BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI) 2010 Number 1

Nutrient Deficiency Photo Contest Winners

In This Issue...

Sensor-Based Nitrogen Management Implications

On-farm Demonstrations in Argentina Central Pampas

Potassium for Quality of Fruits and Vegetables

Also:

Rice-Wheat Cropping under No-till in China

...and much more

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Our cover: Winning images from Nutrient Deficiency Photo Contest. See pages 16-17 for more details.
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Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* (and previous issues) can be found as PDF files at the IPNI website: >**www.ipni.net/bettercrops**<

New Videos from IPNI Feature 4R Nutrient Stewardship

During production of the 4R videos, Dr. Phillips is shown during a field shooting session.

4R nutrient stewardship is focused on four central components: applying the right fertilizer source at the right rate, at the right time in the growing season, and in the right place. Each of the four "rights" is directly related to the other three in at least one way, interconnected into a unified, effective system.

Two new video programs produced by the International Plant Nutrition Institute (IPNI) and introduced in 2010 are carrying the message of 4R nutrient stewardship to audiences around the world.

"The Right Way to Grow…4R Nutrient Stewardship" runs more than 11 minutes and gives an overview of the 4Rs. It explains how the concept can apply to large-scale agriculture in developed countries and also to small-holder farms in less developed regions. Through graphics and field scenes, the presentation provides more insight for further understanding of the 4Rs.

"The Right Way to Grow Wheat…4R Nutrient Stewardship" is a separate video which runs more than 8 minutes and specifically addresses the economic, environmental, and social goals of sustainable agricultural systems needed to meet global demand for wheat. As a staple in almost all human diets, additional wheat production will be needed in the future to help feed rapidly growing populations.

"Agronomists, crop advisers, growers, and others see 4R nutrient stewardship as a positive, proactive approach to achieving better crop nutrient management. Identifying the most appropriate fertilizer source, determining the right rate through soil testing and other methods, timing applications to avoid nutrient loss and get the best response, and choosing the best placement option for the crop – all these are examples of the practical side of 4R nutrient stewardship, " says Dr. Steve Phillips, IPNI Southeast U.S. Regional Director. He was part of a work group that developed the videos and he served as narrator of the wheat video.

IPNI President Dr. Terry Roberts notes that environmental concerns related to nutrient use are becoming increasingly visible in the U.S., with questions about nutrient loads in the Chesapeake Bay and the Mississippi River Basin and in Canada with Alberta's Nitrous Oxide Emission Reduction Protocol (NERP), and in many other regions of the world as policymakers scrutinize nutrient use and consider regulations. "We all share the responsibility to communicate with the public about our industry and help them understand that we are enabling the world to grow food and are doing so in a responsible and sustainable manner," he emphasizes. "IPNI is committed to helping the industry support the appropriate use of fertilizers by providing useful tools that demonstrate our commitment to nutrient stewardship. These two videos are good examples of such tools."

The videos can be viewed for free by visiting the IPNI website at: >www.ipni.net/video<.

Both programs are also available on DVD and may be purchased from IPNI at US$10.00 each, plus shipping.

For more information, contact:
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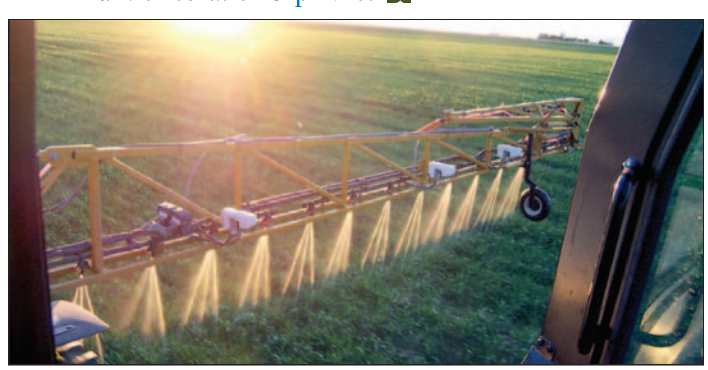
E-mail: circulation@ipni.net BC

Photo courtesy of International Rice Research institute



Whether in large scale production or small farm production, the principles of 4R nutrient stewardship apply.

Economic and Environmental Implications of Sensor-Based Nitrogen Management

By Darrin F. Roberts, Newell R. Kitchen, Kenneth A. Sudduth, Scott T. Drummond, and Peter C. Scharf

Active-light reflectance sensors are currently being studied as a tool to guide in-season "reactive" N application. A recent study evaluated the potential economic benefit and environmental implications for sensor-based N application in corn. Economic benefits and N savings were found for most fields. Results from this study support the continued development of sensor-based technology for in-season N management.

The quest for precision in N management, both by improved prediction of crop N needs (i.e., fertilizer rate) and by synchronizing fertilizer application with plant N uptake, has prompted numerous recent investigations exploring the potential of active-light, crop-canopy reflectance sensors (Raun et al., 2002; Mullen et al., 2003; Raun et al., 2005; Teal et al., 2006; Freeman et al., 2007; Dellinger et al., 2008; Shanahan et al., 2008; Schmidt et al., 2009). These sensor systems contain light emitting diodes that emit modulated light onto the canopy (thus the term "active") and detect reflectance of the modulated light from the canopy with photodiodes (Stone et al., 1996). Both visible and near infrared (NIR) wavelengths are typically included, so that reflectance can be interpreted in terms of commonly used vegetative indices to assess crop growth and N status.

Typically, evaluations using this technology have been obtained by comparing the crop in an area known to be non-limiting in N to the crop in areas yet to be or inadequately fertilized. Measurements from the two areas are used to calculate a relative reflectance (sufficiency index, SI) to represent the potential need for additional N fertilizer. A value of SI = 1 would indicate a crop that looks as good as the non-N-limited crop, while SI = 0.4 would indicate an extremely N-stressed crop. Operationally, these sensors can be mounted on N fertilizer applicators equipped with computer processors and variable rate controllers, so that sensing and fertilization is accomplished in one pass over the crop.

Recent field-scale studies in Missouri evaluated these sensors' ability to determine corn N need on a variety of soils. From these studies, the fertilizer rates that returned the maximum profit relative to the current producer N rates were derived. Concurrently, the potential environmental benefits from using reflectance sensing for N fertilization were determined. Sixteen field-scale experiments were conducted over four seasons (2004 to 2007) in three major soil areas. Multiple blocks (182 total blocks) of N rate response plots traversed the length of each field, with each block consisting of 8 treatments (0 to 210 lb N/A on 30 lb N/A increments) applied at the same time as plant sensing, between V7 to V11 growth stages. Canopy reflectance readings were also obtained at this time from an adjacent non-N-limiting area. At the end of the growing season, yield and optimal N rate were determined for each block of N rate treatments, and plant, grain, and soil samples were analyzed for N content. A computer program was written to evaluate the most profitable N rate at different SI levels and fertilizer cost to corn grain price ratios (FGR). **Table 1** shows various FGR values in both metric and English units. Environmental indicators were also examined at the calculated optimal N rate and the producer N rate.

Table 1. Fertilizer to grain ratio (FGR), using metric units and English units (gold shaded) for various combinations of N fertilizer and corn grain prices.

N fertilizer cost	Corn grain price, $/kg 0.079	0.118	0.158	0.197	0.236	0.276	0.315	N fertilizer cost
--$/kg--	FGR							--$/lb--
0.44	5.6	3.7	2.8	2.2	1.9	1.6	1.4	0.20
0.66	8.4	5.6	4.2	3.4	2.8	2.4	2.1	0.30
0.88	11.2	7.5	5.6	4.5	3.7	3.2	2.8	0.40
1.10	14.0	9.3	7.0	5.6	4.7	4.0	3.5	0.50
1.32	16.8	11.2	8.4	6.7	5.6	4.8	4.2	0.60
1.54	19.6	13.1	9.8	7.8	6.5	5.6	4.9	0.70
1.76	22.4	14.9	11.2	9.0	7.5	6.4	5.6	0.80
1.98	25.2	16.8	12.6	10.1	8.4	7.2	6.3	0.90
2.21	28.0	18.7	14.0	11.2	9.3	8.0	7.0	1.00
	2.00	3.00	4.00	5.00	6.00	7.00	8.00	
	corn grain price, $/bu							

Economic Profitability

For site-specific management technology to be adopted at the farm level, it is essential to examine economic profitability. **Figure 1** shows the N fertilizer rates determined to give the highest marginal profit using the reflectance sensors. The broken lines connected by different colored points represent different FGR values. Across all soils, the amount of N for optimal profit increased as SI decreased from 0.9 to 0.75. This expression, as seen in the graph, validates the canopy sensors' ability to delineate corn N need. Based on preliminary findings later reported in Scharf and Lory (2009), we developed an algorithm in 2004 that farmers could use with reflectance sensors for adjusting N fertilizer rate. This line is shown as a solid black line in **Figure 1**. For typical FGR values, this study validates that algorithm as useful.

Below 0.75, the most profitable N rate stayed approximately the same or decreased slightly. Agronomically, the downward turn in the most profitable N rate seen for the lowest SI values suggests that yields of corn with greater N deficiency generally

Abbreviations and notes: N = nitrogen.

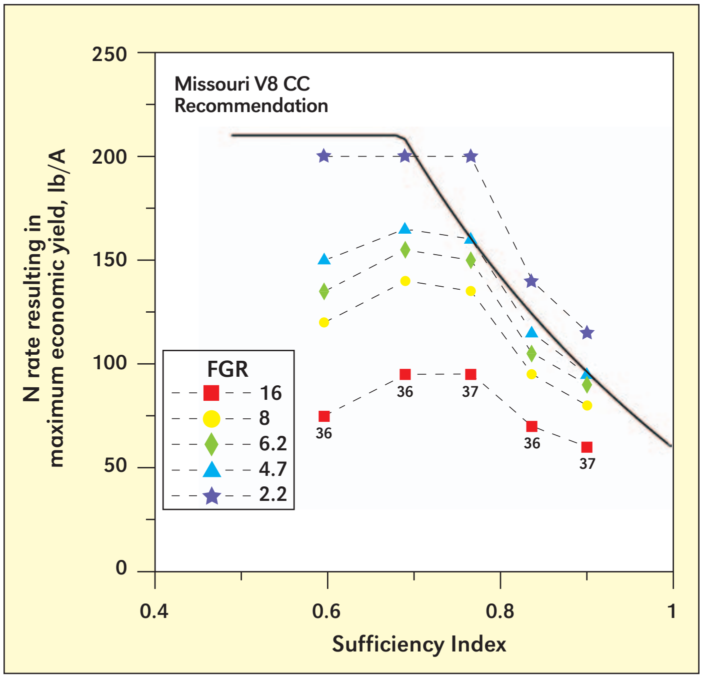


Figure 1. Nitrogen fertilizer rates that gave the maximum economic return compared to producer N rates are shown relative to the canopy sensor sufficiency index. The N rate for highest marginal profit was determined with a number of different FGRs for N.

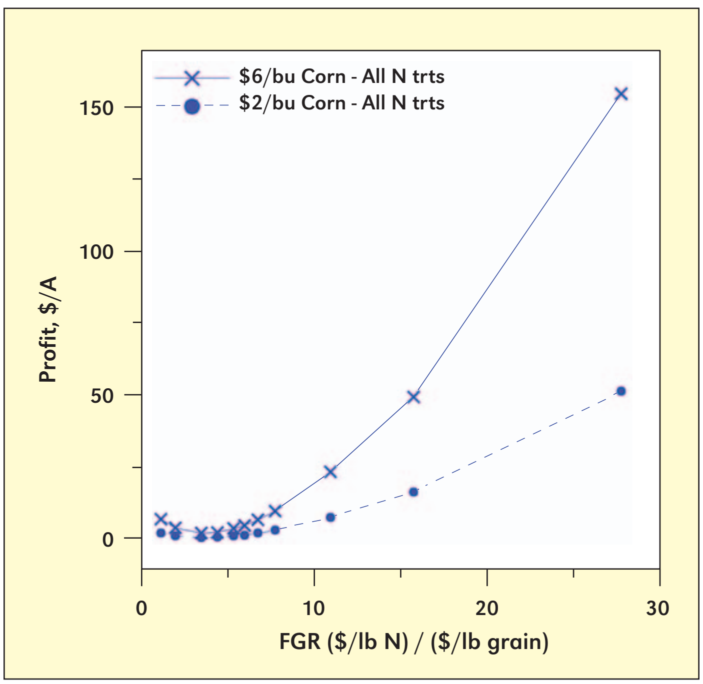


Figure 2. Marginal profit, defined as the difference in the N fertilizer cost and the value of yield gain or loss, relative to FGR.

cannot be compensated by increasing the amount of fertilizer. In general, we believe this to be corn that was severely N-stressed early in the season when yield components were being defined, thus yield potential was lost. The exception would be when fertilizer N is very inexpensive relative to grain prices (i.e., low FGR). Then the most profitable N rate is the maximum (210 lb N/A in our analysis). The upward shift in lines with decreasing FGR values in **Figure 1** indicates that the most profitable N rates increase as FGR decreases. When

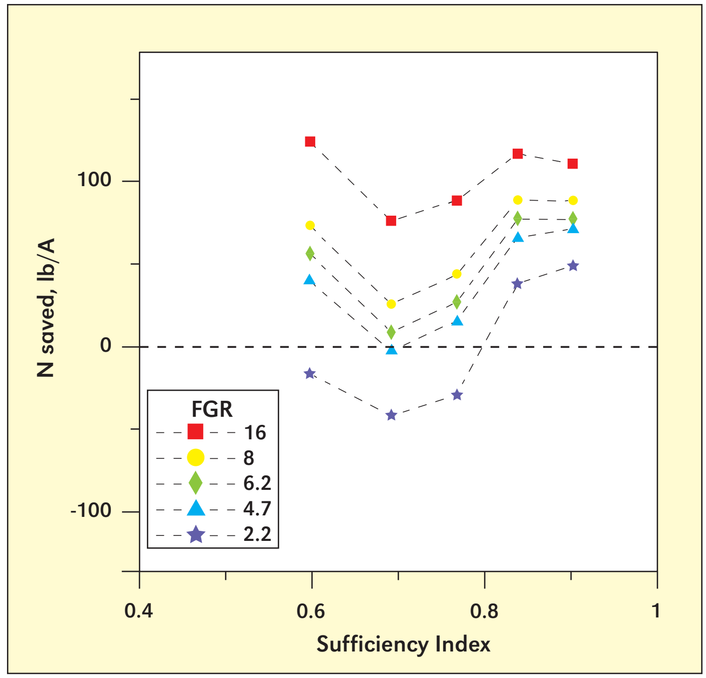


Figure 3. Nitrogen saved relative to the canopy sensor sufficiency index. This relationship for N was evaluated for a number of different FGRs.

the cost of fertilizer relative to grain price increases (high FGR values), the highest profit is achieved by applying less N fertilizer. In other words, N costs become a more important factor in the marginal profit.

Another way of looking at the impact the FGR has on profit is illustrated in **Figure 2**. Here, profit using the sensors increased in an exponential fashion as the FGR increased. Conversely, as fertilizer cost decreased relative to grain price, the economic value of using canopy sensors for N management diminished. We found that with all soils combined, and with FGR values typical of what producers have seen in the past decade, profit using the sensors will range, on average, from $10 to $20/A. However, the price paid for corn grain can have a significant effect. With corn priced at $2/bu, profit ≥ $10/A could only be accomplished when the FGR was ~13 or greater. However, with corn priced at $6/bu, that same profit or more could be achieved when the FGR was ~ 7. In this scenario, corn price tripled while N price increased by only a factor of 1.6. Therefore, equivalent profit was achieved with the higher grain price and lower FGR. Thus, as illustrated in **Figure 2**, both the FGR and the absolute grain price will determine the profit potential.

