeable to water and plant roots.

Calcareous soils can be extremely productive for agricultural use when they are managed properly. Since they are most frequently found in semi-arid and arid regions, supplemental irrigation water is often the first barrier for crop production. Limited availability of P is often the next most limiting factor for plant growth.

When P fertilizer is added to calcareous soils, a series of fixation reactions occur that gradually decrease its solubility and eventually its availability to plants. Phosphorus "fixation" is a combination of surface adsorption on both clay and lime surfaces, and precipitation of various calcium phosphate minerals. While the total lime content of a soil is important for predicting P reactions, the lime particle size (and its effect on reactive surface area) is often a better predictor of P behavior. Although a calcareous soil may be dominated by free lime, it may also contain significant amounts of iron (Fe), aluminum (Al), and manganese (Mn)…either as discrete minerals, as coatings on soil particles, or complexed with soil organic matter. These metals provide strong sorption sites for P and are frequently more significant in controlling P solubility in calcareous soils than lime itself. Their importance should not be ignored.

Effervescence (fizzing) occurs when calcareous soils are treated with dilute acid. Regular soil testing is important to monitor availability of P in calcareous soils.

As fertilizer P reacts in calcareous soils, it is converted to less soluble compounds such as dicalcium phosphate dihydrate or

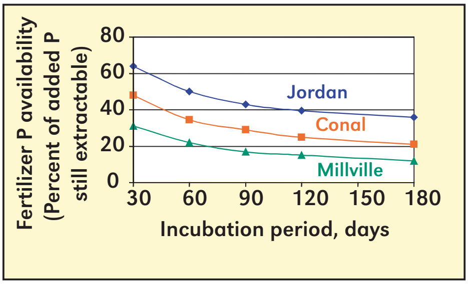


Figure 1. Fertilizer P undergoes a reduction in solubility following addition to three calcareous soils (Sharpley et al., 1989).

octacalcium phosphate. In some cases it may eventually convert to hydroxyapatite. A variety of management practices can be used to slow these natural fixation processes and increase the efficiency of applied fertilizer for crop growth. A number of the factors controlling P availability will be briefly covered.

Time—Insoluble rock P is treated after mining from geologic deposits to enhance its solubility and usefulness for plants. Fertilizer P is most soluble immediately after addition to soil, then it undergoes many chemical reactions that result in gradually diminished solubility (**Figure 1**).

Residual fertilizer P continues to be available for plant uptake for many years, but freshly applied P is generally most soluble and available for plant uptake. The common practice of building soil P concentrations to appropriate agronomic ranges provides a long-term source of this nutrient to crops.

Phosphorus Fertilizer Source—Many studies have demonstrated that there are no consistent agronomic differences in most commercially available P fertilizers added to calcareous soils. The selection of a specific P source should be based on other factors such as application equipment, suitability of fluids or granules, and price.

However, considerable work is currently underway to improve P availability with new P products and fertilizer additives. This topic will be explored in greater detail in future articles. For example, recent work from Australia in extremely calcareous soils has suggested that fluid P sources may have somewhat greater solubility and enhanced plant availability than granular fertilizers. It has been hypothesized that granule dissolution may be suppressed in these soil conditions. Additional work is underway in the U.S. to see if these results hold for soil conditions more typical of North America.

There is large variability in the solubility and availability of P from various materials added to calcareous soil (**Figure 2**). These large differences are largely due to the unique properties of the materials, rather than any unique character associated with a specific soil. For example, the polymer-coated, slow release P source has very low apparent solubility, but is able to support high levels of plant P accumulation. The soluble P sources and liquid manures have very high solubility and also are able to maintain high P recovery by barley.

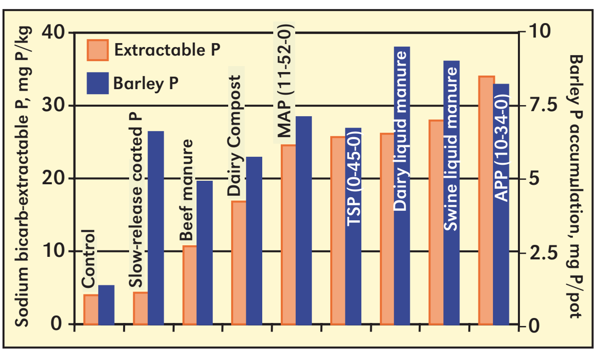


Figure 2. Extractability and P uptake by barley from various sources following incubation in a 12% lime soil. Sources initially added at a rate of 60 mg P/kg; extractions are average of 2- and 6-weeks sampling dates. (Leytem and Westerman, 2005).

Organic Matter—In the soil solution, there are several chemical components that will delay or prevent the reaction of P with lime. Organic matter has been found to interfere in the fixation reactions of P with lime. This inhibition of P

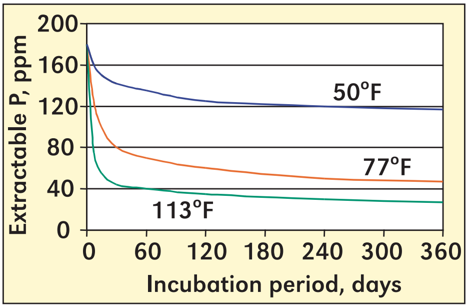


Figure 3. The effect of soil temperature on fertilizer P extractability in a calcareous soil (Javid and Rowell, 2003).

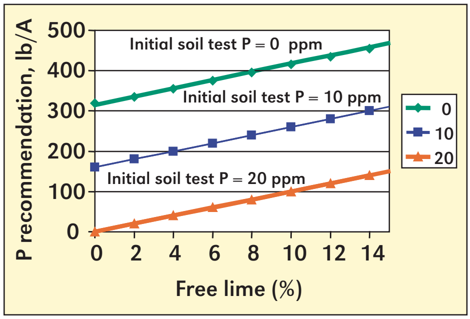


Figure 4. University of Idaho P fertilizer recommendations for potatoes grown in calcareous soil take into account the free lime content of the soil (Tindall and Stark, 1997).

fixation may account for the observation that P availability is frequently greater in manured soils and with the addition of humic substances in lime-rich soil. Higher levels of soluble Fe, Al, and Mn are also related to increased P fixation in calcareous soils.

Temperature—Soil temperature has two opposing effects on soil P availability. When fertilizer P is added to soil, it continually reacts and forms increasingly stable compounds for many months after application. The kinetics of the conversion of P to less soluble forms is more rapid under warmer conditions than in cooler soil (**Figure 3**).

An opposite effect occurs as increased soil temperature raises the solubility of soil P forms (both adsorbed or precipitated P). This well-known phenomenon accounts for frequent crop responses from added P in cool soils in the spring. In addition to improved solubility, higher soil temperature increases P diffusion to plant roots and enhances overall root activity and proliferation. When planting early in the season, or in high-residue conditions, cold soil temperatures can induce an early-stage P deficiency in many types of soil. A starter P fertilizer application may help overcome these limitations.

Adjusting for Calcareous Soils—Since the presence of lime in soils can reduce P availability to crops, fertilizer recommendations are frequently adjusted to account for this condition. For example, the University of Idaho recommendations for potato fertilization state that an additional 10 lb P_2O_5/A needs to be applied for every 1% increase in soil lime (**Figure 4**).

Calcareous soils can be extremely productive when managed properly. Maintaining an adequate supply of plant-available P is essential to profitable and sustainable crop production. Since a variety of soil reactions tend to decrease the plant-availability of added fertilizer P in calcareous soil, regular soil testing should be conducted to avoid crop loss due to plant nutrient deficiency. BC

Dr. Leytem is a Soil Chemist with ARS-USDA in Kimberly, Idaho; e-mail: leytem@nwisrl.ars.usda.gov. Dr. Mikkelsen is PPI West Region Director, Davis, California.