Potential Environmental Benefits

In addition to potential economic benefits, we projected the environmental implications of sensor-based N management. For many fields, the calculated economic optimal N rates were less than the current producer N rate for these same fields. Thus, to the extent the canopy sensors could estimate optimal N rate, we found higher yield efficiency, higher N fertilizer recovery efficiency, less unaccounted-for N, and less post-harvest inorganic soil N (data not shown). Our results generally showed that sensor-based N application would apply less N in many field situations **(Figure 3)**. Combined over all soil types and at FGR values typical in recent years (range from 4 to 9), N savings of 10 to 45 lb/A could be expected. In a

A high clearance vehicle equipped with active-light reflectance sensors to guide in-season N application. Inset: The Holland Scientific Crop Circle™ ACS-210 Sensor (top) and NTech Industries GreenSeeker® Sensor (bottom) project their corresponding light pattern onto the soil surface.

few situations when SI values and FGR ratios were especially low, sensor-based strategies would actually call for more N than the producer N rate, but doing so was the more profitable strategy.

Sensor-Based N Management

Our results affirm that in many fields crop-canopy reflectance sensing has potential for improving N management over conventional uniform N application. A precondition to the benefits of this sensor-based approach is that the sensor information can be processed by a decision-rule algorithm into a N rate that approximates the optimal N rate. The algorithm we have used since 2004 was a good first start. Including specific weather, soil, crop stage, landscape attributes, and corn market factors in the evaluation may be needed to improve estimations of N fertilizer requirements in relation to reflectance sensing. Our results support continued development of reflectance sensing technologies for improved N management. BC

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References

Dellinger, A.E., J.S. Schmidt, and D.B. Beegle. 2008. Agron. J. 100:1546-1552.
Freeman, K.W., K. Girma, D.B. Arnall, R.W. Mullen, K.L. Martin, R.K. Teal, and W.R. Raun. 2007. Agron. J. 99:530-536.
Mullen, R.W., K.W. Freeman, W.R. Raun, G.V. Johnson, M.L. Stone, and J.B. Solie. 2003. Agron. J. 95: 347-351.
Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, and E.V. Lukina. 2002. Agron. J. 94:815-820.
Raun, W.R., J.B. Solie, M.L. Stone, K.L. Martin, K.W. Freeman, R.W. Mullen, H. Zhang, J.S. Schepers, and G.V. Johnson. 2005. Soil Sci. Plant Anal. 36: 2759-2781.
Scharf, P.C. and J.A. Lory. 2009. Agron. J. 101:615-625.
Schmidt, J.P., A.E. Dellinger, and D.B. Beegle. 2009. Agron. J. 101:916-924.
Shanahan, J.F., N.R. Kitchen, W. Raun, and J.S. Schepers. 2008. Comp. Electron. Agric. 61:51-62.
Stone, M.L., J.B. Solie, W.R. Raun, R.W. Whitney, S.L. Taylor, and J.D. Ringer. 1996. Trans. ASAE 39:1623-1631.
Teal., R.K., B. Tubana, K. Girma, K.W. Freeman, D.B. Arnall, O. Walsh, and W.R. Raun. 2006. Agron. J. 98:1488-1494.

Liming Effect on Pineapple Yield and Soil Properties in Volcanic Soils

By Francisco Mite, José Espinosa, and Lorena Medina

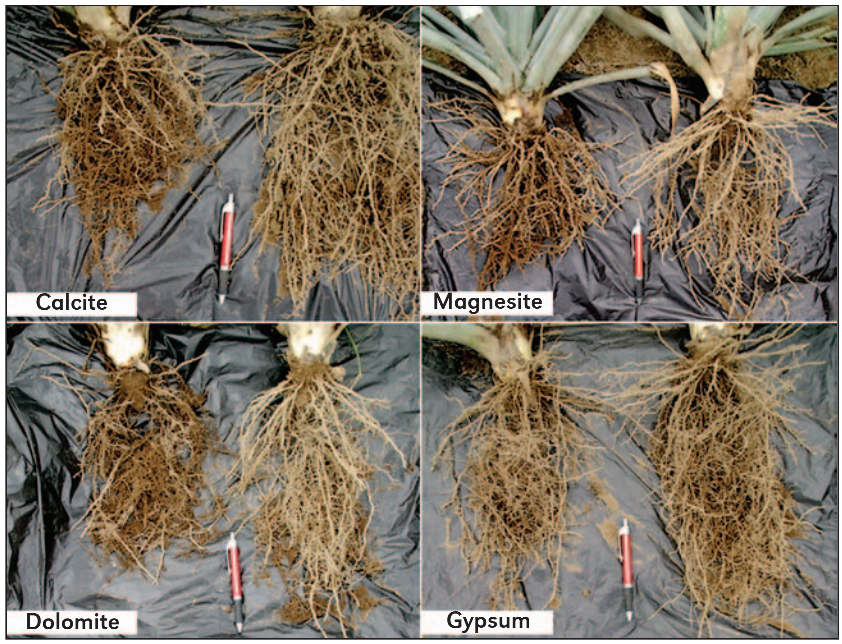
The coastal plain, volcanic soil region of Ecuador is well suited to pineapple cultivation. Crop area expansion continues within the central and northern coastal plain. This growth is based on the availability of new pineapple genetic material, particularly the high yielding MD2 hybrid, which has excellent flavor and good acceptance in the international market.

In Ecuador, the coastal plain region receives over 3,000 mm of rain each year. This high rainfall promotes high rates of leaching, which is related to the low CEC generated by acidity in variable charge soils. This condition, along with the high concentration of Al^{3+}, limits the yield potential of MD2 pineapple. In these conditions, the use of soil amendments can improve chemical, physical, and biological properties of the soil by precipitating Al^{3+} and increasing CEC. However, farmers and technicians commonly resist liming based on the preconceived notion that even severe soil acidity is not a problem in pineapple cultivation. It is commonly accepted that pineapple grows better in acid soils, but extreme soil acidity can cause problems even for this more tolerant crop.

A laboratory and field experiment was designed to test the effect of different soil amendments in volcanic soils cultivated with pineapple. The objectives of the study were: 1) to evaluate the effect of soil amendments on the chemical characteristics of volcanic variable charge soils, 2) to identify the best type and rate of soil amendment, and 3) to evaluate the effect of the amendments on pineapple root growth and yield.

A pot incubation experiment was carried out in this study's laboratory phase to test the effect of the addition of calcite ($CaCO_3$), magnesite ($MgCO_3$), dolomite ($CaCO_3 \cdot MgCO_3$), and gypsum ($CaSO_4 \cdot H_2O$) on soil pH, Al^{3+} precipitation, and CEC. Rates of 0, 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, and 10.5 t/ha of each amendment were applied to an acid volcanic soil (**Table 1**). The treated soil was incubated for 30 days and then analyzed for pH, Al, and CEC.

For the second phase of the study, a field experiment was planted in February 2007 and harvested in May 2008. Climatic conditions of the experimental site are as follows: 24.4 °C average temperature, 3,530 mm annual precipitation, 88% relative humidity, 975 mm annual evaporation, and 779 hours annual solar radiation. The soil was a classic Andisol formed

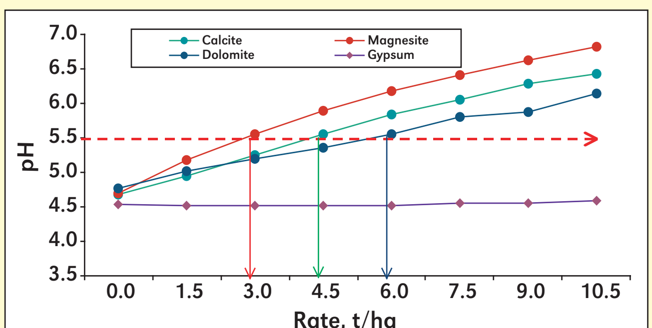


Effect of amendment application on root growth of MD2 pineapple cultivated in an acid volcanic soil.

Table 1. Chemical and physical characteristics of the site (Andisol, Ecuador).

Water (2:1) pH	OM	S	P	NH_4^+	K	Ca	Mg	Al+H
			Modified Olsen ($NaHCO_3$ + EDTA)					
	%	------ mg/kg -------			--------- $cmol_c$/kg ---------			
4.4	5.8	24(H)	16(H)	19(L)	0.3(M)	2.0(L)	0.3(L)	1.5(H)

H=high; M=medium; L=low; OM by Walkley-Black; S by $CaHPO_4 \cdot H_2O$; Al+H by 1N KCl.



Al^{3+} content, cmol/kg

Calcite	0.9	0.3	0.1	0.1	0.0	0.1	0.0	0.0
Magnesite	0.9	0.5	0.2	0.2	0.2	0.3	0.3	0.3
Dolomite	0.9	0.3	0.0	0.2	0.1	0.0	0.1	0.3
Gypsum	0.9	0.6	0.6	0.6	0.7	0.6	0.5	0.5

Figure 1. Soil pH and Al content at each rate of different amendment in a volcanic soil from the coastal plain of Ecuador.

Abbreviations: CEC = cation exchange capacity; Al = aluminum; OM = organic matter; KCl = potassium chloride; $BaCl_2$ = barium chloride.

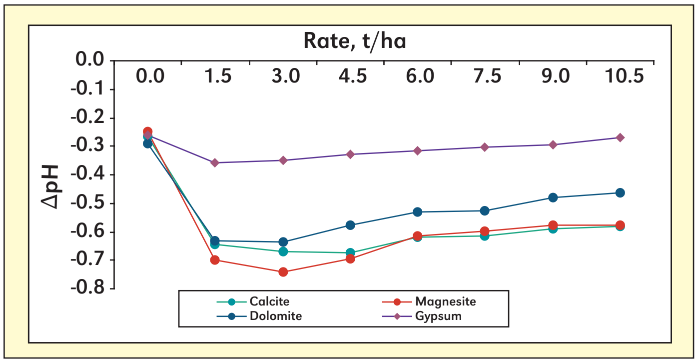
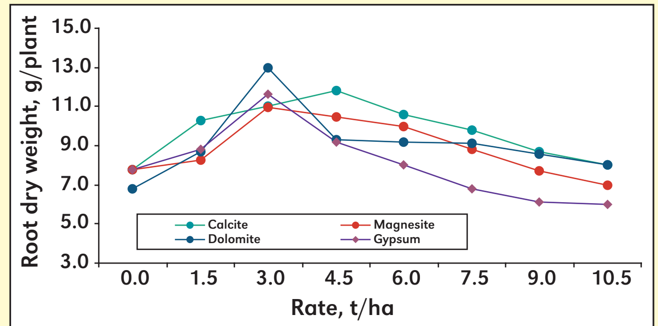


Figure 2. Effect of amendment application on Δ pH volcanic soil from the coastal plain of Ecuador.

from the depositions of volcanic ash from past activity within the northern highlands of Ecuador. The same treatments used in the incubation study were tested in this field experiment. Treatments were placed in the field as a randomized complete block design arranged in split plots with four replications. Main plots were the amendments and subplots were the amendment rates. Root weights at flowering and total yield at harvesting were evaluated.

Results of the incubation experiment show the effect of the different amendments on soil pH after 30 days of incubation (**Figure 1**). As expected, calcite, magnesite, and dolomite had a marked effect on soil pH. To reach a pH value of 5.5, enough to precipitate Al^{3+} in this particular volcanic soil, 2.9, 4.4 and 5.9 t/ha of locally available magnesite, calcite, and dolomite, were needed, respectively. As expected, gypsum did not induce any change in soil pH.

One of the main chemical changes induced by amendment application is an increase in negative charge on the collective soil colloid surface. This change can be measured by the difference between pH determined in 1N KCl and pH measured in water (Δ pH = $pH_{KCl} - pH_{H2O}$). The sign and magnitude of the Δ pH correspond to the sign and magnitude of the colloid surface (Nanzyo et al., 1993), and the effect of amendment application on Δ pH is presented in **Figure 2**. The increase in surface charge was more evident with the carbonate-based amendments compared to gypsum, but in all cases an increase was observed only with the lower rate (1.5 t/ha), which was enough to precipitate Al^{3+}.



Al content at depth of 0 to 10 cm, cmol/kg

	0.0	1.5	3.0	4.5	6.0	7.5	9.0	10.5
Calcite	0.8	0.3	0.1	0.1	0.0	0.1	0.0	0.0
Magnesite	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Dolomite	0.8	0.3	0.0	0.1	0.1	0.1	0.0	0.0
Gypsum	0.8	0.7	0.5	0.6	0.7	0.6	0.7	0.3

Figure 3. Effect of amendment application on pineapple root growth and Al content in the soil.

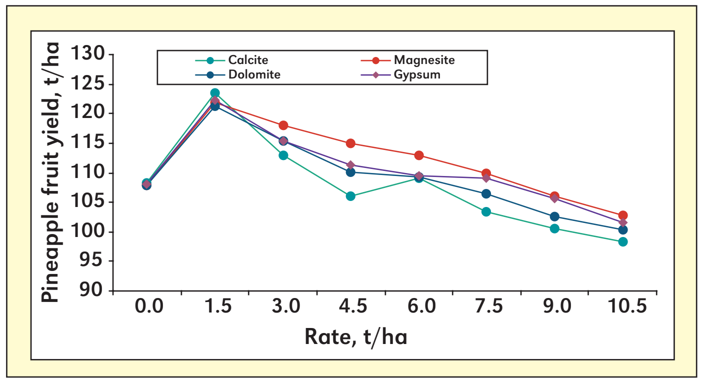


Figure 4. Effect of amendment application on MD2 pineapple fruit yield.

Another way of measuring the effect of soil amendments on surface charge is CEC determination. One of the most popular methods to determine CEC utilizes 1 M ammonium acetate (NH_4OAc) buffered at pH 7.0. There are other methods which also use buffered solutions at pH 7.0 or 8.2. These methods work well in soils dominated by permanent charge clays, but their use in soils dominated by variable charge clays is not satisfactory. Buffered solutions artificially create surface charge in the lab during CEC determination and do not represent the real soil CEC that plants "see" in the field (Uehara and Gillman, 1979). Methods which evaluate CEC using unbuffered (indifferent) solutions perform a better job in these types of soils.

One of these methods uses $BaCl_2$ as the saturating solution. **Table 2** presents CEC data obtained using NH_4OAc and $BaCl_2$ in the incubated volcanic soil utilized in this study. The CEC determination with the indifferent salt allowed for a better assessment of soil capacity to retain cations and reflects clearly the effects of the liming materials (calcite, magnesite, and dolomite) in charge generation on the colloid surface. Liming

Table 2. Comparison of CEC determination with $BaCl_2$ and NH_4OAc in an Andisol incubated after 30 days with four different soil amendments.

Rates, t/ha	$BaCl_2$				NH_4OAc			
	Calcite	Magnesite	Dolomite	Gypsum	Calcite	Magnesite	Dolomite	Gypsum
	CEC, $cmol_c$/kg of soil							
0	7.03	6.43	7.61	5.83	24.02	23.72	23.42	21.84
1.5	7.66	7.43	7.45	6.29	23.72	23.92	24.02	22.03
3.0	8.36	9.41	7.56	6.17	22.83	24.42	24.22	22.13
4.5	9.21	10.15	9.43	6.47	25.81	23.72	24.91	22.03
6.0	9.75	11.75	9.71	6.76	23.62	24.71	24.61	22.33
7.5	11.64	13.31	10.85	6.62	23.52	25.51	25.81	22.43
9.0	12.44	13.74	11.23	6.29	23.72	24.81	24.61	23.22
10.5	13.61	14.63	12.06	6.90	24.12	25.31	25.41	22.23

High rates of amendments can induce the presence of Phytopthora sp in pineapple, as shown in this plot.