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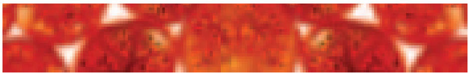

Tomato Flavor and Plant Nutrition: A Brief Review

By R.L. Mikkelsen

Why don't most tomatoes purchased in grocery stores have that same great flavor of vine-ripened tomatoes straight from the backyard garden? The answer is not simple. Here's a summary of information that helps explain the situation.

Much concern has been expressed regarding the perceived low quality of tomatoes available in the consumer market. Some of the blame has been laid on modern tomato varieties, but the degree of ripeness also has an effect. Packing houses commonly expose tomatoes to supplemental ethylene gas (a natural hormone produced by many types of fruit) in order to accelerate the ripening process. Commercial tomatoes are frequently selected for disease and pest resistance or growing season restrictions that are best served by a particular hybrid. Cultural practices such as picking fruit before it is vine ripened also can have negative effects on taste and quality.

For the home vegetable grower, taste is probably the most important concern. Commercial growers have many other concerns involved with successfully producing and marketing their crop, in addition to taste. The effects of phosphorus (P), potassium (K), and other nutrients are generally positive on fruit quality, although some benefits have not been carefully studied.

Tomato Flavor and Degree of Ripeness

Assessing tomato flavor is not a simple matter. The intensity of flavor properties of tomato fruits is determined largely by the amount of **sugar** (primarily fructose and glucose), the **organic acid** content (primarily citric, malic, and total acidity), and the **volatile compound** composition. Typically, human taste panels find best flavor associated with high soluble solids and soluble solids/titrateable acidity ratios. **High sugar and high acid contents generally have a favorable effect on taste.**

Differences between the flavors of varieties...and the weaker flavor of greenhouse-grown or artificially ripened tomatoes...are explained by the different quantitative proportions of the volatile substances. Of the environmental factors, light has the most profound effect on the fruit sugar concentration. Generally, more sunlight reaching the fruit results in higher sugar content. As a consequence, greenhouse tomatoes grown during the winter months contain substantially less sugar than field-grown tomatoes in the summer.

The characteristic tomato flavor is influenced by many volatile substances, many of which develop during ripening. Kadar (1977) reported that tomatoes picked at under-ripe stages were less sweet, more sour, less "tomato like", and had more off-flavor than those picked at the table-ripe state. The development of long-chain carbonyls and terpene esters that occurs during the ripening stage is essential for the typical tomato aroma.

Effects of P and K on Tomato Quality

Several studies have directly or indirectly examined the effect of plant nutrition on tomatoes, which are briefly reviewed here. Of the mineral nutrients, K...by influencing the free acid content...and P...due to its buffering capacity...directly affect tomato quality.

Tomatoes receiving standard nutrition (100%) were compared with enhanced nutrition (150%). The enhanced nutrition treatment was found to have a significant positive effect on tomato quality, color, and acceptability (Kimball and Mitchell, 1981). Other studies have also shown that K and P nutrition has a positive effect on fruit sugar and acid content (Lacatus et al., 1994). Of the nutrition factors, the soil K content most affects the total acid content in the fruit. Davies and Winsor (1967) found a positive logarithmic correlation between the K level in the soil and the acid content of the fruit. However, Wright and Harris (1985) reported that increased nitrogen (N) and K fertilization had a detrimental effect on tomato flavor, as scored by a taste panel (although increased acidity and soluble solid content resulted from increasing fertilization).

The development of red color in tomato fruit during ripening is mainly due to the synthesis of various carotenoid pigments, particularly lycopene. The lack of uniform coloration is a common ripening disorder, often referred to as "blotchy ripening" and "yellow shoulder." Trudel and Ozbun (1971) used sand culture to grow tomatoes with various K concentrations in the nutrient solution. They found that the K content of both fruit and petiole increased with increasing concentration of K in the sand culture. Total carotenoids in the fruit generally increased with increasing amounts of K and the lycopene content rose as the K level increased.

Processing tomatoes have a high K requirement. Crop uptake can exceed 350 lb K/A, the majority of which is removed in the fruit. Uniform fruit color is important for this industry. Lachover (1972) reported that K fertilization increased fruit yield and solid content, even in soils with high K availability. The incidence of both internal and external blotchy ripening was generally decreased with increased K supply. Hartz et al. (2001) conducted a field survey looking at yield and color under a variety of K fertilization practices for processing tomatoes. Results suggested that current soil K recommendations be adjusted upwards for maximum fruit yield, and that optimizing fruit color uniformity may require a greater soil K supply than needed for maximum fruit yield.

Summary

There are many complex factors that determine the flavor and quality of tomato fruit. Commercial fresh tomato production is not always geared to produce the most flavorful fruit, since other economic concerns must also be considered. In addition to primary factors (such as tomato variety selection, degree of ripeness during picking, and growing conditions), proper plant nutrition will also positively contribute to tomato flavor and appearance. BC

Dr. Mikkelsen is PPI West Region Director, Davis, California; e-mail: rmikkelsen@ppi-far.org.

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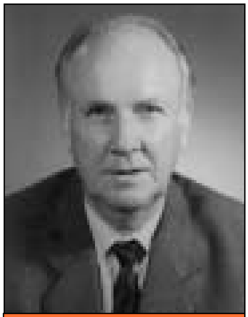
In Memoriam: Dr. H.R. von Uexküll, 1925-2005

Dr. Helmut R. von Uexküll, a recognized world authority in tropical agriculture and a leader in agricultural progress in Southeast Asia, passed away January 13, 2005, in Germany. He served for many years based in Singapore as Director of the East and Southeast Asia Program of PPI/PPIC and the International Potash Institute (IPI) before retiring in 1990.

Born in Latvia/Lithuania in 1925, Dr. von Uexküll earned his Ph.D. in 1954 from the University of Goettingen, Germany. He worked with the Overseas Agricultural Department of the German Potash Industry before joining the American Potash Institute (now PPI) and IPI in Hong Kong as Director, Mission to Southeast Asia. His responsibilities were expanded in 1964 when he was appointed Director, Association for Potash Research, Tokyo, Japan. In 1974, he became Director of the East and Southeast Asia Program and established the office in Singapore.

Through the years, he encouraged research and greater understanding of fertilizers and crop nutrition throughout East and Southeast Asia, including South Korea, the People's Republic of China, the Philippines, Indonesia, Malaysia, Vietnam, Thailand, Burma (Myanmar), and many other countries. Dr. von Uexküll was active in international professional societies and published widely in English, Spanish, Turkish, and Bahasa Indonesia.

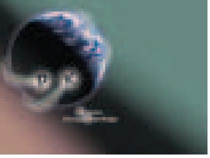


H.R. von Uexküll

He was a pioneer in discerning the intricacies of oil palm plant nutrition, and especially the critical roles of potassium and chloride to sustained high production. His work was widely respected and he put great importance on improving the well-being of the people of East and Southeast Asia. He also was deeply involved in developing a technology to rehabilitate the vast, formerly forested, areas of tropical savannah in Indonesia.

Those who knew and worked with Dr. von Uexküll described him as funny, wise, a natural gentleman, a fantastic raconteur, a great teacher, an expert landscape reader, a practical geologist, a prankster, and wonderful traveler.

"Helmut von Uexküll will surely be missed," said Dr. David W. Dibb, PPI President. "He lived a full, joyful, and productive life, leaving a legacy that will extend through the ages in his family, with his friends, and in the agriculture of Southeast Asia, which he loved. We send our best to his widow, Ines, and to their family." BC



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Nitrogen and Potassium Fertilization Impacts Fruit Yield and Quality of Citrus

By Dirceu Mattos, Jr., José Antônio Quaggio, and Heitor Cantarella

Market destination determines the most beneficial nutrition program in citrus production. Recent studies in Brazil indicate the need to review current fertilizer recommendations for citrus trees based on soil and leaf analysis, as proposed in newly formed recommendations.

Brazil produces 15 million metric tons (M t) of sweet oranges per year, or 30% of the world's production. The strength of local production is due to a large global juice export market. Around 80% is delivered within the country's major citrus-producing state of São Paulo to more than 10 processing plants. In addition to citrus for juice, 2 to 3 M t of oranges, tangerines, and acid limes are produced annually which supply domestic and export fresh citrus fruit markets. The importance of these strong niche markets points to an equally strong need to properly manage for improved yield, quality, and post-harvest qualities.

Nutrient management plays a key role for optimal production of quality fruits intended for either the frozen concentrated orange juice (FCOJ) or fresh fruit markets. By definition, the establishment of best management practices should also reduce cost of production and minimize any potential adverse impact that citrus cropping may have on the environment.

Fruit yield of citrus trees is largely regulated by nitrogen (N) supply because it affects photosynthesis and carbohydrate production, specific leaf weight, and carbon allocation to tree parts. Although optimal N availability results in green foliage color and increased crop yields, excess N can lead to luxury consumption by the tree, negative impacts on fruit size and composition, and reduced commercial value for harvested products. Fine-tuning of N fertilization recommendations based on leaf analysis is critical to maintain a proper N balance. Potassium (K) plays an important role in maintaining cell turgor and extensibility. Many studies have demonstrated the marked effects of K supply on fruit size and rind thickness.

External characteristics, such as fruit size and rind coarseness, are most important for citrus destined for fresh markets.

Research from Brazil

Results of recent field experiments conducted with Pêra and Valencia sweet oranges demonstrate that individual fruit mass will decrease with increased N rate (**Table 1**). This

Table 1. Selected data observed on fertilization experiments conducted with sweet orange trees.

Nutrient rate, kg/ha	Fruit yield, t/ha	Fruit mass, g	TSS, °Brix	Juice content, %	Box/ton juice[1], #	TSS/area, kg/ha
Nitrogen						
30	43.0	230	10.8	51.4	285	2,411
240	47.8	219	11.0	52.0	275	2,724
Potassium						
25	33.0	159	11.5	56.2	254	2,344
223	38.8	176	11.0	55.7	264	2,466

[1] Number of boxes (40.8 kg of fruits) required for production of concentrated juice (66 °Brix).
Source: Quaggio et al., submitted for publication.

characteristic was also inversely related with total fruit yield since higher N rates increased the fruit set of citrus trees, thus producing a greater number of smaller-sized fruits per unit volume of canopy.

The effects of K fertilization on orange yield are strongly related to the availability of exchangeable soil K. A linear response was observed at an experimental site with a low soil K availability of 1.2 $mmol_c\ dm^{-3}$ exchangeable-K at 0 to 20 cm depth layer, where an 18% increase in fruit yield occurred as K rate increased from 25 to 223 kg/ha (**Table 1**). At another site, where exchangeable-K was considered high at 2.9 $mmol_c\ dm^{-3}$, average fruit yield has not varied significantly with K supply over the last four seasons (data not shown).

Most literature agrees that citrus fruit becomes larger and coarser with increasing K application rate. This might explain observed reductions in juice and total soluble solids (TSS) content of fruits (**Table 1**), constituents considered important for the FCOJ market, but a detriment to the fresh fruit market.

Fruit yield may also be negatively impacted by excess. An experiment conducted in a commercial Murcott tangor (Honey Tangerine) grove found that fruit yield (average for six harvests) was reduced by 53% as K application rate increased from 25 to 225 kg/ha. Trees that received the highest K rate had excessive defoliation and decreased calcium (Ca) and magnesium (Mg) contents in the spring flush of leaves

Lower N and higher K application rates are usually best if fruit is intended for fresh market, while higher N and lower K rates may be more appropriate for frozen concentrated orange juice market destinations.

Figure 1. Calcium and Mg concentrations in leaves of Murcott trees planted on a sandy loam oxisol 6 years after a yearly schedule of K application. Source: Mattos, Jr. et al., 2004.

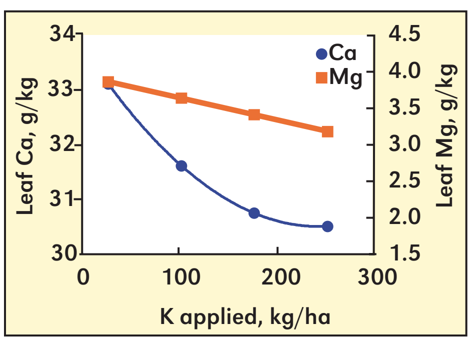

Table 2. Fertilizer recommendations for citrus in Brazil based on expected yield, soil analysis, and fruit quality.											
Yield	Leaf N, g/kg			Soil P (resin), mg dm^{-3}				Soil exch. K, $mmol_c dm^{-3}$			
target,	<23	23-27	>27	<6	6-12	13-30	>30	<0.8	0.8-1.5	1.6-3.0	>3.0
t/ha	---------- $N/P_2O_5/K_2O$, kg/ha ----------										
FCOJ production											
<16	90	70	60	50	40	20	0	60	40	30	0
17 - 20	100	80	70	70	50	30	0	70	50	40	0
21 - 30	140	120	90	90	70	40	0	90	70	50	0
31 - 40	190	160	130	130	100	50	0	120	100	70	0
41 - 50	240	200	160	160	120	60	0	160	120	90	0
>50	260	220	180	180	140	70	0	180	140	100	0
Fresh fruit											
<15	80	60	40	60	50	30	0	100	80	60	0
16 - 20	100	80	60	80	70	40	0	140	120	100	60
21 - 30	120	100	80	120	90	50	0	160	140	120	80
31 - 40	160	140	100	140	110	60	0	200	180	160	100
>40	180	160	120	160	120	80	0	220	220	180	120

Source: Quaggio et al., in press.

collected from fruiting terminals (**Figure 1**). Excess soil K levels are frequently found in citrus orchards where traditional fertilizer formulas are applied without consulting a soil test.

Therefore, best management nutritional programs will depend on the market destination. In general, the external fruit characteristics, such as size and rind coarseness, are most important for fruit destined for fresh markets. These characteristics are normally obtained with lower N and higher K application rates than those used for fruits produced for FCOJ processing (**Table 2**). Of course, soil testing and leaf analyses play an important role in defining fruit quality parameters for citrus trees. These studies have pointed out the need to review the current recommendation of fertilizers for citrus trees based on soil and leaf analyses, as is proposed in the newly formed table of recommendations. BC

Dr. Mattos is with the Sylvio Moreira Citrus Research Center, Instituto Agronomico (IAC), Cordeiropolis (SP), Brazil; e-mail: ddm@centrodecitricultura.br. Dr. Quaggio and Dr. Cantarella are with the Soil and Environmental Resources Center, IAC, Campinas, Brazil.

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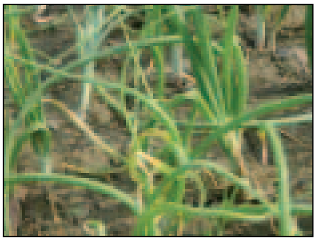
Looking for Images of Crop Deficiency Symptoms?

The world's agriculture provides ample crop diversity and just as much opportunity to discover potential symptoms of nutrient deficiency. While some symptoms appear in a similar manner across a wide variety of crop types, the growth characteristics of certain crops will result in some variation. More often than not, the differences between symptoms can be quite subtle. To be sure, it is useful to have some real-world examples.

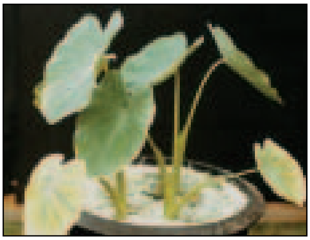
The images featured here show potassium (K) deficiency conditions in various crops. The photos are from the PPI/PPIC India Programme.