This study indicates that in tropical Andisols, soil amendments can be beneficial if caution is used to avoid over-application.

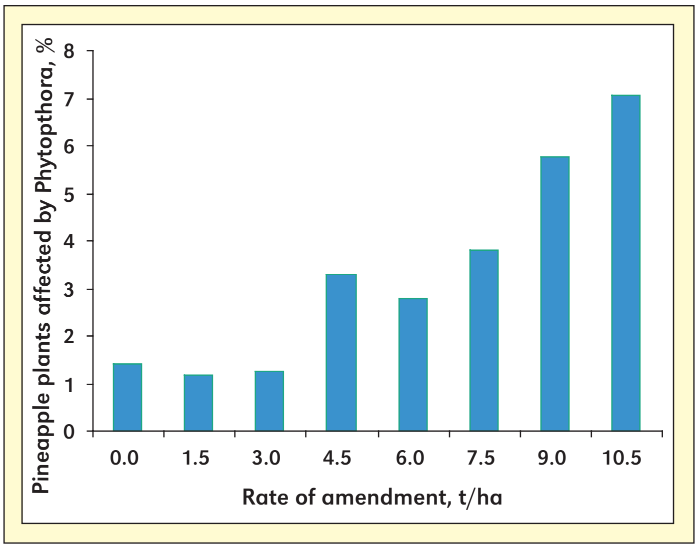


Figure 5. Effect of rates, across amendment materials, on the percentage of Phytopthora sp infection on MD2 pineapple.

of variable charge soils does not produce a radical change in soil pH. The OH^- ions, product of the lime reaction in the soil, are adsorbed by the active colloid surface generating negative charge. **Table 2** also shows that CEC determination with NH_4OAc overestimates the charge on the colloidal surface and for this reason it loses sensitivity in its ability to evaluate charge generation by lime application. One of the benefits of liming variable charge soils is the increase in CEC which allows greater cation retention, an important factor in soils subject to high leaching like the volcanic soils of the study.

Figure 3 presents the data of root growth measured at flowering and the concentration of Al^{3+} as affected by amendment application. A positive effect on root growth is observed with the 1.5 and 3.0 t/ha rates. The positive effect of amendment application is related to Al^{3+} precipitation by lime and the complexation of Al^{3+} by gypsum (van Raij, 2008). There is no response to amendment application once Al^{+3} has been eliminated as limiting factor as indicated by lack of response to the higher amendment rates. The reduction of root growth with the higher amendment rates suggests that other limiting conditions are affecting pineapple plants after soil reached pH values over 5.5.

The effect of amendment application on pineapple fruit yield is presented in **Figure 4**. A rate of 1.5 t/ha was sufficient to obtain the highest yields. Again, the effect of amendment application on soil Al^{3+} explains the response. Once Al^{3+} has been precipitated or complexed, there is no need for higher rates of application. Actually, fruit yield was reduced with higher amendment rates, due to the presence of *Phytopthora* sp, a known risk of over-applying lime (Fitchner et al., 2006) See **Figure 5** and photo of plots. This is perhaps the reason why pineapple producers resist lime application to improve soil pH.

The data of this study demonstrate that in tropical Andisols the application of soil amendments to eliminate Al^{3+} as a limiting factor is a proper and profitable practice if caution is used to avoid over-application. It is well known that Andisols have a high buffering capacity which varies with the type of ash and soil history (Nanzyo et al., 1993). For this reason, it's difficult to use general lime recommendation for all the sites based only on Al^{3+} content of the soil as is common practice in Ultisols and Oxisols. In the case of Andisols, this study suggests a simple incubation experiment as a good strategy to assess appropriate lime amendment rates required on a site-specific basis. BC

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References

Fitchner, E.J., D.L. Hesterberg, T.J. Smyth, and H.D. Shew. 2006. Phytopathology 96(3):212-220.

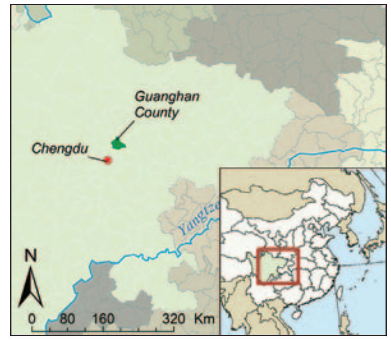
Nanzyo, M., R. Dahlgren, and S. Shoji. 1993. *In* S. Shoji, et al., eds. Volcanic ash soils, Vol. 21. Elsevier Science Publishers, Amsterdam.

Uehara, G. and G. Gillman. 1979. The mineralogy chemistry, and physics of tropical soils with variable charge clays. Westview Press, Boulder, Colorado, USA.

van Raij, B. 2008. Gesso na agricultura. Instituto Agronomico de Campinas, Campinas, Brasil.

Determining an Optimal Fertilization Strategy for No-till Rice-Wheat Cropping

By Shihua Tu, Xifa Sun, Minglan Liao, Yusheng Qin, and Wenqiang Feng



Continuous no-till cultivation is a novel practice that is gaining popularity over conventional methods in the Chengdu Plain and elsewhere in China. The effect of fertilizer rate, balance, and timing on agronomic and environmental parameters is outlined in this multi-year study.

Rice accounts for about one-third of the farmland area used for grain production in Sichuan Province. The majority of paddy rice in the Sichuan Basin, the fertile lowland located in central and eastern Sichuan framed by mountains on all sides, is grown as a single summer crop which is rotated with wheat or rapeseed in the winter season. Prior to 2000, most of these farmlands were plowed (with cattle or by hand with hoes) after each crop harvest before seeding or seedling transplanting. As more and more rural labor has migrated to cities for better incomes, no-till or reduced tillage practices have become popular by necessity. This is especially true for the light-textured alluvial soils of the Chengdu Plain where it is common to find fields under 5 years or more of continuous no-till cultivation. The objective of this study was to provide science-based information for nutrient management in the no-till cropping system.

The experiment was located in Village No. 5, Xigao Town, Guanghan City of Sichuan, from 2005 to 2008 on an alluvial soil typical of the Chengdu Plain. The soil, sampled and analyzed prior to the field experiment in 2005, was acidic (pH 5.4), relatively rich in organic matter (31.2 g/kg determined using H_2SO_4-$K_2Cr_2O_7$ digest), deficient in P (6.2 mg/kg as Olsen extractable P) and Zn (DTPA extractable Zn 1.3 mg/kg), marginally deficient in K (97.4 mg/kg as 1.0 mol/L neutral ammonium acetate extractable K) and Mn (DTPA extractable Mn 3.7 mg/kg), and medium to high in Ca, Mg, S, Fe, Cu, and B. This soil test information was combined with existing knowledge on fertilizer recommendations used in conventional rice cultivation systems to set up an optimal NPK treatment (OPT) of 150-90-120 kg N-P_2O_5-K_2O/ha for rice and 150-75-60 kg N-P_2O_5-K_2O/ha for wheat. An OPT+ 15 kg $ZnSO_4$/ha treatment was tested in rice, as was an OPT+ 15 kg $MnSO_4$/ha treatment in wheat, to validate soil test values with crop response data and verify the effects of annual applications of Zn and Mn. Nutrient deletion plots individually omitted N, P, and K for both rice and wheat. And lastly, two treatments individually tested reduced N and K rates (75% N and 50% K).

A randomized plot design was used with seven treatments and three replications, all planted no-till into fields that were also previously no-till. The plot size was 12 m^2 (4 m x 3 m). Urea, monoammonium phosphate, and potassium chloride were used as sources of N, P, and K.

In the rice season, all P and Zn rates were applied basally prior to rice transplanting; N fertilizer was split twice with 40% applied basally and 60% as a topdressing at the tillering stage.

Abbreviations for this article: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; Fe = iron; Cu = copper; B = boron; Zn = zinc; Mn = manganese; OPT = optimum.

Table 1. Rice yields as affected by soil test-based OPT recommendation and its variations.

	---------------- Rice yield, kg/ha ----------------				
Treatment	2005	2006	2007	2008	Cumulative
OPT	9,500 a	11,852 a	10,998 a	11,004 a	43,353
-N	8,505 b	9,500 d	9,609 c	8,784 c	36,396
-P	9,240 a	10,595 b	10,907 a	10,175 b	40,914
-K	8,742 b	10,100 c	10,158 b	9,492 c	38,490
75% N	9,521 a	10,230 c	10,508 ab	10,545 ab	40,803
50% K	9,599 a	10,805 b	10,365 b	10,205 b	40,973
+Zn	9,678 a	10,511 bc	10,880 a	10,749 a	41,820

Means in each column followed by the same letter are not significantly different at p = 0.05.
The same applies to the following tables when applicable.

Potassium fertilizer was also split twice with half applied at rice transplanting and the remainder at tillering. In wheat, P and Mn were applied basally at seeding; N fertilizer was split between the basal application (30%) and a side dressing (70%) at tillering stage. Potassium fertilizer was split equally between the basal and tillering stage applications. The plant density was 400,500 hills/ha (dug manually at 2 cm depth) for wheat variety Chuanmai 42 in 2007 and Mianmai 39 in 2008; density was 225,100 seedlings/ha for hybrid rice variety II-You 7 in 2006 and variety Chuanxiangyou 9838 in 2007-2008.

Crop Yields

Rice yields from the 4 individual years and a cumulative total are provided in **Table 1**. Year-to-year fluctuations in rice (and wheat) yields were most likely due to changes in cultivars and weather variation (Xu et al., 2006). The OPT produced a highest rice yield among treatments in 2006 only. Rice yields when no N or K was applied were usually among the lowest, indicating that these two nutrients were the two most prominent yield-limiting factors for no-till paddy rice production. The 75% N treatment was equivalent to the OPT in the first, third, and fourth years, while the 50% K treatment was equal to the OPT in the initial year. Relatively high yields within these reduced rate treatments could be attributed to high soil N and K carry-over from nutrient applications in crops grown just prior to this experiment. In 2004, the region's winter season experienced a severe drought and crops grew poorly, required less nutrients, and yields suffered. Yields from the -P treatment were equal to the OPT in the first and third years despite initial indications of low soil test P. Evidence of significant benefits for Zn could not be detected and it is likely that continuous

Table 2. Wheat yields as affected by soil test-based OPT recommendation and its variations.

Treatment	Wheat yield, kg/ha 2005	2006	2007	Cumulative
OPT	9,270 a	7,322 a	6,510 a	23,102
-N	5,477 e	4,728 c	3,677 e	13,880
-P	8,759 bc	5,562 a	5,336 c	19,654
-K	8,402 d	4,904 b	4,188 d	17,493
75% N	8,940 b	5,636 ab	5,642 bc	20,217
50% K	8,441 d	5,133 b	5,397 c	18,970
+Mn	8,730 bc	6,792 a	6,408 a	21,930

application of Zn fertilizer to paddy rice may be inappropriate since one application is known to correct soil Zn deficiency over several years (Martens and Westermann, 1991).

Wheat yield data from the 3 years of research are provided in **Table 2**. Similar to observations in rice, N, K, and P were identified (in that order) as primary nutrient limitations. Wheat yields fell significantly under the reduced N rate in the first and third year. The reduced K treatment generated yields that were comparable to those with complete omission of K. Though soil Mn was considered marginally deficient, addition of Mn showed a yield loss in year 1, but no effect in year 2 or 3.

The yield reduction caused by the omission of nutrients was more severe in wheat than in rice. The drier winter seasons with lower temperatures appears to have magnified the effect of any nutrient limitations due to increased crop stress, less nutrient diffusion, hampered soil microbial activities, and microbial associated nutrient mineralization, as well as chemical reactions related to soil nutrient chemistry (Jansson and Persson, 1982; Balasubramanian et al., 2004; Havlin et al., 2005). Thus, seasonal differences in temperature and water availability between cropping seasons must be considered to achieve better crop yield and nutrient utilization.

Nitrogen Use Efficiency

Apparent crop recovery efficiency data for N in rice is calculated as: $(U-U_0)/F$; where U = total cumulative N uptake in aboveground crop biomass with N applied and U_0 = total cumulative N uptake in aboveground crop biomass with no N applied, and F = cumulative amount of N applied (Snyder and Bruulsema, 2007) shows a clear effect of reduced N efficiency when K application was omitted or reduced **(Table 3)**. Potassium is crucial in enhancing N uptake by crops and N use efficiency (Dibb and Thompson, 1985; Aulakh and Malhi, 2004). Nitrogen recovery in the 75% N treatment was improved to this study's high of 48.5%. Numerous reports have found decreased N use efficiency with increased N input (Zhu, 1990; Sun et al., 2009). Without proper nutrient balance and timing, higher rates of N do not contribute to improved yields and can lead to higher risk of N loss to the surrounding environment. Nitrogen recovery under the P omission treatment was similar to that observed under the OPT. Uptake of N by paddy rice was not significantly affected by the soil P status at this site. Zinc fertilization had a positive impact on N recovery by rice compared to the OPT. This could be attributed to its function in plants where it forms tetrahedral complexes with N-, O-, and S-ligands (Vallee Auld, 1990), thereby influencing both

No-till rice plots in Sichuan were most limited by N, followed by K and P. Yields from the K-deficient rice plants (right) were partially hampered by advanced heading which took place one week prior to other treatments.

Table 3. Nitrogen use efficiency of rice as affected by soil test-based OPT recommendation and its variations.

Treatment	Cumulative N uptake, kg/ha Grain	Straw	Total	N recovery, %
OPT	568.9	223.8	793	38.5
-N	400.6	161.0	562	-
-P	544.1	254.6	800	39.6
-K	531.9	226.5	759	32.9
75% N	543.2	250.5	795	48.5
50% K	557.1	215.6	771	34.9
+Zn	554.3	285.5	840	46.3

Table 4. Nitrogen use efficiency of wheat as affected by soil test-based OPT recommendation and its variations.

Treatment	Cumulative N uptake, kg/ha Grain	Straw	Total	N recovery, %
OPT	328.5	26.4	355	35.4
-N	170.8	14.1	185	-
-P	280.8	35.7	316	27.4
-K	268.6	31.5	300	24.0
75% N	291.7	29.0	321	30.2
50% K	294.3	30.6	325	29.2
+Mn	331.2	40.7	372	39.0

the tertiary structure of proteins and enzymatic activity. Zinc deficiency was also linked to disorders in N metabolism in rice plants by Kitagishi and Obata (1986).

Compared to rice, wheat had much lower N recovery values regardless of treatment **(Table 4)**. This could be attributed to seasonal differences in temperature and water availability between the two cropping systems.

Soil Nutrient Balance

The partial soil N balance after four seasons of rice and three seasons of wheat is shown in **Table 5**. Considering the entire system, negative soil N balances were calculated for all treatments. However, the N balance was strictly in deficit in rice and in surplus during the winter wheat season (excluding

Table 5. Soil partial N balance as affected by a soil test-based OPT recommendation and its variations after four seasons of rice and three seasons of wheat.

	- - N input, kg/ha - -			- N removal, kg/ha -			Balance,
Treatment	Rice	Wheat	Total	Rice	Wheat	Total	kg/ha
OPT	600	450	1,050	793	355	1,148	-98
-N	0	0	0	562	185	747	-747
-P	600	450	1,050	800	316	1,116	-66
-K	600	450	1,050	759	300	1,059	-9
75% N	480	360	840	795	321	1,116	-276
50% K	600	450	1,050	771	325	1,096	-46
+Zn or +Mn	600	450	1,050	840	372	1,212	-162

The amounts of N input shown do not account for N derived from atmospheric deposition, irrigation water, and microbial fixation. Similarly, N removal lost through runoff or leaching, volatilization, or denitrification is not accounted for.

the -N treatment). Paddy rice generally removed at least twice as much N as was removed by winter wheat. The -N treatment generated the highest N deficit followed by the reduced N treatment, while the -K treatment had the lowest N deficit.