Additional images and descriptive information can be found at this website: >**www.ppi-ppic.org/web/gindia.nsf**<.

Potato: Interveinal chlorosis of the older leaves; afterward, leaf tips and margins become necrotic.



Onion: Chlorosis and necrosis of tips and withering of older leaves in acute K deficiency.

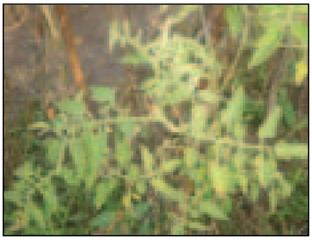


Arum: Chlorosis and necrosis of tips and withering of older leaves in acute K deficiency.

Lettuce: Chlorosis and necrosis of margins and tips and withering of older leaves in acute K deficiency.

Bitter gourd: Interveinal necrosis of old leaves, puckering, distortion and outward rolling of middle leaves.

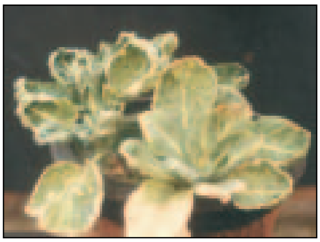
Bottle gourd: Lower (old) leaves show puckering and yellowing interveinal areas, with marginal scorching.



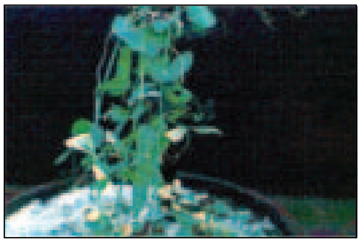
Tomato: Yellowing and premature shedding of old leaves; downward cupping of old leaves.

Cucurbits: Interveinal chlorosis of the older leaves; afterward, leaf tips and margins become necrotic.

Spinach: Chlorosis followed by necrosis of the tips of older leaves.



Cabbage: Acute K deficiency, showing puckering and marginal scorching of old leaves. Withering of lowest whorl of leaves is visible in one plant.



Pea: Acute K deficiency; chlorosis and scorching of the tips of older leaves.

Brinjal: Old leaves show brown necrotic lesions in the interveinal areas, almost covering the entire lamina. Loss of chlorophyll from middle leaves.

Are you looking for images showing crop nutrient deficiency symptoms in various parts of the world? Several other PPI/PPIC international region programs also offer image galleries.

For example, perhaps you want to see magnesium (Mg) deficiency in cacao or bananas. Go to: >**www.ppi-ppic.org/ppiweb/gltamn.nsf**<.

Or maybe you need to know how copper (Cu) deficiency in soybeans or citrus might appear. Visit: >**www.ppi-ppic.org/ppiweb/gbrazil.nsf**<.

Or do you want a look at nutrient response in the Argentine pampas? Try: >**www.ppi-ppic.org/ppiweb/gltams.nsf**<.

Another option is to begin at the central website of PPI/PPIC: >**www.ppi-ppic.org**<. From there you can browse any of the more than 20 regional websites of our North America and international programs. BC

Optimizing the Nitrogen/Potassium Balance for High Quality Spinach

By Lin Xianyong and Zhang Yongsong

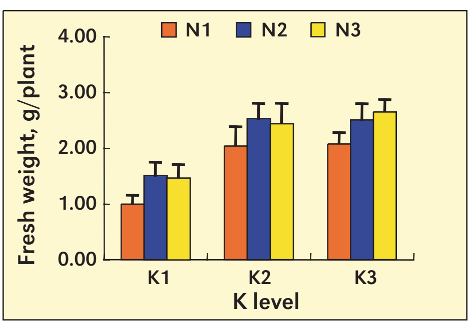
Researchers determined how nitrogen (N) and potassium (K) supply can be managed to maximize vitamin C in spinach while minimizing both nitrate (NO_3^-) and oxalate accumulation.

Ascorbate (vitamin C), NO_3^-, and oxalate are three major quality-related compounds present in high quantities in spinach, a frequently consumed vegetable in China. Research indicates that vitamin C in its reduced form functions as an important antioxidant, whereas NO_3^- and oxalate have adverse effects on human health when present in high concentrations.

In the human body, NO_3^- is enzymatically reduced to nitrite (NO_2^-) which, in combination with amine compounds from other foods, can form nitrosamine, a carcinogen. Excess intake of oxalate can increase the risk of developing kidney stones and can also contribute to calcium (Ca) deficiency in humans. Little is known about how N and K supply can influence the plant concentrations of these three compounds. However, it may be possible that proper management of plant nutrients is key to producing spinach with low NO_3^- and oxalate contents while maintaining high vitamin C content.

Spinach was greenhouse grown at Zhejiang University using three N levels...N_1 (4.0 mmol/L), N_2 (8.0 mmol/L), and N_3 (12.0 mmol/L), and three K levels...K_1 (0.5 mmol/L), K_2 (4.0 mmol/L), K_3 (8.0 mmol/L). Hoagland nutrient solution was used to prepare the nutrient solutions. Nitrogen was supplied as $Ca(NO_3)_2$ and $NaNO_3$, and K as K_2SO_4. Spinach seeds were germinated and planted in sand and, after growing to about 5 mm in length, the seedlings were transferred to the above hydroponic culture solution. Nitrate, oxalate, and vitamin C contents of the leaf tissue were determined as plant tissue matured.

Figure 1. Effects of N and K level on fresh weight of spinach seedling.



Both N and K influenced the fresh weight of spinach seedlings (**Figure 1**). At the same K level, biomass increased with N rate up to 8 mmol/L. At the same N level, the lowest K rate produced the smallest amount of fresh weight and this increased with K rate up to 4 mmol/L.

The effect of N on NO_3^- content was similar for both the leaves and petioles (**Figure 2**). Concentrations increased up to the N_2 level with the highest N input level having little additional effect with the exception of a large increase in petiole NO_3^- concentration in plants, also grown under the K_1 level. Potassium showed a similar influence on NO_3^- accumulation although a large

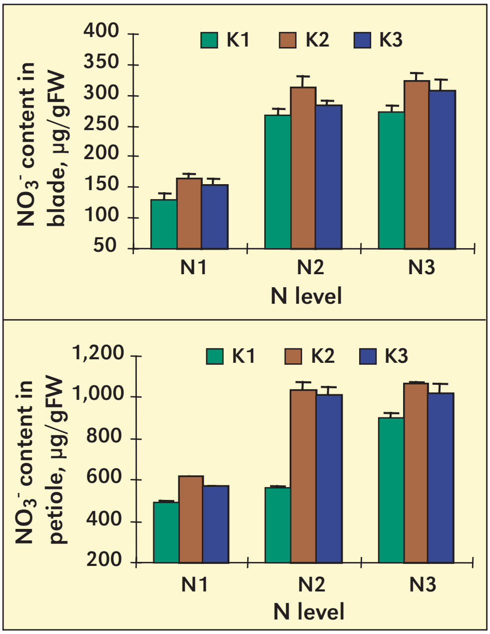


Figure 2. Effects of N and K level on NO_3^- content in blade and petiole of spinach seedling.

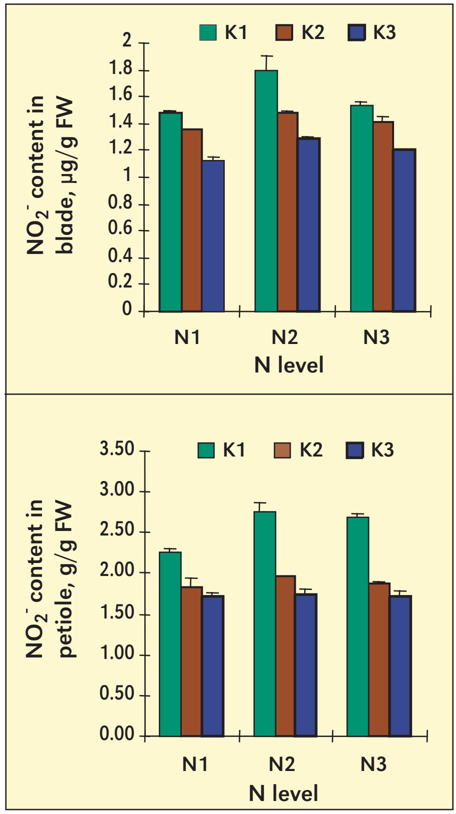


Figure 3. Effects of N and K level on NO_2^- content of spinach seedling.

increase in nitrate was observed as K supply increased from 0.5mmol/L to 4mmol/L. A further increase in K supply to 8mmol/L caused incidences of reduced NO_3^- content in the leaf (N_2K_3) and petiole (N_1K_3) indicating that higher K supplies favored plant NO_3^- assimilation.

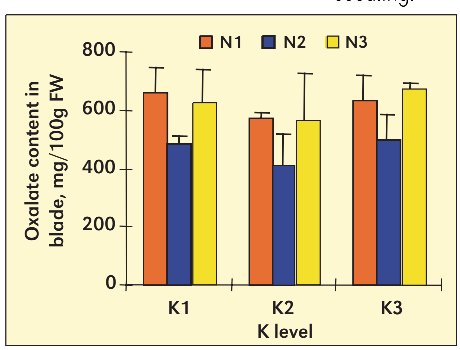
Nitrite contents of the leaf and petiole were also affected by N and K supply (**Figure 3**). At the same N level, NO_2^- contents of both plant parts decreased greatly as K supply increased. Comparisons across the same K level show that NO_2^- contents in both plant parts increased greatly at the N_2 level, but further N input showed no further increase in NO_2^- contents and actually showed cases of decreased NO_2^- content. Note that elevated K supply lowered the potential for NO_2^- accumulation in both plant parts, especially under the highest N input levels.

Oxalate Content

The effect of selected N and K input combinations on plant oxalate concentration was blurred by variability between replicates (**Figure 4**). However, comparing means across the same K input level, leaf blade oxalate concentration was suppressed in the N_2K_1, N_2K_2, and N_2K_3 treatments. Thus, a threshold balance between N and K is suggested to exist and an optimal combination will lower oxalate concentrations in spinach plant tissue.

Variation in vitamin C content was large and limited the ability to identify strong trends (**Figure 5**). Although differences were found across each level of K input, results were mixed. Com-

Figure 4. Effects of N and K level on oxalate content of spinach seedling.



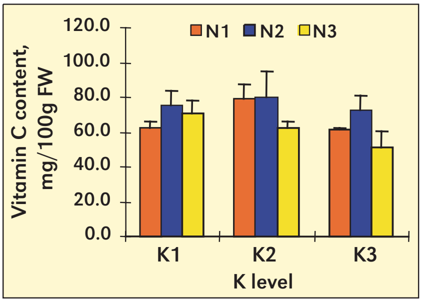


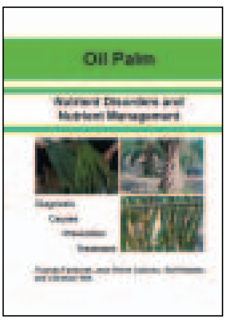
Figure 5. Effects of N and K level on vitamin C content of spinach seedlings.

parisons across means with the same N input level also produced three distinct responses. Nonetheless, vitamin C concentration of spinach tissue does seem to depend on N and K supply, and conditions of excess nutrient supply may result in a dilution effect.

Conclusions

This research affirms that a balanced supply of N and K strongly influences both yield and the nutritional quality of spinach. An optimal N and K level and ratio, in this case 8 mmol N/L and 4 mmol K/L, were essential for spinach to achieve good biomass yields while minimizing tissue NO_3^- and NO_2^-. It is apparent that plant oxalate and vitamin C can be positively affected through optimized N and K nutrition…and in this case, lower leaf blade oxalate concentration was associated with higher vitamin C concentration. Thus, the goal of producing high quality spinach can be consistent with a high yield strategy. BC

The authors are Professors with the College of Natural Resource and Environmental Sciences, Zhejiang University, Hangzhou, 310029, PR China; e-mail: xylin@zju.edu.cn.



Oil Palm: Nutrient Disorders and Nutrient Management—Pocket Guide

A new edition of the pocket-sized guide book for identifying nutrient deficiencies in oil palm is now available. The full-color publication has been completely revised and now includes an extensive color annex with diagnostic keys and photos for identifying deficiencies in oil palm and legume cover plants.

Authors of the new publication are Dr. T. Fairhurst, Dr. J.P. Caliman, Dr. R. Härdter, and Dr. Christian Witt, Director of the PPI/PPIC-IPI Southeast Asia Program (SEAP). It is based on Volume 7 of the Oil Palm Series published by SEAP.

Using a new format, the content is presented in two sections—the main text has been extensively revised, while the new color annex section provides a quick summary of the main text. Color coded-tabs enable fast cross-referencing between the two sections. The main text section contains 67 pages, including information on field monitoring, nutrient deficiency symptoms, nutrient disorders, and reference tables. The color annex contains 51 pages with diagnostic keys and color photographs for identifying nutrient deficiencies, diseases and disorders, and other important field management practices.

The price for the publication is US$9.00 (Singapore$15.00). For more information, contact: PPI/PPIC-IPI Southeast Asia Program, 126 Watten Estate Road, Singapore 287599; fax +65 6467 0416 (Attn: Doris Tan). Additional details and an order form are also available at the website: >**www.ppi-ppic-ipi.org**<. BC

Balanced Fertilization for Tea Production in Yunnan

By Su Fan, Fu Libo, Chen Hua, Hong Lifang, and Wang Pingsheng

The main reasons for low tea production in Yunnan are poor soil fertility and unbalanced fertilization. Site-specific research conducted at three plantations highlights benefits that can be expected from science-based nutrient management.

Tea is a major crop in Yunnan...its total production ranks highest amongst all provinces of China. Despite this prominence, Yunnan's numerous tea-growing counties produce at relatively low yield levels—the majority with yields below 4.5 t/ha and some producing under 2.2 t/ha. A series of field studies at Menghai, Eshan, and Simao addressed this production gap and evaluated the effects of soil test-based fertilizer applications on tea yield and quality.

According to soil testing results, nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) were deficient at all three locations. Menghai and Eshan showed sulfur (S) deficiencies, and Simao was deficient in manganese (Mn). Specific ranges of fertilizer application rates were selected for each site (**Table 1**) and combined into a set of eight distinct treatments (**Table 2**). Each site used a plant density (Yunkang 10 tea variety) of 84,000 shoots/ha.

Research in Yunnan Province shows that soil test-based fertilizer applications can improve tea yield and quality.

Leaf Composition

Amino acid and protein content of tea leaves affect the quality of green tea and both of these are influenced by soil fertility. Long-term observations show that continued reliance on N alone reduces soil quality, in part through hastening of basic cation depletion. This decreases the potential for sustained high quality tea production. This experiment found enhanced accumulation of amino acids and proteins in leaves with increased supply of P, K, secondary nutrients, and micronutrients (**Table 2**). Leaf amino acid and protein content increased with K application up to 200 kg K_2O/ha. Beyond that level, K appeared to have a negative effect, possibly due to the competing effect between K^+ and cations like ammonium (NH_4^+). High rates of K did depress N uptake by tea at all locations (data not shown). The concentration of water extractable compounds was also enhanced with use of N, P, K, and Mg, but neither S nor Mn had

Table 1. Range of fertilizer application rates (kg/ha) selected for each plantation site, Yunnan.