Summary

This study showed the degree to which no-till rice and wheat yields, and fertilizer use efficiency, are affected by fertilizer treatment. Rice produced much higher grain yields and N use efficiency than wheat no matter if the treatment was balanced or imbalanced. These results offer science-based information for improving nutrient management in the rice-wheat system under no-till. BC

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References

Aulakh, M.S and S.S. Malhi. 2004. *In* Mosier et al. (ed) Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and environment. Island Press.

Balasubramanian, V., B. Alves, M. Aulakh, M. Bekunda, Z. Cai, L. Drinkwater, D. Mugendi, C. Kessel, and O. Oemema. 2004. *In* Mosier et al. (ed) Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and environment. Island Press.

Dibb, D.W. and W.R. Thompson, Jr. 1985. *In* Munson, R.D. (ed.) Potassium in agriculture. SSSA. Madison, USA.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 2005. Soil fertility and fertilizers: An introduction to nutrient management, seventh ed. Pearson Education, Inc., Upper Saddle River, New Jersey, USA.

Jansson, S.L. and J. Persson. 1982. *In* Stevenson F.J. et al. (ed) Nitrogen in agricultural soils. SSSA, Madison, USA.

Kitagishi, K. and H. Obata. 1986. Soil Sci. Plant Nutr., 32(3):397-405.

Martens, D.C. and D.T. Westermann. 1991. *In* Mortvedt, J.J. et al. (ed.) Micronutrients in Agriculture, 2nd ed. SSSA. Madison, USA.

Sun, X.F., S. Tu, M.L. Liao, Y.S. Qin, and W.Q. Feng. 2009. *In* Tu, S. (ed.) Research on best nutrient management for different cropping systems in the Southwest China. Sichuan Univ. Publishing House, Chengdu.

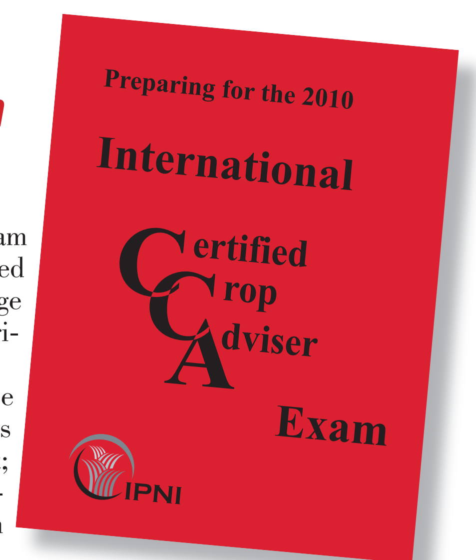
Snyder, C.S. and T.W. Bruulsema. 2007. Nutrient Use Efficiency and Effectiveness in North America: Indices of Agronomic and Environmental Benefit. IPNI, Ref. # 07076.

Vallee, B.L. and D.S. Auld. 1990. Biochemistry, 29:5647-5659.

Xu, M.G., G.Q. Liang, and F.D. Zhang. (ed). 2006. Evolution of soil fertility in China. Publication House of Chinese Agri. Sci., Beijing.

Zhu, Z.L. 1990. Fate of N fertilizers and N management in farmland ecosystems. *In* Zhu,Z.L. and Q.X. Wen, (ed.) Nitrogen in soils of China. Jiangsu Sci-tech Publishing House, Nanjing.

Preparing for the 2010 International Certified Crop Adviser Exam Study Guide Available from IPNI



Individuals preparing for the 2010 International Certified Crop Adviser (ICCA) exam will be interested to know that an updated edition of the popular study guide offered by the International Plant Nutrition Institute (IPNI) is now available. The 173-page training guide is organized and updated each year by Dr. John Gilmour, Professor Emeritus, University of Arkansas, and published by IPNI.

The ICCA exam is based on performance objectives considered as areas of expertise that a Certified Crop Adviser (CCA) should possess. The performance objectives areas are: Nutrient Management, Soil and Water Management; Integrated Pest Management; and Crop Management. The study guide presents subject information for each performance objective, supplemented by sample questions. The study guide includes an answer key for the sample questions.

The 2010 edition of the ICCA exam study guide (Item #50-1000) is available for purchase directly from IPNI. The price of US$50.00 includes shipping and handling. Contact: Circulation Department, IPNI, 3500 Parkway Lane, Suite 550, Norcross, GA 30092-2806. Phone: 770-825-8084; Fax: 770-448-0439. E-mail: circulation@ipni.net.

The ICCA exam study guide may also be purchased on-line by visiting this URL: >www.ipni.net/ccamanual<. BC

Thomas Oberthür Joins Staff of IPNI as Regional Director, Southeast Asia Program

Dr. Thomas Oberthür

Dr. Thomas Oberthür will join the staff of the International Plant Nutrition Institute (IPNI) as Director for the Southeast Asia Region, effective May 1, 2010. He will be based in Penang, Malaysia, and will serve as the leader of IPNI's programs of agronomic research and education in the region. Dr. Oberthür succeeds Dr. Christian Witt in this responsibility. Dr. Witt has joined the Bill & Melinda Gates Foundation as Senior Program Officer for Soil Health, Agricultural Development Program. He will be part of a team focusing on farmer production and agricultural development, targeting Africa and South Asia.

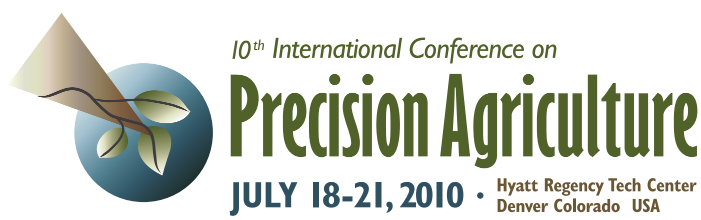
"With his strong skill sets related to problem solving and strategic thinking, plus his expertise in relationships between agricultural product quality and farming systems management, Dr. Oberthür will be a valuable addition to our scientific staff," said IPNI President Dr. Terry Roberts. "We welcome Thomas to the staff and feel assured he will continue the high standards of positive results for the IPNI program in Southeast Asia."

In 1999, Dr. Oberthür received his Ph.D. in Geography at the University of Western Australia, Perth. His dissertation was on improving land resource information and its management in heterogeneous rain-fed environments. In 1994, he received the degree of Diploma Engineer (equivalent to Master of Science) degree through Leipzig University and the International Rice Research Institute. His thesis research was on spatial soil fertility management in irrigated rice. In 2004, he earned Project Management Certification through Crawford Masters Class in Management in Sydney, Australia.

Most recently, Dr. Oberthür worked for the Australian Center for Agricultural Research in research and program operations management. He was responsible for a wide range of adaptive and market driven research projects in Eastern Indonesia. From 2007 to 2008, he was with Ecoagriculture Partners (EP) in program operations management and project development. Previously, Dr. Oberthür was with the International Center for Tropical Agriculture (CIAT) in research and program operations management from 1999 to 2007. As a manager and senior soil scientist, he had a scientific focus on site-specific soil and land management, spatial analyses of production systems, causal relationships between agricultural production and natural resources, and the use of commercial data in agriculture. His experience also includes soil survey and data analyses for the national agronomic soil map for the rice lands of Cambodia, spatial analysis of soils in rice-based cropping systems in the Philippines and other countries, and contributions to the conceptualization and introduction of precision agriculture in tropical farming systems. Dr. Oberthür has worked extensively with the food sector industry and has served as an adviser to projects related to coffee-growing communities.

As a prolific writer and presenter, Dr. Oberthür has contributed to more than 10 books and book chapters, 15 peer-reviewed papers, nearly 20 conference papers, and four technical papers. BC

10th International Conference on Precision Agriculture Set for July 18-21 in Denver



The 10th International Conference on Precision Agriculture (ICPA) is set for July 18-21, 2010, in Denver, Colorado. Dr. Rajiv Khosla of Colorado State University will serve as Conference Chairperson for the event. Dr. Harold Reetz of IPNI/FAR serves on the Organizing Committee, along with Dr. Dwayne Westfall of Colorado State University and Mr. Quentin Rund of PAQ Interactive.

The ICPA is oriented primarily to research progress, and facilitates interactions among scientists, producers, technology company representatives, equipment manufacturers, input dealers, agronomic consultants, software developers, educators, government personnel, and policymakers. Find out more at the ICPA website: **www.icpaonline.org**. BC

Visual Indicators of Potassium Deficiency in Corn

By T.S. Murrell

While marginal chlorosis and necrosis are the most widely recognized symptoms of K deficiency, they are not the only ones. Other plant manifestations can exist and may or may not be accompanied by marginal chlorosis or necrosis. As the number of visible symptoms increases, there is greater likelihood that the plant is experiencing a K deficiency.

The most widely recognized visual expression of K deficiency is marginal chlorosis or necrosis on older, lower leaves on the plant, such as that shown in the accompanying photo. By the time this symptom appears, however, grain yield may have already been lost (Bly et al., 2002). Although this sign is the most well known, it is not the only visual indicator of K deficiency, as this can be also evidenced by many other visual manifestations that can occur, either with or without marginal necrosis, and with severity that varies considerably within a field. As the number of visible symptoms increases, there is greater likelihood that the plant is experiencing a K deficiency. This article lists these additional evidences along with some key references. Seeing some of these indicators can be difficult, however, without a reference area in the field where K is known to be sufficient. Such an area can be created with an ample application of K that is replenished over time to keep up with the K removed by successive crop harvests.

Shorter Plants

It has been known for many years that K deficiency can result in shorter plants. Younts and Musgrave (1958) demonstrated this effect decades ago in two field studies examining different K rates, sources, and placement methods. Across all factors, they found that K fertilization significantly ($p = 0.05$) increased plant heights by 11 to 28%, 10 to 12%, 9 to 16%, and 15 to 36% when measured at 26, 31, 44, and 65 days after planting, respectively.

Reduction in Leaf Dimensions and Surface Area

A measurement quantifying relative differences in leaf area is the leaf area index, or LAI. Leaf area index is the ratio of leaf area to a given unit of land surface area (Watson, 1947). Jordan-Meille and Pellerin (2004) found that corn plants that were deficient in K had a lower LAI than healthy plants. Most of the leaves of K deficient corn plants were narrower and shorter than leaves of K sufficient plants, reducing their overall surface area (**Figure 1**). Leaf numbers 5-7 were most affected by K deficiency and showed reductions in length of approximately 25%. Similar reductions were observed for leaf width, resulting in a nearly 50% reduction in total leaf area. Leaves emerging earlier or later in the season were less affected. For example, leaf numbers 17-20 had lengths, widths, and surface areas equal to or greater than K sufficient plants. Even though these later-developed leaves had larger surface areas, increases were not great enough to compensate for the reductions coming from the older leaves, leading to an overall decrease in LAI.

Slowed Vegetative Development

Potassium deficiency can also delay corn development.

Abbreviations and notes for this article: GDD = growing degree days; K = potassium; N = nitrogen.

Photo source: Dr. C.R. Crozier, Peanut Belt Research Station, North Carolina; second place PPI Photo Contest winner, 2006

Marginal chlorosis and necrosis on lower, older leaves — a visual symptom of K deficiency. The stake indicates zero K treatment.

At all sampling periods, Jordan-Meille and Pellerin (2004) measured a slight but significant reduction in the number of visible and fully expanded leaves in K deficient plants. The maximum difference occurred when 15 leaves were visible in K sufficient plants. At this time, K deficient plants had 0.8 visible leaves less than K sufficient ones, indicating a delay in growth of nearly one vegetative stage. In an earlier greenhouse study, Koch and Estes (1975) reported no delay in the number of fully expanded leaves up to the end of their sampling period, which was leaf 11. These results are not necessarily inconsistent with those of Jordan-Meille and Pellerin (2004), since their maximum delay in maturity was less than one leaf and they reported visible, rather than fully expanded leaves.

Delayed Tasseling

Corn plants with insufficient K may take longer to reach the VT growth stage (tasseling) than plants with sufficient K. Peaslee et al. (1971) found that unfertilized, K deficient plants sown early in the season took 84 growing degree days (GDD) longer to reach VT than plants well supplied with K. Unfertilized corn planted later took 53 GDD longer to reach

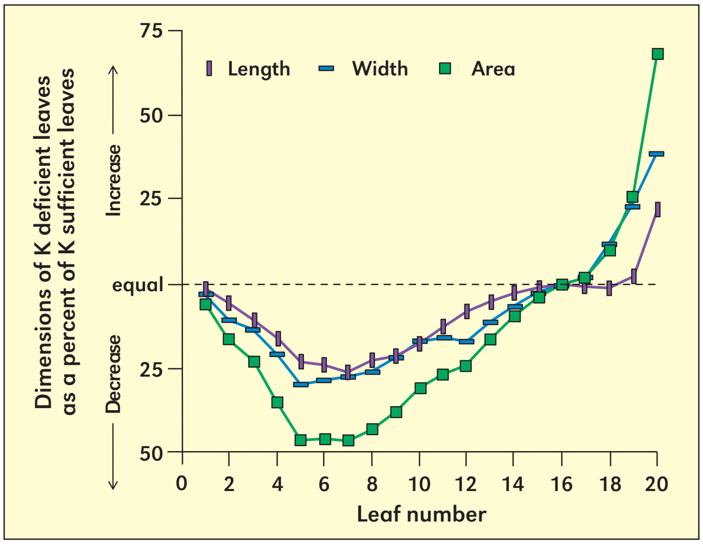


Figure 1. Leaf dimensions (length and width) and surface areas of K deficient leaves, expressed as a percentage of the leaf dimensions and surface areas of K sufficient leaves (Jordan-Meille and Pellerin, 2004).

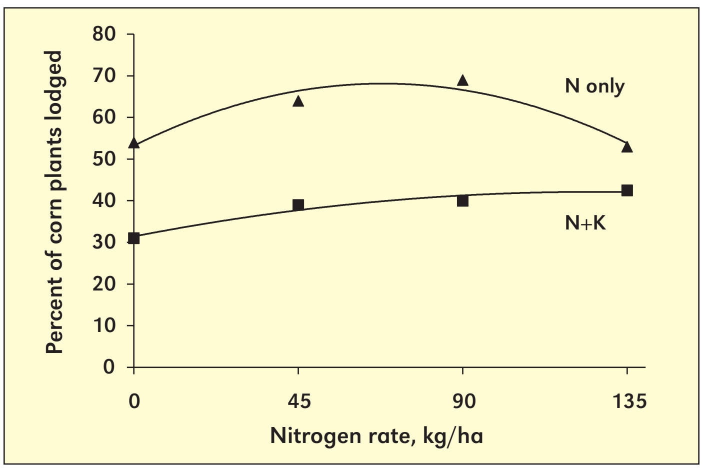


Figure 2. Percent of lodged corn as a function of N rate with and without K. Response to K was averaged over the 45 and 90 kg/ha (40 and 80 lb/A) K_2O rates (Fisher and Smith, 1960).

VT. Younts and Musgrave (1958) made a similar observation at 65 days after planting in one of their experiments, where K fertilization significantly ($p = 0.05$) increased the percentage of plants that had reached VT by 8 to 16%. However, in their other experiment, K fertilization did not produce any significant increase in percent of plants tasseled. Conversely, one of their treatments, a 135 kg/ha (120 lb/A) rate of K_2O applied as KCl, caused a significant ($p = 0.05$), 16% decrease in percent of plants reaching VT when sampled 61 days after planting. So while a delay in tasseling is possible, it may not be a consistent result.