Nutrient	Menghai	Simao	Eshan
N	414	375	420
P_2O_5 (P_1, P_2)	200, 300	200, 300	225, 300
K_2O (K_0, K_1, K_2, K_3)	0, 100, 200, 300	0, 100, 200, 300	0, 100, 200, 300
S (S_0, S_1)	0, 60	–	0, 50
Mg (Mg_0, Mg_1)	0, 60	0, 37.5	0, 50
Mn (Mn_0, Mn_1)	–	0, 7.5	–

Table 2. Treatment effect on amino acid, protein, and water extractable compounds in tea leaf tissue, Yunnan.

	Amino acid, %			Protein, %			Water extractable compounds, %		
Treatment	Menghai	Simao	Eshan	Menghai	Simao	Eshan	Menghai	Simao	Eshan
1. $NP_1K_0S_1Mg_1Mn_1$	16.03	18.35	18.20	25.74	28.45	27.16	52.99	55.75	54.51
2. $NP_1K_1S_1Mg_1Mn_1$	17.93	19.19	18.41	24.91	28.33	27.48	53.05	56.45	54.72
3. $NP_1K_2S_1Mg_1Mn_1$	18.24	19.24	18.85	26.63	28.57	28.13	53.25	56.32	55.20
4. $NP_1K_3S_1Mg_1Mn_1$	17.11	18.31	17.01	23.97	27.82	26.92	53.90	56.91	55.24
5. $NP_2K_2S_1Mg_1Mn_1$	18.78	19.56	18.77	24.90	28.39	27.16	55.04	56.74	57.13
6. $NP_1K_2S_0Mg_1Mn_0$	16.64	19.01	19.20	25.57	28.67	27.92	53.11	56.29	56.82
7. $NP_1K_2S_1Mg_0Mn_1$	17.81	18.20	17.86	26.24	28.48	26.95	53.06	55.88	55.03
8. $NP_1K_2S_1Mg_1Mn_1$	17.71	19.89	21.98	25.57	28.26	27.32	54.26	56.33	56.60

Selected fertilizers were urea, monoammonium phosphate, single superphosphate, KCl, K_2SO_4 (treatment 8), gypsum, magnesium chloride, magnesium sulfate, and manganese sulfate.
Note: Only the Simao site received Mn, and no S.

much influence on any of these leaf quality related compounds.

Agronomic Features of Tea

The agronomic quality of tea plants is evaluated by three indices: bud length, hundred-bud weight, and density of buds. Data indicate that all traits tended to increase with improved K nutrition status (**Table 3**). However, the use of potassium sulfate (K_2SO_4) did not offer any advantage over potassium chloride (KCl). Phosphorus had a major effect on bud length at all sites, while density of buds improved at all sites receiving S and Mn.

Tea Yield

Balanced fertilization noticeably increased yield since levels obtained with the best treatments were over three times those obtained by the vast majority of tea-growing counties in the province (**Table 4**). The three sites responded well to the range of K treatments with yield increases of up to 15% at Menghai, 30% at Simao, and 42% at Eshan. Simao showed an additional, albeit small, yield response (2.1%) as K rate increased from 200 to 300 kg K_2O/ha. The K source comparison (treatment 3 vs. treatment 8) showed an apparent yield advantage for K_2SO_4 over KCl at Simao and Menghai, but not Eshan.

Simao was the only site which responded to P application beyond 200 kg P_2O_5/ha. The effect of Mg was significant at all sites as yield increased by 1.22 t/ha (10.8%) at Menghai, 1.17 t/ha (9%) at Simao, and 770 kg/ha (7.7%) at Eshan. The S response was marginal at the two

Table 3. Treatment effect on selected agronomic features of tea, Yunnan.

		Treatment							
Location	Feature	1	2	3	4	5	6	7	8
Menghai	Bud length, cm	3.1	3.1	3.1	3.1	3.2	3.1	3.1	3.1
	Hundred-bud weight, g	91.8	92.4	94.6	109.0	95.5	95.0	95.8	99.2
	Germinate density, buds/m^2	1,536	1,555	1,654	1,619	1,620	1,538	1,551	1,623
Simao	Bud length, cm	3.0	3.1	3.2	3.3	3.3	3.2	3.1	3.2
	Hundred-bud weight, g	105.3	105.4	107.9	107.2	107.4	107.5	106.1	107.9
	Germinate density, buds/m^2	1,154	1,160	1,280	1,272	1,215	1,274	1,208	1,298
Eshan	Bud length, cm	2.5	2.9	2.9	3.0	3.0	2.9	2.9	3.0
	Hundred-bud weight, g	66.5	66.8	68.5	68.4	69.7	68.4	67.8	68.9
	Germinate density, buds/m^2	474	482	488	492	418	483	481	488

sites tested and Mn application at Simao produced a 285 kg/ha (2.2%) yield increase.

Table 4. Treatment effect on tea yield, Yunnan.

Treatment	Menghai		Simao		Eshan	
	----- Yield, t/ha -----					
1	9.76	(86.8)[1]	10.20	(78.8)	7.04	(70.2)
2	10.39	(92.4)	11.81	(90.9)	8.89	(88.7)
3	11.25	(100.0)	12.99	(100.0)	10.02	(100.0)
4	10.98	(97.6)	13.26	(102.1)	10.02	(100.0)
5	11.10	(98.7)	14.07	(108.3)	10.04	(100.2)
6	11.21	(99.6)	12.70	(97.8)	9.92	(99.0)
7	10.03	(89.2)	11.82	(91.0)	9.25	(92.3)
8	11.90	(105.8)	14.31	(110.2)	10.06	(100.4)
F-Test treatment	1.98*		2.83**		2.37**	

[1]Numbers in parenthesis represent relative yield.
*Significantly different at $p = 0.25$ level; **Significantly different at $p = 0.1$ level.

Economic Efficiency

Despite the varying degree of response to applied nutrients across sites, economic analysis found substantial advantage to a balanced approach to fertilization (**Table 5**). Amongst treatments 1 to 4 which varied K rate alone, net income at Menghai and Eshan was maximized with 200 kg K_2O/ha. At Simao, the marginal yield increase gained from applying 300 kg K_2O/ha was slightly more profitable. The use of 300 instead of 200 kg P_2O_5/ha was more profitable at Simao. However, these incomes were all lower than amounts generated with the complete treatment 8 which also relied on K_2SO_4 as the source. The Menghao site showed a similar advantage to the K_2SO_4-supplying treatment. At Eshan, which was the most responsive to K and the least responsive to S and Mg, no economic advantage was apparent for either K application beyond the 200 kg K_2O/ha level or any secondary and micronutrient application.

Table 5. The economic analysis for balanced fertilization on tea (US$/ha), Yunnan.

Locations	Treatment	1	2	3	4	5	6	7	8
Menghai	Output	4,167	4,433	4,801	4,686	4,738	4,785	4,280	5,078
	Input	457	486	516	545	568	481	403	558
	Balance	3,710	3,947	4,285	4,141	4,170	4,304	3,877	4,520
Simao	Output	2,487	2,880	3,168	3,234	3,433	3,098	2,882	3,490
	Input	303	332	362	391	413	355	352	449
	Balance	2,184	2,548	2,806	2,843	3,020	2,743	2,530	3,041
Eshan	Output	2,574	3,252	3,668	3,668	3,672	3,631	3,384	3,682
	Input	407	439	472	504	494	449	321	523
	Balance	2,167	2,813	3,196	3,164	3,178	3,182	3,063	3,159

Conclusion

Among the fertilizer nutrients tested, the influence of K on yield and profitability made its application essential at all locations. Combinations of secondary and micronutrient application had prominent importance at two of three sites. BC

The authors are staff of the Soil and Fertilizer Institute of the Yunnan Academy of Agricultural Sciences, Kunming, China; e-mail: lfhong@ppi.caas.ac.cn.

Nutrient Depletion in the Rice-Wheat Cropping System of the Indo-Gangetic Plains

By A.K. Shukla, S.K. Sharma, R. Tiwari, and K.N. Tiwari

Despite being a major source of food security and livelihood for over a billion people, the rice-wheat cropping system of the most fertile Indo-Gangetic Plains region of India is under stress due to depletion of native nutrient reserves, emergence of multi-nutrient deficiencies, and consequent decline in factor productivity of applied nutrients. The authors discuss the status of plant nutrient use, nutrient removal, and nutrient balances for this system with the aim to enhance productivity and develop balanced and efficient fertilizer management strategies for the region.

The rice-wheat cropping system (RWCS) is the world's largest agricultural production system occupying 24 million hectares (M ha) throughout India and China alone. In the Indo-Gangetic plains region of India, the cropping system spreads over a vast area spanning from Punjab in the Northwest to West Bengal in the East. More than 85% of the system is located on the plains of the Indus and Ganges, and is conveniently divided into four sub-regions: the Trans-Indo-Gangetic Plains (TGP), Upper Indo-Gangetic Plains (UGP), Middle Indo-Gangetic Plains (MGP), and Lower Indo-Gangetic Plains (LGP), as shown in **Figure 1**.

For over a decade, RWCS yields in high productivity zones have either stagnated or declined. The most important reason is a decline in factor productivity resulting from depletion of soil fertility. The system commonly shows signs of fatigue and is no longer exhibiting increased production with higher input use based on the current pattern. Even with current generalized recommended rates of fertilization for this system, a negative balance of the primary nutrients exists. Recent surveys in the Upper-Gangetic Plain zone reveal that farmers apply greater than recommended rates of both nitrogen (N) and phosphorus (P), but ignore the replenishment of other nutrients. Such an unbalanced use of fertilizer not only aggravates the deficiency of potassium (K), sulfur (S), and micronutrients in the soil, but it also proves uneconomic and environmentally unsafe. The high yield potential of modern varieties can never be exploited under this scenario.

Materials and Methods

A primary survey collected regional data on area, production, productivity, and nutrient input use in the Indo-Gangetic Plain region covering Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal, involving 40 districts, 360 villages, and 3,309 farmers (Sharma et al., 2003). Nutrients (NPK) added to the soil through chemical fertilizers, organic manures, crop residues, and irrigation water were estimated using aver-

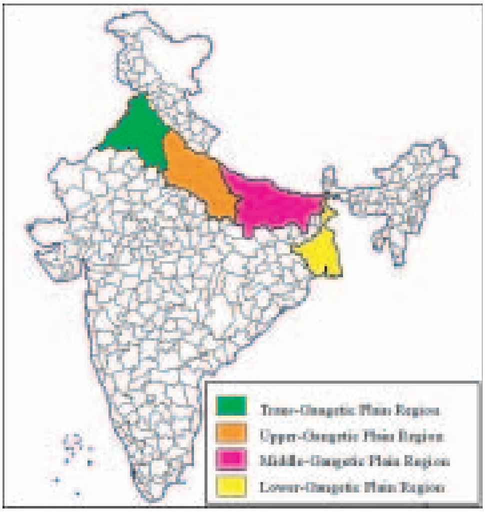


Figure 1. Map of India showing the regions discussed.

age nutrient contents of collected materials. Nutrient removals were determined using estimated production and average nutrient contents of harvested product. Apparent (gross) nutrient balances were calculated by the difference between total crop removal and total nutrient input. A net nutrient balance was calculated based on 50%, 35%, and 70% use efficiencies for N, P, and K used in the system.

Nutrient Addition—Total addition of N, P, and K for the Indo-Gangetic Plains region is 2.96, 0.48, and 0.84 M t, respectively (**Table 1**). Of the total N added, 38% is applied in the TGP followed in order by the UGP (32%), MGP (28%), and the LGP (2%). The corresponding figures for P are: 36%, 37%, 26%, and 1%; and for K: 3%, 52%, 40%, and 5%.

Chemical fertilizers are the major N supplying source and provide 81% of the total annual N input (**Figure 2**). Farmyard manures (FYM) and irrigation waters are the next important N sources, each contributing 8 to 9% of the total. Similar to N, 82% of the annual P supply comes from fertilizers. Manure is the second most significant P source and contributes 14% of the total P input. Irrigation water and crop residues contribute relatively small quantities of P. Fertilizer K provides only 12% of the total contribution towards K input to soil. Irrigation water, residue, and manures are the major contributors at nearly 30% each.

Nutrient Removal—Total N removal for the region is estimated at 1.6 M t. TGP alone accounted for 43% of this total, followed by UGP (34%), MGP (21%), and LGP (2.0%). Total P removal for the region is estimated at 433,800 t. Removal for the different sub-regions generally follows the pattern observed for N. However, the order changes on the basis of P removal per hectare, with TGP still having the highest depletion rate of 54.4 kg P/ha, and MGP the lowest (32.1 kg P/ha). Rice-wheat cropping removes an estimated 2.31 M t of K—the highest amongst the three major nutrients. Similar to N removal, TGP accounts for 42% of this total followed by UGP (34%), MGP (21%), and LGP (2%). On a per hectare basis, the MGP region has the lowest rate of removal of 173.3 kg K/ha.

Removal of secondary and micronutrients from the RWCS is also

Table 1. Total NPK addition ('000 t) through FYM, fertilizer, water, and crop residue in RWCS, Indo-Gangetic plains region.

Region	Fertilizer			FYM			Water			Residue			Total		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
TGP	986	172	0	10.9	4.4	13.1	88.9	3.9	98.8	19.8	4.2	73.8	1,127	185	221
UGP	702	119	22.7	153	28.6	85.8	69.9	2.8	72.4	23.4	4.9	87.1	970	156	309
MGP	638	92.8	51.6	89.7	33.3	99.9	52.8	1.8	44.1	10.8	2.4	41.9	807	131	282
LGP	47.8	1.1	13.3	5.3	2.1	6.3	6.9	0.2	5.4	1.0	0.2	4.0	61.2	3.6	32.7
Total	2,374	384	87.6	259	68.4	205	219	8.7	221	55.0	11.6	207	2,965	476	844

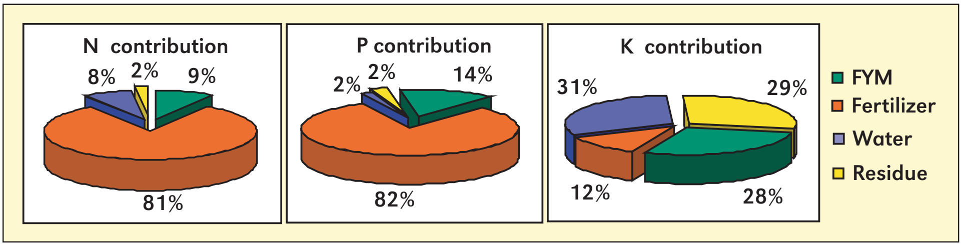


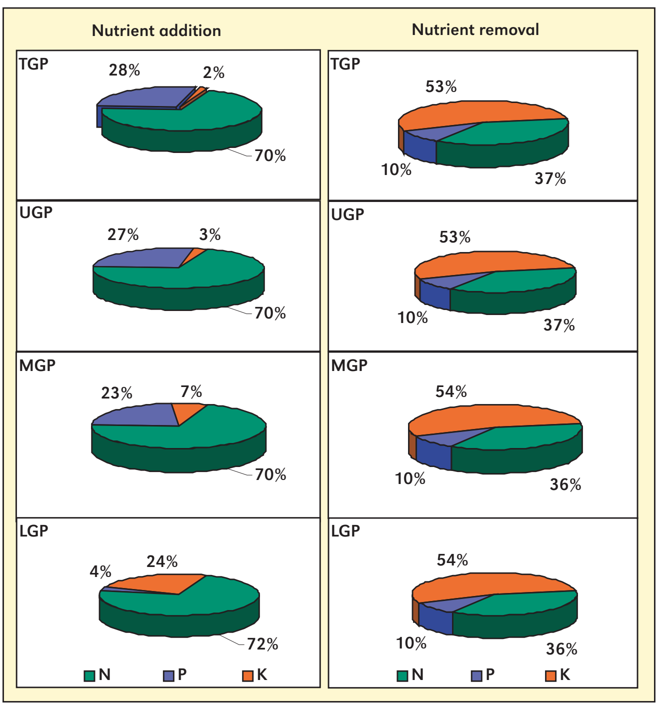
Figure 2. Share of different sources to nutrient contribution (NPK addition) in RWCS, Indo-Gangetic plains region.