Delayed Silking

Like tasseling, crop development to silking (R1) may also be delayed by K deficiency. Younts and Musgrave (1958) observed that maize fertilized with K exhibited significant ($p = 0.05$) increases in percentages of plants that had reached R1 at 69 to 73 days after planting, depending on the experiment. These increases ranged from 8 to 34%.

Increased Lodging

Lodging in corn may result from disease, insect damage, poor plant development arising from K deficiency, or a combination of these factors.

Lodging caused by poor plant development arising from K deficiency was demonstrated by Liebhardt and Murdock (1965). In their research, they found that K deficiency led to a hastening of parenchyma cell (pith) breakdown in brace roots and caused parenchyma cell disintegration in the stalk. Poorly developed brace roots, observable in the field, led to "root lodging" which occurred earlier in the season, after R1. Parenchyma cell disintegration in the stalk led to "stalk breakage" which occurred later, during the dent stage (R5).

No disease in the stalk was observed until crop maturity (R6), when stalk parenchyma tissue had already significantly disintegrated. Boswell and Parks (1957) demonstrated that hybrids differed in their susceptibility to root lodging and stalk breakage. However, regardless of susceptibility, low soil supplies of K increased root lodging and stalk breakage by an average of 12%.

Stalk breakage was shown to be related to the ratio of N: K elemental concentrations in the stalk when K concentrations were low. Parenchyma cell breakdown was observed when N was 3 to 4 more times concentrated in the stalk than K (Liebhardt and Murdock, 1965). Fisher and Smith (1960) isolated the effects of N and K on lodging and found that lodging incidence increased when N was applied without K on a low K testing soil (**Figure 2**), consistent with the results of Liebhardt and Murdock (1965).

Lodging can also be caused by fungal diseases and K deficiency has been shown to increase the severity of them. In a recent review, Prabhu et al. (2007) catalogued three stalk rot pathogens (*Fusarium moniliforme*, *Gibberella zeae*, and *Diplodia zeae*) to which corn had greater susceptibility when deficient in K.

Summary

While marginal leaf chlorosis and necrosis are the most well known visual signs of K deficiency, there are other indicators of K shortage exhibited by corn. Although not complete, several delays or changes in plant development have been listed here to assist farmers and crop advisers as they make observations in the field. Detecting these delays and changes can be difficult without a reference area that is known to have an adequate supply of K. It is therefore suggested that such an area be established and maintained over time to provide a basis for comparison. BC

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References

Boswell, F.C. and W.L. Parks. 1957. Soil Sci. Soc. Am. J. 21:301.
Bly et al., 2002. Better Crops 86(3):12-15.
Fisher, F.L. and O.E. Smith. 1960. Agron. J. 52:201.
Jordan-Meille, L. and S. Pellerin. 2004. Plant Soil 265:75-92.
Koch, D.W. and G.O. Estes. 1975. Crop Sci. 15:697-699.
Liebhardt, W.C. and J.T. Murdock. 1965. Agron. J. 57:325.
Peaslee et al. 1971. Agron. J. 63:561.
Prabhu et al. 2007. p. 57-78. *In* Datnoff et al. (ed.) Mineral nutrition and plant disease. The American Phytopathological Society, St. Paul, Minnesota.
Watson, D.J. 1947. Ann. Bot. 11:41-76.
Younts, S.E. and R.B. Musgrave. 1958. Agron. J. 50:423-426.

Winners of IPNI 2009 Nutrient Deficiency Photo Contest

The 2009 edition of the IPNI nutrient deficiency photo contest has once again assembled many excellent quality images entered from around the world. For 2009, our judges have selected two prize winners for each category as well as a grand prize winner for the best photo across categories.

"This contest was initially designed to appeal to the competitive spirit of all who work in support of crop production," said IPNI President Dr. Terry Roberts. "It is apparent that each year's set of entries are adding to a valuable collection of documented examples of crop nutrient deficiency."

Entries were judged on the overall quality of the image as well as any supporting data provided by entrants. Entries are posted for viewing at: www.ipni.net/2009photocontest.

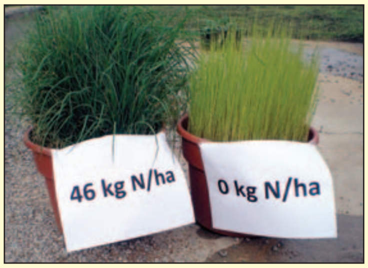
Congratulations to all winners and sincere thanks to everyone who participated. IPNI would encourage all readers to look for other opportunities to capture digital photos and share documented cases of crop nutrient deficiencies in 2010. Also watch for details outlining the 2010 edition of the IPNI nutrient deficiency photo contest.

Grand Prize for Best Overall Photo

Grand Prize (US$200): Cui Rongzong, Shandong Soil & Fertilizer Institute, Jinan, Shandong, China, entered this excellent close-up of Fe deficiency in peanut just prior to the crop's flowering stage. Plants are clearly displaying the symptoms of strongly chlorotic young leaves while leaf veins remain green. "The image was taken near Ouyu Village, Zaozhuang City in Shandong. The site has characteristically high soil pH values and Fe fertilizers have not been used for many years. Soil test Fe was measured at 3.3 mg/kg and the active Fe content of young leaves was determined to be 10.4 mg/kg."

Nitrogen Category: N-Deficient Maize

1st Prize (US$150): M.R. Umesh, Post Doctoral Fellow at New Mexico State, submitted this field trial shot of N deficiency at the Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, in Bangalore, Karnataka, India. "The photos were taken 69 days after planting and showed a significant N deficiency through a side-by-side comparison of a 100 kg N/ha application (left) and a N omission plot (right). Plant tissue analysis and soil test values both indicated a deficiency of available soil N." He acknowledges Dr. M.A. Shankar, who supervised planning and execution of field trials.



Runner-up (US$75) - Teff: Assen Yesuf, Oklahoma State University, Plant and Soil Sciences Department, Stillwater, Oklahoma, USA.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Fe = iron; Mn = manganese.

Phosphorus Category: P-Deficient Cassava

1st Prize (US$150): S. Srinivasan, Agricultural College, Tamil Nadu Agricultural University, Killikulam, Vallanad, India, shot this vivid example of P deficiency in a 4-month old cassava crop. "I captured this image of a plant that received no P after planting. The deficiency was confirmed with chlorotic lower leaves while upper leaves had a healthy green appearance. The lower yellow leaves eventually turned purple and shriveled. Thin stems and narrow leaf lobes and poor root growth were also noticed. A history of mono-cropping cassava has depleted soil P. The soil test revealed that P content was very low (less than 2.8 mg P/kg). Leaf tissue analysis also registered a lower value of 0.19%."

Runner-up (US$75) - Canola: Lu Jianwei, Huazhong Agricultural University, Environment and Resources College, Wuchang, Wuhan, Hubei, China.

Potassium Category: K-Deficient Sugarcane

1st Prize (US$150): S. Srinivasan, Agricultural College, Tamil Nadu Agricultural University, Killikulam, Vallanad, India, also submitted this crisp example of K deficiency. "I photographed this view of K deficiency in a 6-month old sugarcane crop in Tamil Nadu. The deficiency was confirmed by typical yellow-orange chlorosis of lower leaf tips and borders. Stalks were slender and older leaves had a fired appearance. Fully developed leaves had 0.9% K."

Runner-up (US$75) - Cluster bean, Guar Gum: Ch. Srinivasa Rao, Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India.

Other Category: Mn-Deficient Oil Palm

1st Prize (US$150): Hendra Sugianto, of Sampoerna Agro, Sukamara, Kalimantan Tengah, Indonesia, shot this close-up view of Mn deficiency. "The deficiency was discovered within a 2-year old (immature) oil palm stand. Plant symptoms dissipated and stands recovered with an application of 300 g $MnSO_4$ or a foliar spraying at 0.20%."

Runner-up (US$75) Mn-Deficient Wheat: U.S. Sadana, Department of Soils, Punjab Agricultural University, Ludhiana, Punjab, India.

Impact of Potassium Nutrition on Food Quality of Fruits and Vegetables: A Condensed and Concise Review of the Literature

By Gene E. Lester, John L. Jifon, and Donald J. Makus

Among the many plant mineral nutrients, K stands out as a cation having the strongest influence on quality attributes that determine fruit marketability, consumer preference, and the concentration of critically important human health-associated phytonutrients. However, many plant, soil, and environmental factors often limit uptake of K from the soil in sufficient amounts to satisfy fruit K requirements during development to optimize the aforementioned quality attributes. This was demonstrated in a study reported in this publication in 2007 (Lester et al., 2007) where foliar K markedly improved several cantaloupe fruit quality parameters, despite sufficient soil test K levels. This article expands on the previously reported work from the Rio Grande Valley of Texas by providing a review of published study abstracts on the effects of soil and/or foliar K fertilization on several fruit and vegetable quality characteristics, including phytonutrient concentrations.

Potassium is an essential plant mineral element (nutrient) having a significant influence on many human-health related quality compounds in fruits and vegetables (Usherwood, 1985). Although K is not a constituent of any organic molecule or plant structure, it is involved in numerous biochemical and physiological processes vital to plant growth, yield, quality, and stress (Marschner, 1995; Cakmak, 2005). In addition to stomatal regulation of transpiration and photosynthesis, K is also involved in photophosphorylation, transportation of photoassimilates from source tissues via the phloem to sink tissues, enzyme activation, turgor maintenance, and stress tolerance (Usherwood, 1985; Doman and Geiger, 1979; Marschner, 1995; Pettigrew, 2008). Adequate K nutrition has also been associated with increased yields, fruit size, increased soluble solids and ascorbic acid concentrations, improved fruit color, increased shelf life, and shipping quality of many horticultural crops (Geraldson, 1985; Lester et al., 2005, 2006, 2007; Kanai et al., 2007).

Even though K is abundant in many soils, the bulk of soil K may be unavailable to plants, in part, because the pool of plant-available K is much smaller compared to the other forms of K. Potassium exists in several forms in the soil, including mineral K (90 to 98% of total), nonexchangable K, exchangeable K, and dissolved or solution K (K^+ ions), and plants can only directly take-up solution K (Tisdale et al., 1985). Uptake in turn depends on numerous plant and environmental factors (Tisdale et al., 1985; Marschner, 1995; Brady and Weil, 1999). For instance, adequate soil moisture supply is necessary to facilitate diffusion of K (which usually accounts for > 75% of K movement) to plant roots for uptake. Mass flow, which also accounts for some soil K transport, also requires sufficient water in the soil. Skogley and Haby (1981) found that increasing soil moisture from 10 to 28% more than doubled total soil K transport. Therefore, soil moisture deficits can limit soil K transport as well as uptake into the plant, thereby causing K deficiency.

Soil properties also have a strong influence on K availability. For instance, clay soils may have high K-fixing capacities and thus can show little response to soil-applied K fertilizers because much of the available K quickly binds to clays (Tisdale et al., 1985; Brady and Weil, 1999). Such K retention can help reduce leaching losses and be beneficial in the long-term as storage reservoirs of K for subsequent crops. Sandy soils, on the other hand usually have a low K-supplying power because of low cation exchange capacity.

Abbreviations and notes: K = potassium.

Dr. Lester checks on muskmelon plants in a glasshouse experiment. Fine-tuning plant nutrition practices is an important consideration for improving fruit quality (inset).

Calcareous soils tend to have high concentrations of calcium ions (Ca^{2+}) that dominate clay surfaces and other exchange sites. Even though this can limit K sorption and increase solution K, high concentrations of cationic nutrients...particularly Ca^{2+} and magnesium (Mg^{2+})...tend to limit K uptake by competing for binding sites on root surfaces. Consequently, crops grown on highly calcareous soils can show K-deficiency symptoms even though the soil test may report sufficient K (Havlin et. al., 1999).

Potassium uptake also depends on plant factors, including genetics and developmental stage (vegetative versus reproductive stages; Rengel et al., 2008). In many fruiting species, uptake occurs mainly during vegetative stages, when ample carbohydrate supply is available for root growth and uptake processes. Competition for photoassimilates between developing fruits and vegetative organs during reproductive growth

Table 1. Review of published abstracts on the influence of K: effects by crop, K application, and K form on fruit attributes.

Crop	K application	K form[a]	Attributes (improved)[b]	Reference[c]
Apple *(Malus X domestica)*	Soil	KCl;	Color, firmness, sugar;	Nava (2009);
		K_2SO_4;	Size, color, firmness, sugars;	El-Gazzar (2000);
		K_2SO_4;	Wt. yield, firmness, sugars	Attala (1998)
Apple	Foliar	Unknown;	Size, color, firmness, sugars;	Wojcik (2005);
		KCl	No change	Hassanloui (2004)
Banana *(Musa sp.)*	Soil	Unknown;	Quality;	Naresh (1999);
		KCl	Size, sugars, acid	Suresh (2002)
Citrus *(Citrus sinensis)*	Foliar	KCl, KNO_3;	No change;	Haggag (1990);
		Unknown;	Yield, quality;	Dutta (2003);
		K_2SO_4	Quality	Shawky (2000)
Citrus *(Citrus reticulata)*	Soil	Unknown;	Yield, quality;	Lin (2006);
		Unknown	Quality, shelf-life	Srivastava (2001)
Citrus *(Citrus reticulata)*	Foliar	KCl >KNO_3	Peel thickness, quality	Gill (2005)
Cucumber *(Cucumis sativus)*	Soil	K_2SO_4 > KCl;	Amino acids, quality;	Guo (2004);
		KCl	No change	Umamaheswarappa (2004)
Cucumber	Foliar	KCl >KNO_3	"Quality", disease tolerance	Magen (2003)
Grapes *(Vitis vinifera)*	Soil	K_2SO_4	"Quality", sensory	Sipiora (2005)
Guava *(Psidium guajava)*	Soil	Unknown	Yield, weight, "quality"	Ke (1997)
Guava	Foliar	K_2SO_4 > KCl	Acidity, "quality"	Dutta (2004)
Kiwifruit *(Actinidia deliciosa)*	Soil	K_2SO_4 > KCl	Firmness, acid, grade	He (2002)
Litchi *(Litchi chinensis)*	Foliar	KNO_3	Weight., yield,	Ashok (2004)
Mango *(Mangifera indica)*	Soil	KNO_3	No change	Simoes (2001)
Mango	Foliar	KNO_3;	No effect;	Rebolledo-Martinez (2008);
		Unknown	Texture, flavor, color shelf-life	Shinde (2006)
Muskmelon *(Cucumis melo)*	Soil	Unknown	Yield	Demiral (2005)
Muskmelon	Foliar	Gly-amino-K;	Firmness, vitamins;	Lester (2005);
		Gly-amino-K > KCl;	Firmness, sugars, vitamins;	Lester (2006);
		Gly-amino-K = K_2SO_4 > KCl > KNO_3	Firmness, vit. sugars, yield, marketable fruit	Jifon (2009)
Nectarine *(Prunus persica)*	Soil	Unknown	Firmness, shelf-life, reduced cracking	Zhang (2008)
Okra *(Abelmoschus esculentus)*	Foliar	Naphthenate-K	Chlorophyll, protein, carotene	Jahan (1991)
Passionfruit *(Passiflora edulis)*	Hydroponic	K_2SO_4	Yield, seed number, "quality"	Costa-Araujo (2006)
Papaya *(Carica papaya)*	Soil	Unknown	Weight, sugars, "quality"	Ghosh (2007)
Pears *(Pyrus communis)*	Soil	K_2SO_4	No change	Johnson (1998)
Phalsa *(Grewia subinaequalis)*	Foliar	K_2SO_4	Size, weight, "quality"	Singh (1993)
Pepper *(Capsicum annuum)*	Soil	KCl;	Little change;	Hochmuth (1994):
		K_2SO_4;	Pungency, "quality";	Ananthi (2004);
		K_2SO_4 > KNO_3;	Pungency, yield, weight;	Golcz (2004);
		K_2SO_4	"Quality"	El-Masry (2000)
Pepper	Hydroponics	KNO_3	No change	Flores (2004)
Pineapple *(Ananas comosus)*	Soil	KCl	Vit. C, and reduced internal browning	Herath (2000)
Pomegranate *(Punica granatum)*	Foliar	K_2SO_4 > KCl	Growth, yield, "quality"	Muthumanickam (1999)
Strawberry *(Fragaria X ananassa)*	Soil;	KCl;	No change;	Albregts (1996);
	Fertigation	KCl >KNO_3	"Quality"	Ibrahim (2004)
Strawberry	Hydroponics	K_2SO_4	Yield, total quality	Khayyat (2007)
Tomato *(Lycopersicon esculentum)*	Soil	KCl;	Lycopene;	Taber (2008);
		K_2SO_4;	"Quality";	Si (2007);
		K_2SO_4;	Yield, earliness, quality	Hewedy (2000)
Tomato	Fertigation/soilless	KCl >KNO_3;	Appearance, quality;	Chapagain (2003);
		KCl >KNO_3;	Yield, "quality";	Chapagain (2004);
		K_2SO_4;	Carotenoids, vit.E,	Fanasca (2006);
		Unknown;	Antioxidants;	Li (2006);
		Unknown	Lycopene; "quality"	Yang (2005)
Tomato	Foliar	Unknown	Growth, protein, vit. C, sugar, acid	Li (2008)
Vegetables	Soil	K_2SO_4 > KCl	Dry weight., vitamin C	Ni (2001)
Watermelon *(Citrullus lanatus)*	Soil	KCl;	No change;	Locascio (2002);
		KCl	No change	Perkins-Veazie (2003)

[a]Sources from different studies are separated by a semi-colon; K form attributing to improved quality greater than another K form is indicated by the > symbol.
[b]Attributes from different studies are separated by a semicolon. The word "quality" indicates the authors listed no specific attributes, or the attributes were too numerous to list.
[c]References from different studies are separated by a semi-colon, and only first author names are listed for brevity.

stages can limit root growth/activity and K uptake. Under such conditions, increasing soil K fertilization may not be enough to alleviate this developmentally-induced deficiency partly because of reduced root growth/activity during reproductive development and also because of competition from other cations for binding sites on roots (Marschner, 1995).

A study reported in this magazine and elsewhere (Lester et al., 2005, 2006, 2007) showed that foliar K improved cantaloupe fruit marketable quality by increasing firmness and sugar content, and fruit human health quality by increasing ascorbic acid, beta-carotene, and K levels in a soil that tested high in K. Nevertheless, there remains confusion in the literature regarding the benefit of K fertilization due to different K sources, soil vs. foliar applications, the environment (season), and timing and frequency of application. This review summarizes some of the published abstracts on K fertilization of several fruit crops, with special attention given to the effectiveness of various K fertilizer sources, and soil vs. foliar application on fruit quality.

Fruit Studies Comparing K Sources

Although many examples have been reported on the positive effects of K fertilization improving fruit disease control, yield, weight, firmness, sugars, sensory attributes, shelf-life, and human bioactive compound concentrations, the scientific literature also contains examples of studies with conflicting results of the beneficial effects of K fertilization on fruit quality **(Table 1)**. These conflicting results cannot be resolved, but they can be explained by differences in modes of fertilization (e.g., soil vs. foliar, fertigation or hydroponic applied), and differences in sources of K fertilizer (e.g. KCl, K_2SO_4, KNO_3, Glycine-complexed K).

A review of published abstracts spanning the last 20 years is shown in **Table 1**. The vast majority of the papers reviewed showed that K fertilization had an effect on some crop quality attribute. However, eight particular studies [apple, (Hassanloui, et al., 2004); cucumber, (Umamaheswarappa and Krishnappa, 2004); mango, (Rebolledo-Martinez et al., 2008); pear, (Johnson et al., 1998); bell pepper, (Hochmuth et al., 1994); strawberry, (Albregts et al., 1996); and watermelon, (Locascio and Hochmuth, 2002; Perkins-Veazie et al., 2003)] stand out because of their conclusions: there is 'little or no change' (i.e. improvement) in fruit quality due to K fertilization. Interestingly, except for the apple study, these studies have a common denominator in that K was applied directly to the soil and in many cases little information was given regarding timing of application or soil chemical and physical properties. These factors can influence soil nutrient availability and plant uptake, and soil fertilizer K additions under some conditions may have little or no effect on uptake, yield, and fruit quality (Tisdale et al., 1985; Brady and Weil, 1999).

In a number of studies involving several fruiting crops (e.g. cucumber, mango, and muskmelon) where soil-applied fertilizer K was compared to foliar K applications, the latter approach consistently resulted in improved fruit quality attributes. On the other hand, soil applications generally had little or no effects (Demiral and Koseoglu, 2005; Lester et al., 2005, 2006; Jifon and Lester, 2009; **Table 1**).

Furthermore, in studies where several fertilizer K salts were evaluated, fruit quality improvements appeared to depend on K source. For instance, Jifon and Lester (2009) showed that when mid-to-late season soil or foliar K applications were made using KNO_3 there were little or no improvements in fruit marketable or human-nutritional quality attributes and in some instances, these attributes were actually inferior compared to fruit from control plots.

This article demonstrates that when making K fertilization decisions, the practitioner should be aware that soil test data alone might not be sufficient to make the best decisions. Soil test information is certainly important and useful in decision-making, but accounting for other factors such as timing, crop demand dynamics, and source are all important as well. High soil K level alone does not always guarantee there will be no response to K fertilizer. Moreover, where there is a high demand for K during fruit development foliar K can improve several fruit quality attributes. BC

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References

Albregts, E.E., G.J. Hochmuth, C.K. Chandler, J. Cornell, and J. Harrison. 1996. J. Amer. Soc. Hort. Sci. 121: 164-168.

Ananthi, S., D. Veeraragavathatham, K. Srinivasan. 2004. South Indian Hort. 52: 152-157.

Ashok, K. and K. Ganesh. 2004. Adv. Plant Sci. 17: 519-523

Attala, E.S. 1998. Egyptian J. Agric. Research. 76:709-719.

Brady, N.C. and R.R.Weil. 1999. The Nature and Properties of Soils. 9th Edition. Macmillan Publishing Company New York. 750 p.

Cakmak, I. 2005. J. Plant Nutr. Soil Sci. 168:521-530

Chapagain, B.P. and Z. Wiesman. 2004. Sci. Hort. 102:177-188

Chapagain, B.P. and Z.Wiesman. 2003. Sci Hort. 99: 279-288

Chapagain, B.P., Z. Wiesman, M. Zaccai, P. Imas, and H. Magen. 2003. J. Plant Nutr. 26: 643-658.

Cooke, D.L. and D.T. Clarkson.1992. Plenum Press, N.Y. pp 75-208

Costa-Araujo, R., C.H. Bruckner, H.E. Prieto-Martinez, L.C. Chamhum-Salomao, V.H. Alvarez, A. Pereira de-Souza, W.E. Pereira, and S. Hizumi. 2006. Fruits. 61:109-115

Demiral, M.A. and A.T. Koseoglu. 2005. J. Plant Nutr. 28: 93-100

Doman, D.C. and D.R. Geiger. 1979. Plant Physiol. 64:528-533.

Dutta, P. 2004. Orissa J. Hort. 32: 103-104.

Dutta, P., A.K. Chakroborty, and P.K. Chakroborty. 2003. Ann. Agric. Res. 24:786-788

El-Gazzar, A.A.M. 2000. Ann. Agric. Sci., Cairo. 3(Special):1153-1160

El-Masry, T.A. 2000. Ann. Agric. Sci., Moshtohor. 38:1147-1157

Fanasca, S., G. Colla, Y. Rouphael, F. Saccardo, G. Maiani, E. Venneria, and E. Azzini. 2006. HortScience. 41:1584-1588

Flores, P., J.M. Navarro, C. Garrido, J.S. Rubio, and V. Martinez. 2004. J. Sci. Food Agric. 84: 571-576.

Geraldson, C.M. 1985. Potassium nutrition of vegetable crops. *In* Munson, R.D. (ed) Potassium in Agriculture. ASA-CSSA-SSSA, Madison, WI. pp 915- 927.

Ghosh, S.N. and R.K.Tarai. 2007. Indian J. Fertilisers. 3:47-49.

Gill, P.S., S.N. Singh, and A.S. Dhatt. 2005. Indian Journal Hortic. 62:282-284

Golcz, A., P. Kujawski, and B. Politycka. 2004. Folia Universitatis Agriculturae Stetinensis, Agricultura. (95):109-113.

Guo, X.S., S.Y. Ye, W.J. Wang, H.B. Zhu, J. Xu, and L.S.Wu. 2004. Plant Nutr. Fertilizer-Sci. 10:292-297.

Haggag, M.N.1990. Alexandria J. Agril. Res. 1988. 33:157-167.

Hassanloui M.R.D., M. Taheri, and M.J. Malakouti. 2004. J. Agric. Eng. Res. 5:71-84.

Havlin, J.L., J.D. Beaton, S.L.Tisdale, and W.L. Nelson. 1999. Soil Fertility and Fertilizers. 6th Edition. Prentice Hall. Upper Saddle River, NJ. 499 p.

He, Z.J., G.L. Zhang, G.W. Zhang, L. Ma, and Y. Tong. 2002. J. Fruit Sci. 2002 19:163-166.

Herath, H.M.I., D.C. Bandara, and D.M.G.A. Banda. 2000. Trop. Agric. Res. 12:352-359.

Hewedy, A.M. 2000. Egyptian J. Agric. Res. 78:227-244.

Hochmuth, G., K. Shuler, E. Hanlon, and N. Roe.1994. Proc. Florida State Hort. Soc. 107:132-139.

Ibrahim, A., T. Abdel-Latif, and S. Gawish, and A. Elnagar. 2004. Arab Universities J. Agric. Sci. 12:469-48.

Jifon, J.L. and G.E. Lester. 2009. J. Sci. Food Agric. 89:2452-2460.

Jahan, N., Q.A. Fattah, and M.A. Salam. 1991. Bangladesh J. Bot. 20:163-168.

Johnson, D.S., T.J. Samuelson, K. Pearson, and J. Taylor. 1998. J. Hort. Sci. Biotechnol. 73:151-157.

Kanai, S., K. Ohkura, J.J. Adu-Gyamfi, P.K. Mohapatra, N.T. Nguyen, H. Saneoka, and K. Fujita. 2007. J. Experimental Bot. 58:2917-2928.

Ke, L.S. and W.D. Wang. 1997. J. Agric. Assoc. China. 179:15-29.

Khayyat, M., E. Tafazoli, S. Eshghi, M. Rahemi, and S. Rajaee. 2007. Amer. Eurasian J. Agric. Environ. Sci. 2:539-544.

Lester, G.E., J.L. Jifon, and W.M. Stewart. 2007. Better Crops. 91:(1)24-25.

Lester, G.E., J.L. Jifon, and D.J. Makus. 2006. HortScience. 41:741-744.

Lester, G.E., J.L. Jifon, and G. Rogers. 2005. J. Amer. Soc. Hort. Sci. 130:649-653.

Lester, G.E., Arias L. Saucedo, and Lim M. Gomez Lim. 2001. J. Amer. Soc. Hort. Sci. 126:33-36.

Li, R.H., D.B. Xu, and Q.W. Huang. 2008. China Vegetables. 6:17-20.

Li, S., Y. Xu, W.S. White, S. Rodermel, and H. Taber. 2006. FASEB J. 20(5, Part 2):A1059.

Lin, X.Y, Y.S. Zhang, M.Z. Cai, Y.P. Zhang, G. Li, and X.E.Yang. 2006. Plant

Nutr Fertilizer Sci. 12:82-88.

Locascio, S.J. and G.J. Hochmuth. 2002. HortScience. 37:322-324.

Magen, H., P. Imas, Y. Ankorion, and A. Ronen. 2003. Proc International Fertiliser Soc. (524):13-24.

Marschner, H. 1995. Functions of mineral nutrients: macronutirents, p. 299-312. In: H. Marschner (ed.). Mineral nutrition of higher plants 2nd Edition. Academic Press, N.Y.

Muthumanickam, D. and G. Balakrishnamoorthy.1999. South Indian Hort. 47:152-154.

Naresh, B. 1999. Bioved. 10:39-42

Nava, G., A. Roque-Dechen, and G. Ribeiro-Nachtiga. 2008. Communications Soil Sci. Plant Analysis. 39:96-107.

Ni, W.Z., J.S. Liang, and R. Hardter. 2001. Pedosphere. 11:251-255.

Perkins-Veazie, P., W. Roberts, and K. Perez. 2003. Hortscience. 38:816-817.

Pettigrew, W.T. 2008. Physiol. Plant. 133:670-681.

Rebolledo-Martinez, A., A. Lid-del-Angel-Perez, and J. Rey-Moreno. 2008. Interciencia. 33:518-522.

Rengel, Z., P.M. Damon, and I. Cakmak. 2008. Physiologia Plantarum 133:624-636.

Shawky, I., A. Montasser, M. Nageib, L. Haggag, and M. Abd-El-Migeed. 2000. Effect of fertilization with potassium and some micronutrients on Navel orange trees. II - Effect on yield, fruit quality and juice mineral content. *In* El-Sawy M, Francis RR, El-Borollosy MA, Hosni AM (ed) Annals Agric Sci Cairo. 3(Special): 1215-1226.

Shinde, A.K., D.J. Dabke, B.B. Jadhav, M.P. Kandalkar, and M.M. Burondkar. 2006. Indian J. Agric. Sci. 76:213-217.

Si, S.K.G., M. Bellal, and F. Halladj. 2007. Acta Hort. (758):269-274.

Simoes, Ado-N, J.B. Menezes, S.E.V.D. Lima, J.F. Medeiros, G.F. Silva, D.F. Freitas. 2001. Caatinga. 14:31-35.

Singh, H.K., K.S. Chauhan, and B.P. Singh.1993. Haryana J. Hort Sci. 22:276-279.

Sipiora, M.J., M.M. Anderson, and M.A. Matthews. 2005. Proc. Soil Environment Vine Mineral Nutr. Symp. San Diego, CA, 29-30-June,-2004. pp 185-192.

Skogley, E.O. and V.A. Haby. 1981. Soil Sci. Soc. Am. J. 45:533-536.

Srivastava, A.K., A.D. Huchche, R. Lallan, and S. Shyam. 2001. J. Potassium Res. 17:93-97.

Suresh C.P. and M.A. Hasan. 2002. Res Crops. 3:398-402.

Taber, H., P. Perkins-Veazie, S.S. Li, W. White, S. Rodermel, and Y. Xu. 2008. HortScience. 43:159-165.

Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil and Fertilizer Potassium. Ch. 7 in S.L. Tisdale, W.L. Nelson, and J.D. Beaton (eds). Soil Fertility and Fertilizers, 4th ed. Macmillan, New York. 249-291.

Umamaheswarappa, P. and K.S. Krishnappa. 2004. Trop Sci. 44:174-176.

Usherwood, N.R. 1985. The role of potassium in crop quality. *In* Munson, R.D. (ed). Potassium in Agriculture ASA-CSSA-SSSA, Madison, WI. pp 489-513.

Wójcik, P. 2005. Proceedings International Scientific Conference: Environmentally friendly fruit growing, Polli, Estonia,-7-9-September,-2005. pp 44-50.

Yang, X.Y., Y.S. Bu, and X.Z. Duan. 2005. Xinjiang Agric Sci. 42:272-275.

Zhang, S.Y., J. Yang, and G.H. Liu. 2008. J. Anhui Agric. Univ. 35:289-292.