alarming (**Table 2**). An average system producing 3.92 t/ha of rice and 3.95 t/ha of wheat annually removes 331,000, 2,900, 3,800, 6,700, 9,200, and 800 t of S, zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and boron (B), respectively. With the exception of Zn, which has a positive balance, additions for these nutrients are almost completely ignored. Many long-term experiments provide evidence of declining productivity and increasing soil micronutrient deficiency can be considered a likely cause.

Table 2 Region-wise nutrient removal ('000 t) in RWCS, Indo-Gangetic plain region.

Sub-regions	Removal of Nutrient								
	N	P	K	S	Zn	Fe	Mn	Cu	B
TGP	682	186	982	142	1.23	1.65	2.87	3.92	0.32
UGP	548	146	782	113	1.00	1.31	2.31	3.16	0.26
MGP	335	92.6	500	69.8	0.60	0.80	1.40	1.92	0.16
LGP	33.5	9.2	49.8	7.0	0.06	0.08	0.14	0.19	0.02
Total	1,598	434	2,314	331	2.89	3.84	6.72	9.19	0.76

Figure 3. Share of NPK addition and removal by RWCS, Indo-Gangetic plains region.



It is clear that N is the dominant nutrient used in all sub-regions…on average, 71% of total NPK added (**Figure 3**). The share of P addition ranges from 4% in the LGP to 28% in the TGP; however, the share of K application is as low as 2% in the TGP, 30% in the UGP, 7% in the MGP, and 24% in the LGP. In contrast, K removal is higher than N removal (54% versus 36%). Phosphorus has the lowest share (10%) of total NPK removal.

Nutrient Balance—The apparent (gross) and net NPK balances for the different sub-regions are provided in **Table 3**. All sub-regions have positive gross N balances which sum to 1.31 M t for the whole. Though the overall gross P balance is also positive, TGP and LGP have negative balances. The gross K balance is negative in all sub-regions and sum to an overall imbalance of -1.59 M t (**Figure 4**).

Based on use efficiencies of 50%, 35%, and 70% for N, P and K, the net balances are negative for all three nutrients in all sub-regions, except for N in the MGP. Thus, taking the whole region, annual NPK depletion from soil reserves is estimated at 2.22 M t.

Table 3 Nutrient balance (Gross and Net, '000 t) in RWCS, Indo-Gangetic plains region.

Sub-regions	Gross nutrient balance			Net nutrient balance		
	N	P	K	N	P	K
TGP	424	-2.1	-797	-129	-122	-852
UGP	401	9.2	-514	-73.4	-91.6	-594
MGP	457	37.7	-262	60.9	-47.0	-333
LGP	27.5	-5.6	-20.9	-3.0	-7.9	-29.5
Total	1,309	39.2	-1,593	-145	-268	-1,810

Note: Net return is based on recovery efficiency of NPK @ 50, 35, and 70%, respectively, in cropping system.

Potassium's share of this deficit is 82% while P and N are 12.5% and 5.5%, respectively. Potassium additions for the different sub-regions range be tween 57.6 to 104.3 kg K/ha...much lower than the range of K uptake by crops (175 to 287 kg K/ha) leading to an average negative balance of 142 kg K/ha. These highly negative K balances are confirmed by a series of long-term experiments conducted with alluvial soils in Ludhiana, Pantnagar, Kanpur, Varanasi, Faizabad, Sabour, and Kalyani under the aegis of the All India Coordinated Project on Cropping Systems Research (Ladha et al. 2003).

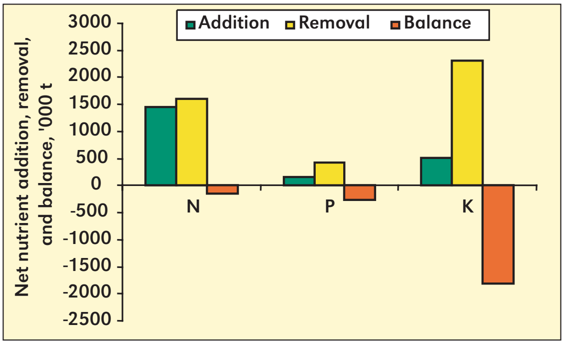


Figure 4. NPK addition, removal, and balance in RWCS, Indo-Gangetic Plains region.

The nutrient balances for the different sub-regions appear to be of serious concern, particularly with respect to soil K. The affect of these negative K balances is also visible on available soil K contents at present, despite high K-supplying capacity of illite-dominated soils and moderate to high non-exchangeable K contents. As the contribution of this pool to crop uptake is greater than the exchangeable pool, available soil K content is not providing a good reflection of the degree soil depletion resulting from actual removal of K by the RWCS. The negative balances for N and P are also troubling.

When considering nutrient use needs, the present and projected crop production goals and nutrient supplying capacity of soils also needs deliberation. For the Indo-Gangetic plains of India, nutrient depletion (particularly of K and P) on a continued basis would lead to serious loss of soil fertility and eventually jeopardize future sustainability. BC

Dr. Shukla is Senior Scientist with Central Potato Research Institute Campus, Modipuram, Meerut-250110. Dr. Sharma is Project Director and Mr. R. Tiwari is Research Associate with Project Directorate for Cropping System Research, Modipuram, Meerut-250110. Dr. K.N. Tiwari is Director, PPI/PPIC-India Programme, 133 Sectors – 23, Gurgaon, 122017, Haryana, India; e-mail: kntiwari@ppi-ppic.org.

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Fertilizer Nutrients and Human Nutrition

It's easy to see the link between fertilizers and food production. The world could not produce the food it needs without fertilizers. In fact, research summaries show that commercial fertilizers are responsible for at least 40 to 60% of crop yields in North America and Europe and much more in tropical areas. But at least as important is the potential for fertilizers to alleviate human nutrition problems.

Human nutritional deficiencies are widespread. While hunger...lack of adequate food...affects hundreds of millions, many more suffer from some kind of nutritional deficiency, which may result in stunted growth, retardation, disease, physical deformity, or even death. Society generally recognizes that fertilizers are needed to produce food, but there is often confusion or misinformation about the role, the source, and the management of nutrients that form or help build the nutritional components of the food we eat. Confusion about the similarities and differences between organic and inorganic nutrient sources is common. Many people believe that organic nutrients promote food quality, while inorganic nutrients promote only quantity...this differentiation is incorrect. High yielding and nutritious food can be and is produced with either organic or inorganic fertilizers.

The key to producing high quantity and high quality food is adequate and balanced nutrition. Just like people, crops need a balanced diet of essential nutrients in sufficient amounts to ensure that growth is not limited and nutrition is not compromised. Organic nutrients work well if there is access to them, but there are just not enough manure and other organic nutrient sources available to produce all the food the world needs, and these sources often do not contain enough of the essential nutrients to produce nutritious foods. Inorganic fertilizers in concert with available organic sources are the solution to most of the world's food and human nutrition problems. **Let's make sure society is aware of how essential commercial nutrients are for producing adequate and nutritious food.**

David W. Dibb
President, PPI

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