Soil System-Based Approach: A Tool for Fish Pond Fertilization

By Abira Banerjee, G.N. Chattopadhyay, and C.E. Boyd

To obtain maximum production of fish from any aquatic environment, it is necessary to maintain the nutrient status of the pond above critical levels in the soil-water system. This study describes an approach that achieves this goal through proper use of fertilizers and manures in fish ponds in India.

The major objective in application of fertilizers and manures to fish ponds is to encourage the growth and abundance of different fish food organisms, which in turn promotes the growth of fish (Boyd and Tucker, 1998). The aquatic environment supports various communities of living organisms which constitute the biotic load of a pond. Natural productivity is the capacity to increase this biotic load (i.e., all biomass) over time. In fish culture, which depends largely on natural foods, there is normally a close dependence of fish production on the level of primary productivity. This primary productivity in a fish pond indicates the rate of formation of organic matter due to photosynthesis, and is comprised of different groups of living communities, mainly phytoplankton, benthos, and periphyton (Chattopadhyay, 2004). These primary producers either form the natural food item to different phytophagous fishes or give rise to secondary or tertiary organisms as foods of various kinds of fishes with varying food habits **(Figure 1)**. All other environmental factors remaining favorable, nutrient concentrations determine the magnitude of primary production in a water body.

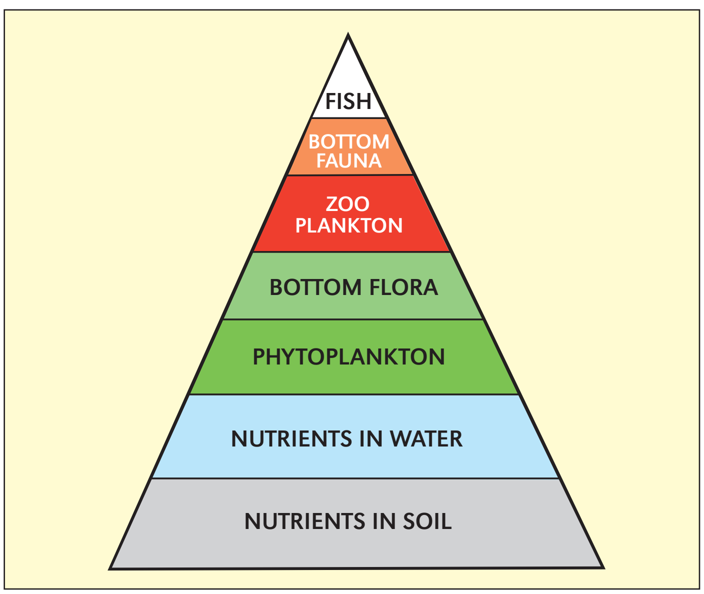

Figure 1. Food chain in fish ponds.

Mortimer and Hickling (1954) established clearly the efficiency of pond fertilizing materials in increasing the productivity of fish ponds. While Saha (1979) reported a four-fold increase in fish yield due to pond fertilization in India, positive effects of fertilization on pond productivity have been reported by many other workers from different parts of the world (Hepher, 1962: Dobbins and Boyd, 1976; Mandal and Chattopadhyay, 1992). While fertilizers and manures are applied directly to the soil through which plants derive their nutrients, in aquaculture this effect is brought about through a longer chain consisting of soil-water fertilization-bacteria-aquatic plants-zoo plankton, and zoo benthos – fish. During the course of this conversion, plant nutrients undergo various transformations in the soil and water phases. For fixing the rates and manners of use of fertilizers in fish ponds, therefore, due consideration is to be exercised to these echelons of productivity.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium.
Note: US$1 is equal to approximately Rs.46

Maintenance of favorable environmental conditions in fish ponds depends largely on the bottom soil.

Soil System-Based Approach in Fish Pond Fertilization

Bottom soils play an important role in controlling such nutrient transformations, especially the behaviors of the fertilizers in fish ponds (Chattopadhyay, 2004). The significance of bottom soils in influencing availability of different nutrient elements to primary fish food organisms has been discussed in detail by Boyd and Bowman (1997). Behavior of these nutrients and also maintenance of a favorable environmental condition in any pond are controlled largely by the bottom soil of the pond where a series of chemical and biochemical reactions continuously take place. These reactions influence not only the release of inherent nutrients from soil to the water phase, but also the transformation of added fertilizers in the ponds.

Table 1. Average productivity of fish ponds in red and lateritic soil zones under two different fertilization programs.

Parameter	Traditional fertilization	Soil system-based fertilization	Average increment, %
Gross primary production (Mean), mg C/m^3/hr	175 to 600 (371)	251 to 665 (480)	29.3
Net primary production (Mean), mg C/m^3/hr	75 to 425 (214)	100 to 525 (295)	37.8
Estimated fish yield (Mean), t/ha	0.92 to 2.56 (1.74)	1.25 to 3.00 (2.12)	22.1
Chattopadhyay and Banerjee, 2005.			

Wudtisin and Boyd, (2005) discussed considerable variations in the results of pond fertilization under different locations and these were attributed to variations in the nature and properties of bottom soils. In view of the wide variations in the properties of bottom soils situated in different soil zones and their influence on pond productivity, it appears to be appropriate to develop a soil system-based nutrient management approach for different fish ponds. While working with fish ponds situated in red and latertic soil zones, Banerjee and Chattopadhyay (2004) studied the nature and properties of large numbers of fish pond soils with relation to their primary productivity of water and identified the major soil factors responsible for variations in gross production of primary fish food organisms in such ponds **(Figure 2)**.

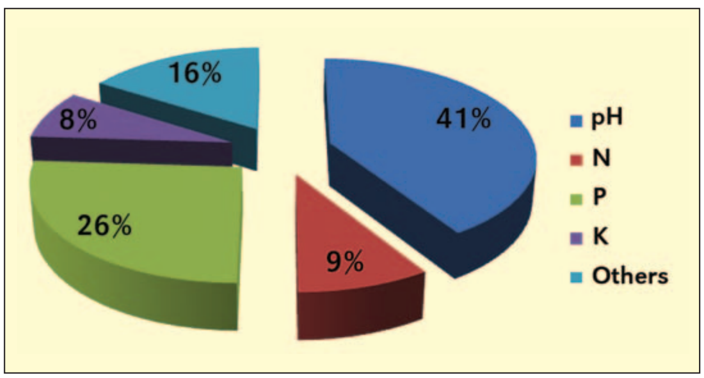

Figure 2. Percent contribution of different soil properties on gross primary productivity of fish pond water in red and lateritic soil zones.

Based on the information on the relative importance and status of the productivity-limiting plant nutrients in such pond soils, a soil system-based pond fertilization program was developed. This approach appeared to be more efficient than the traditional method of fertilizer application in fish ponds since it took into consideration the inherent nutrient supplying capacity of the pond soils along with other relevant properties of the ecosystem **(Table 1)**.

Use of Critical Levels of Nutrients for Optimizing Fertilizer Rates in Aquaculture

Fertilization rates for agricultural crops are commonly determined from the availability of nutrients in the soils. In view of the importance of bottom soils in influencing the efficiency levels of different pond fertilizing materials, it should be possible to apply the approach used in agriculture to assess the relationship between bottom soil nutrient concentrations and production of primary fish food organisms. This will also help to determine the requirements of different fertilizers for achieving economic benefits from fish pond fertilization under different soil zones. After the initial work of Cate and Nelson (1965), a large number of studies throughout the world determined the critical levels of various plant nutrients for different crops under varying soil conditions. Recently, Banerjee et al., (2009) reported a systematic study to adopt this principle in determining the critical levels of three major plant nutrients viz. N, P, and K in fish pond soils of red and lateritic soil zones and to assess the threshold levels of pond fertilizers required for attaining these critical limits.

Bottom soils were collected from different fish ponds situated in typical red and lateritic soil zones of West Bengal, India. To represent each pond, one kg of the 80 mesh sieved pond soil sample was taken into each of nine aquariums and the soils were incubated with 20 L of de-ionized water for 15 days to develop a semi-aerobic condition that simulated a typical fish pond. To determine the critical level of any nutrient, the pond soils were treated at different doses. For example, P was used at 0, 75, and 150 mg/kg/yr doses, split into 10 monthly applications. Along with the nutrient under study, the samples also received uniform doses of N and K, split as before. This was done to prevent any possibility of these two primary nutrients behaving as productivity-limiting factors. Each of the treatments were replicated three times and incubated under illuminated conditions. Soil samples were collected at weekly intervals from each of the aquariums for 3 weeks and were analyzed for gross primary productivity (GPP) of water and available P in soil. Similar studies were carried out for determining the critical limits of the other two primary nutrients.

The mean values of GPP of water, as well as availability of the particular nutrient in the soil, were monitored during the period of incubation under each soil-water system with different doses of fertilization for assessment of critical levels of available soil nutrients. For this purpose, Bray's percent yield (BPY) concept (Bray, 1948) was modified slightly by adopting the following formula.

$$\text{BPY} = \frac{\text{GPP with added nutrient - GPP with no added nutrient}}{\text{GPP with added nutrient}} \times 100$$

The obtained BPY values for different soil-water systems were then used for graphical determination of critical levels of the available nutrients in fish pond soils by following the principle of Cate and Nelson (1965). The studies showed the critical levels of the three nutrients to be 200, 13, and 80 mg/kg soil for N, P, and K, respectively, in red and lateritic soil zones. The necessary amount of N, P, and K fertilizers should be applied for maintaining the observed critical levels of these three nutrients in fish pond soils.

To test the effects of maintaining the critical levels of the major nutrients on productivity levels, on-farm trials were carried out in 18 ponds located on nine fish farms representing different red and lateritic soil zones. The mean effect of the three pond productivity-limiting nutrients on GPP of pond

Table 2. Estimated economic return from the inputs used in the soil system-based pond management program.

Inputs	Traditional fertilization	Soil system-based fertilization
	- - - - - - - - - - Costs, Rs./ha - - - - - - - - - -	
N fertilizer	1,000	2,000
P fertilizer	2,500	5,000
K fertilizer	-	498
Lime	1,280	640
Total cost	4,780 A	8,138 B
Return	- - - - - - - - - - Income - - - - - - - - - -	
Fish yield, kg/ha	1,758	2,153
Gross return, Rs.30/kg	52,740	64,590
Net return over fertilization cost, Rs./ha	47,960 C	56,452 D
Added cost due to soil system-based fertilization, Rs./ha		3,358 (B-A)
Added benefit due to soil system-based fertilization, Rs./ha		8,492 (D-C)
Benefit-to-cost ratio	2.53	

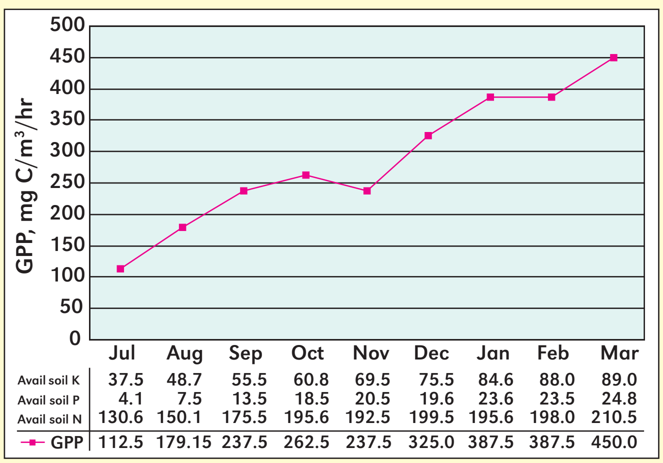

Figure 3. Variation in Gross Primary Productivity due to soil nutrient supply during the second year of study (Banerjee, 2005).

water are presented in **Figure 3**. Mean available P status attained its critical level in pond soils during September, after which the GPP values recorded an increasing trend. However, the availability of N and K were below this threshold limit during this period. Both of the nutrients neared the critical limits during November-December and GPP values exhibited a sharp increase owing to optimal presence of all the three productivity-limiting nutrients in the pond environment.

An approximate assessment of additional economic return from the proposed soil system-based pond fertilization, using local rates for different inputs and outputs, is presented in **Table 2**. Adoption of the proposed nutrient management program required an extra input cost of Rs.3,358/ha. However, this helped to produce an additional 395 kg fish/ha which under a conservative price of Rs.30/kg could fetch an additional income of Rs.8,492/ha of pond area. This resulted in an encouraging benefit-to-cost ratio of 2.53, supporting the developed this soil system-based pond productivity management program.

Even with added input cost, an improved nutrient management program can have a very favorable benefit.

All these results show that a soil system-based approach to pond management involving identification of major productivity-limiting soil factors, determination of critical levels for relevant plant nutrients, and maintenance of those nutrients at adequate levels, may be considered as an effective proposition for increasing the productivity of fish ponds and improving the response of fertilizers in the aquatic ecosystem. BC

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References

Banerjee, Abira. 2005. Ph.D. Thesis. Visva-Bharati University, India.

Banerjee, Abira and G.N. Chattopadhyay. #2004. National Seminar on Responsible Fisheries and Aquaculture. Berhampore, India.

Banerjee, Abira, G.N. Chattopadhyay, and C.E. Boyd. 2009. Aquacultural Engineering 40: 144-148.

Boyd, C.E. and J.R. Bowman. 1997. *In* H.S. Egna and C.E. Boyd (Eds). Dynamics of Pond Aquaculture. CRC Press, Boca Raton/ New York, pp. 135-162.

Boyd, C.E. and C.S. Tucker. 1998. Pond Aquaculture Water Quality Management. Kluwer Academic Publishers, Boston, Massachusetts, USA.

Bray, R.H. 1948. *In* Diagnostic Techniques for Soils and Crops. H.B. Kitchen (Ed.) The American Potash Institute, Washington D.C. pp. 53-85.

Cate, R.B., Jr. and L.A. Nelson. 1965. International Soil Testing Series Technical Bulletin No. 1. North Carolina State University. Agricultural experiment Station. Raleigh.

Chattopadhyay, G.N. 2004. Fert. News 49(4): 87-93

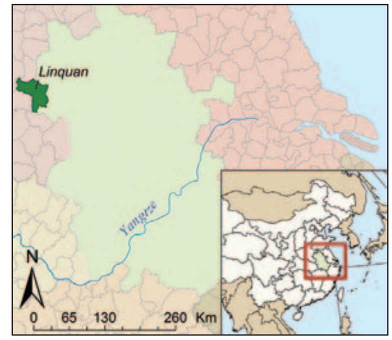
Chattopadhyay, G.N. and Abira Banerjee. 2005. World Aquaculture 36(2): 57-61.

Dobbins, D.A. and C.E. Boyd. 1976. Trans. Amer Fisheries Soc. 105:536-540.

Hepher, B. 1962. Bamidgeh. 1 4:29-38.

Mandal, L.N. and G.N. Chattopadhyay. 1992. *In* H.L.S. Tandon (Ed.) Non- Traditional Sectors in Fertilizer Use, FDCO, New Delhi. pp. 1-17.

Balanced Fertilization for Ginger Production – Why Potassium Is Important



By Lujiu Li, Fang Chen, Dianli Yao, Jiajia Wang, Nan Ding, and Xiyu Liu

Potassium is one of the most important limiting factors for ginger production. The main practices to obtain high rhizome yield with optimal nutrient use efficiency include fertilizer application based on soil testing, topdressing K fertilizer at growth stages with peak demand, and applying enough K to balance the appropriate N and P application rates.

Ginger is a leading high value crop in southeastern China and a primary source of income for the region's farmers. Ginger rhizomes and their products are consumed as a spice, in Chinese medicine, and as a special vegetable in daily diets worldwide. Most recent statistics indicate that area planted to ginger in China is about 240,000 ha, which accounts for 48% of the total ginger crop area globally.

This paper focuses on Anhui Province, which is one of the most important ginger production regions. Nutrient management is always an important consideration for ginger because it requires large quantities of nutrients, especially K. However, farmers in Anhui typically overuse N and P, and ignore K fertilization. They are unaccustomed to applying potash in upland crops, and this region has a general lack of K fertilization products and knowledge regarding balanced fertilization.

This research program in Linquan County began with a series of field experiments carried out in 2002 and 2003 in the towns of Gaotang and Tanpeng to test fixed 'optimum' (OPT) NPK treatments, as well as corresponding nutrient omission treatments. Recommended N, P, and K rates in the OPT considered both the average rates traditionally used by local farmers as well as soil analysis and fertilizer recommendation according to the Agro-Services International (ASI) method (Portch and Hunter, 2002), which is used by the National Laboratory of Soil Testing and Fertilizer Recommendations in Beijing. According to traditional practice, basal fertilization included all of the P and K plus 60% of the total N rate. The remaining N was split between topdressings applied at the vigorous growth stage and rhizome expansion growth stage.

Table 1. Physical and chemical properties of tested soils by National Laboratory of Soil Testing and Fertilizer Recommendations in Beijing.

Year/Location	pH	OM %	Ca	Mg	N	P	K	S	B	Cu	Fe	Mn	Zn
			mg/L										
2002/Gaotang	6.9	0.5	3,040	396	13	33	73	12	0.7	3.3	38	17	1.8
2003/Tanpeng	6.2	0.6	3,039	618	15	40	67	13	0.5	2.9	84	83	1.5
2007/Shanqiao-1	6.4	0.6	3,206	418	12	25	70	9	0.1	1.3	21	12	0.9
2007/Shanqiao-2	6.2	0.8	3,306	555	13	15	62	8	0.1	1.6	42	15	2.4
2008/Yangqiao-1	6.5	1.3	4,336	556	24	15	74	4	2.5	2.9	15	46	1.6
2008/Yangqiao-2	6.6	1.4	3,683	473	18	17	59	12	2.2	2.6	16	69	1.2
Critical values	–	1.5	401	122	50	12	78	12	0.2	1.0	10	5	2.0

Experimental sites that test below the soil test critical level are likely to respond positively to the nutrient application.

Ginger rhizomes are consumed as a spice, in medicine, and as a vegetable in diets around the world.

List of Abbreviations: N = nitrogen; P = phosphorus; K = potassium; DAP = diammonium phosphate; SSP = single superphosphate; KCl = potassium chloride; Zn = zinc; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cu = copper; Fe = iron; Mn = Mangenese; OM = organic matter.

Fixed OPT field trials were also conducted in 2007 (Shanqiao-1) and 2008 (Yangqiao-1). Field testing at these sites evolved to include more detailed investigation of the effects of N, P, and K application rates on rhizome yield, K uptake, and profitability. The trials were designed as three independent experiments, each focusing on the evaluation of five rates of either N, P, or K co-applied with fixed rates of the other two nutrients. As an alternative to traditional practice, basal fertilization in these trials included 40% of the total N and K plus the entire P rate. The remaining N and K were equally topdressed by in-row band application in early August (three branch growth stage) and early September (vigorous growth stage). Usually, common practice does not include any topdressing of K fertilizer. A plant biomass and K accumulation experiment was also initiated in 2007 at Shanqiao in order to describe crop K demand throughout the season. Ginger plant samples were taken on July 11 (seedling stage), August 1 (three branch stage), August 27 (vigorous growth stage), September 23 (rhizome expansion stage), and October 22 (harvest stage). Stalk, foliage, and rhizome of ginger were collected and analyzed.

All experiments were located on a common Shajiang black vertisol **(Table 1)**. The list of soil properties indicates the soils of these fixed trials were low in organic matter, available N, K, S, and Zn. The soil in Shanqiao also showed low B content. Because of many years of P fertilization, available soil P was relatively high in all of the sites, especially in Gaotang and

Table 2. Effect of K rates on accumulation of ginger plant biomass and K uptake.

	-- Biomass accumulation, kg/ha --					K nutrient uptake, kg/ha				
$N-P_2O_5-K_2O$	S[1]	T	V	E	H	S	T	V	E	H
400-90-0	396	525	1,567	4,418	744	21	21	45	80	25
400-90-200	612	861	1,722	4,946	1,267	35	38	45	133	54
400-90-400	779	955	2,046	5,305	1,439	49	47	68	214	84
400-90-600	865	722	1,931	5,227	1,356	58	38	76	271	89
400-90-800	714	734	1,930	4,783	1,119	53	46	79	228	126

[1]S = seedling stage (1 to 90 days after seeding [DAS]); T = three branches stage (90 to 110 DAS); V = vigorous growth stage (110 to 130 DAS); E = rhizome expansion stage (130 to 160 DAS), and H = harvest stage (160 DAS).

Ginger plants require large amounts of nutrients, especially K.

Table 3. Effect of K rates on ginger rhizome yield and net returns.

Year/Location	$N-P_2O_5-K_2O$	Yield, kg/ha	Yield increase, %	Total K uptake, kg/ha	Net return over fertilizer, US$/ha
2007/Shanqiao-1	400-90-0	37,847 c	-	108	14,975
	400-90-200	42,188 b	11.5	154	16,791
	400-90-400	45,651 a	20.6	236	18,256
	400-90-600	41,319 b	9.2	285	16,603
	400-90-800	40,858 bc	8.0	264	16,499
2008/Yangqiao-1	450-90-0	36,382 d	-	104	19,104
	450-90-225	45,384 b	24.7	166	23,995
	450-90-450	51,260 a	40.9	250	27,228
	450-90-675	44,789 b	23.1	309	23,918
	450-90-900	41,288 c	13.5	267	22,181

For Tables 3 to 6, numbers followed by the same letter are not significantly different at $p = 0.05$.
In 2007, the price of ginger rhizome was $US0.40/kg, N was $US0.53/kg, P_2O_5 was $US0.53/kg, and K_2O was $US0.40/kg.
In 2008, the price of ginger rhizome was $US0.53/kg, N was $US0.53/kg, P_2O_5 was $US0.67/kg, and K_2O was $US0.53/kg.
(1US$=7.5 RMB).

Table 4. Effect of N rates on ginger rhizome yield and net returns.

Year/Location	$N-P_2O_5-K_2O$	Yield, kg/ha	Yield increase, %	Total K uptake, kg/ha	Net return over fertilizer, US$/ha
2007/Shanqiao-1	0-90-400	32,350 c	-	173	13,052
	200-90-400	39,931 b	23.4	247	16,074
	400-90-400	45,602 a	41.0	323	18,237
	600-90-400	37,529 b	16.0	272	14,901
	800-90-400	35,010 bc	8.2	262	13,788
2008/Yangqiao-1	0-90-450	34,976 c	-	187	18,715
	225-90-450	42,647 b	21.9	263	22,782
	450-90-450	51,117 a	46.1	362	27,152
	675-90-450	43,657 b	24.8	316	23,079
	900-90-450	41,440 b	18.5	310	21,785

Tanpeng. All plots were arranged in a randomized complete block design with four replicates. The sources of fertilizer were urea, DAP or SSP, and KCl. The cultivar was local "lion-head" ginger, and the plant populations were 106,000 plants/ha.

Results from the biomass and nutrient accumulation study found relatively slower rates for both plant growth and K uptake prior to the vigorous growth stage, which marked the beginning of much more rapid accumulation of both until plant harvest **(Table 2)**. The mean proportion of total biomass accumulated at the seedling, three branch, vigorous growth, rhizome expansion, and harvest stages was 7%, 8%, 20%, 53%, and 12%, respectively. Plant biomass responded to increases in K application rate, and the highest biomass accumulation was commonly observed under 400 kg K_2O/ha. The mean proportion of total K accumulated at each of the stages listed was 11%, 10%, 16%, 45%, and 18%, respectively. The effect of N and P application rates was consistent with results observed for that of K (data not shown).

Results from the three NPK rate trials at Shanqiao in 2007 agreed that the most profitable, high yielding combination was 400 kg K_2O/ha applied along with 400 kg N/ha and 90 kg P_2O_5/ha. The best results at Yangqiao in 2008 were achieved with 450-120-450 kg $N-P_2O_5-K_2O$/ha **(Tables 3, 4, and 5)**. For farmers who traditionally ignore K application, the economic benefit from co-applying adequate K represented an additional net return approaching US$3,000/ha.

The OPTs were tested once again against nutrient omission plots at two other locations (Shanqiao-2 and Yangqiao-2) and results agreed with earlier attempts at identifying an optimal NPK strategy **(Table 6)**. That is, collectively the six fixed OPT trials conducted over 4 years agree that N is the most important limiting factor for ginger rhizome yield in Anhui, followed by K and P. Across sites, balanced fertilization significantly increased ginger rhizome yield by 42%, 13%, and 27%, compared to the OPT-N, OPT-P, and OPT-K, respectively. Any increase in N application rate towards the OPT should be accompanied with a proportional increase in K application rate.

Table 5. Effect of P rates on ginger rhizome yield and net returns.

Year/Location	N-P_2O_5-K_2O	Yield, kg/ha	Yield increase, %	Total K uptake, kg/ha	Net return over fertilizer, US$/ha
2007/Shanqiao	400-0-400	40,567 b	-	168	16,175
	400-60-400	44,213 a	9.0	199	17,665
	400-120-400	45,685 a	12.6	251	18,286
	400-160-400	43,345 ab	6.8	242	17,371
	400-240-400	42,604 ab	5.0	233	17,117
2008/Yangqiao	450-0-450	42,940 c	-	178	22,758
	450-60-450	46,678 b	8.7	210	24,780
	450-120-450	51,386 a	19.7	282	27,315
	450-180-450	46,998 b	9.5	262	25,030
	450-240-450	45,634 bc	6.3	250	24,347

Table 6. Effect of N, P, or K omission on ginger rhizome yields.

Treatments	2002 Gaotang	2003 Tanpeng	2007 Shanqiao-1	2007 Shanqiao-2	2008 Yangqiao-1	2008 Yangqiao-2
	-------------	-------------	------------- kg/ha	-------------	-------------	-------------
OPT1	43,120 a	37,790 a	46,290 a	47,220 a	52,190 a	50,160 a
OPT-N	32,010 d	27,530 c	33,560 c	32,180 c	34,910 d	34,850 d
OPT-P	39,250 b	34,120 b	42,130 b	41,120 b	45,380 b	43,380 b
OPT-K	35,370 c	29,210 c	36,570 c	38,660 b	39,110 c	39,290 c

[1]OPT: N-P_2O_5-K_2O rates were 375-90-450 (2002 and 2003); 400-90-400 (2007); and 450-120-450 (2008).

Studies in Anhui Province show benefits of soil testing to evaluate nutrient supply for ginger.

The authors recommended P fertilization rate for ginger in this region at 120 kg P_2O_5/ha and as such recommend an N: P_2O_5: K_2O fertilization ratio of 100: 25 to 30: 100.

These results show that K is an important limiting factor for ginger production in Anhui. Ginger is sensitive to and needs a large amount of available soil K. Balanced use of fertilizers will improve rhizome yields and it contributes greatly to the economic viability of the crop. Profits were highest under this study's recommended K rates, and balanced fertilization of N and P were effective at supporting improved farmer profit. Soil testing used to evaluate soil nutrient supply also provided good guidance for avoiding over fertilization. BC

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References

Portch, S. and A. Hunter. 2002. PPI/PPIC China Program Special Publication, No. 5.

Long-term On-farm Demonstrations in the Central Pampas of Argentina: A Case Study

By Hugo Ghio, Vicente Gudelj, Gabriel Espoturno, Mauricio Boll, Juan Bencardini, and Fernando García

The Pampas region includes most of the annual cropping area of Argentina, with almost 30 million ha of cropped land. Cropping is relatively recent, with a history of 100 to 120 years for the oldest fields. Low fertilizer use and continuous nutrient removal, with increasing crop yields in recent years, has resulted in deficiencies of N, P, and S in most of the region. Under these circumstances, research has shown that nutrient application rates close to crop removal could be an alternative to sustain the trend in increasing yields while reducing depletion of soil nutrients.

In 1998 and 1999, two long-term on-farm demonstrations under continuous no-tillage were established at two farms located in southeastern Cordoba Province in the central Pampas of Argentina. The objective of these demonstrations is to evaluate the impact of various fertilization treatments on i) crop yields, ii) soil nutrient balances, and iii) soil chemical, physical and biological properties. In this article, we briefly discuss crop yield responses and trends, soil nutrient balances, and some soil properties.

One demonstration was established at Los Chañaritos farm in 1998 on a Typic Argiudoll with approximately 10 years of continuous cropping after the last pasture. In 1999, a second demonstration was established at the Don Osvaldo farm on a similar soil, but with more than 30 years since the last pasture. The Don Osvaldo site is considered under a degraded soil condition, while the Los Chañaritos site is considered as a typical soil condition for highly productive soils of the area. Results of chemical analyses carried out at the establishment of the demonstrations are shown in **Table 1**.

Table 1. Soil chemical properties of the A horizon (0 to 18 cm) at the establishment of the field demonstrations.

Depth, cm	Organic matter, %	Bray P-1, mg/kg	Exchangeable K, mg/kg	pH 1:2.5	EC mmhos/cm
- - - - - Los Chañaritos - - - - -					
0-5	3.5	24	1,059	6.2	0.17
5-18	2.9	11	795	6.3	0.10
- - - - - Don Osvaldo - - - - -					
0-5	2.9	14	949	6.1	0.10
5-18	2.2	5	659	6.2	0.06

At both sites, the crop rotation was wheat/doublecropped soybeans-corn. At Don Osvaldo, corn had been cropped in odd years and wheat/soybean in even years, and at Los Chañaritos, corn was planted in even years and wheat/soybean in odd years. The information reported in this article includes six corn seasons and five wheat/soybean seasons at Los Chañaritos, and five corn and wheat/soybean seasons at Don Osvaldo.

Both field demonstrations included similar fertilization treatments aimed at evaluating selected N, P, and S combinations at sufficiency and removal rates. An extra treatment included the application of micronutrients (Zn, B, and Cu). The treatments evaluated and their nutrient rates are indicated in **Table 2**. The treatments were arranged in strips of 30 m by 200 m without replication. Crop management at both sites followed normal best management practices for high yielding crops in the area. All operations were performed using farm equipment.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; S = sulfur; K = potassium; B = boron; C = carbon; Cu = copper; Zn = zinc.

Editor's note: As a leading famer, Hugo Ghio has intensified grain production in the Pampas by adjusting fertilization management in sustainable rotations under no-tillage, following the 4R stewardship concept. He states: "We doubled our crop yields just by applying the right rate and source of nutrients at the right place and time for each crop and field situation... it is as if we doubled the area that we crop."

Table 2. Treatments and nutrient rates applied at both field demonstrations from 1998/1999 to 2006/07.

Treatment	Check	Ss[1]	Ns	NPs	NPSs	NPSr[1]	NPSr+M[1]
Nutrient	- - - - - - - - - - kg/ha - - - - - - - - - -						
N	0	0-34[2]	60-113	70-83	70-108	85-232	86-232
P	0	0	0	11-30	11-30	27-64	23-64
S	0	12-24	0	0	9-24	11-30	11-30
K	0	0	0	0	0	0	0-13
Mg	0	0	0	0	0	0	0-30
Zn	0	0	0	0	0	0	0.4-8
B	0	0	0	0	0	0	0-1
Cu	0	0	0	0	0	0	0-5

[1]s stands for sufficiency rate, r for removal rate, M for micronutrients.
[2]N was applied only in the first year in this treatment since ammonium nitrosulfate (26-0-0-14S) was used as S source.

Soybean at Don Osvaldo 2006/07; Check at left, NPSr at right.

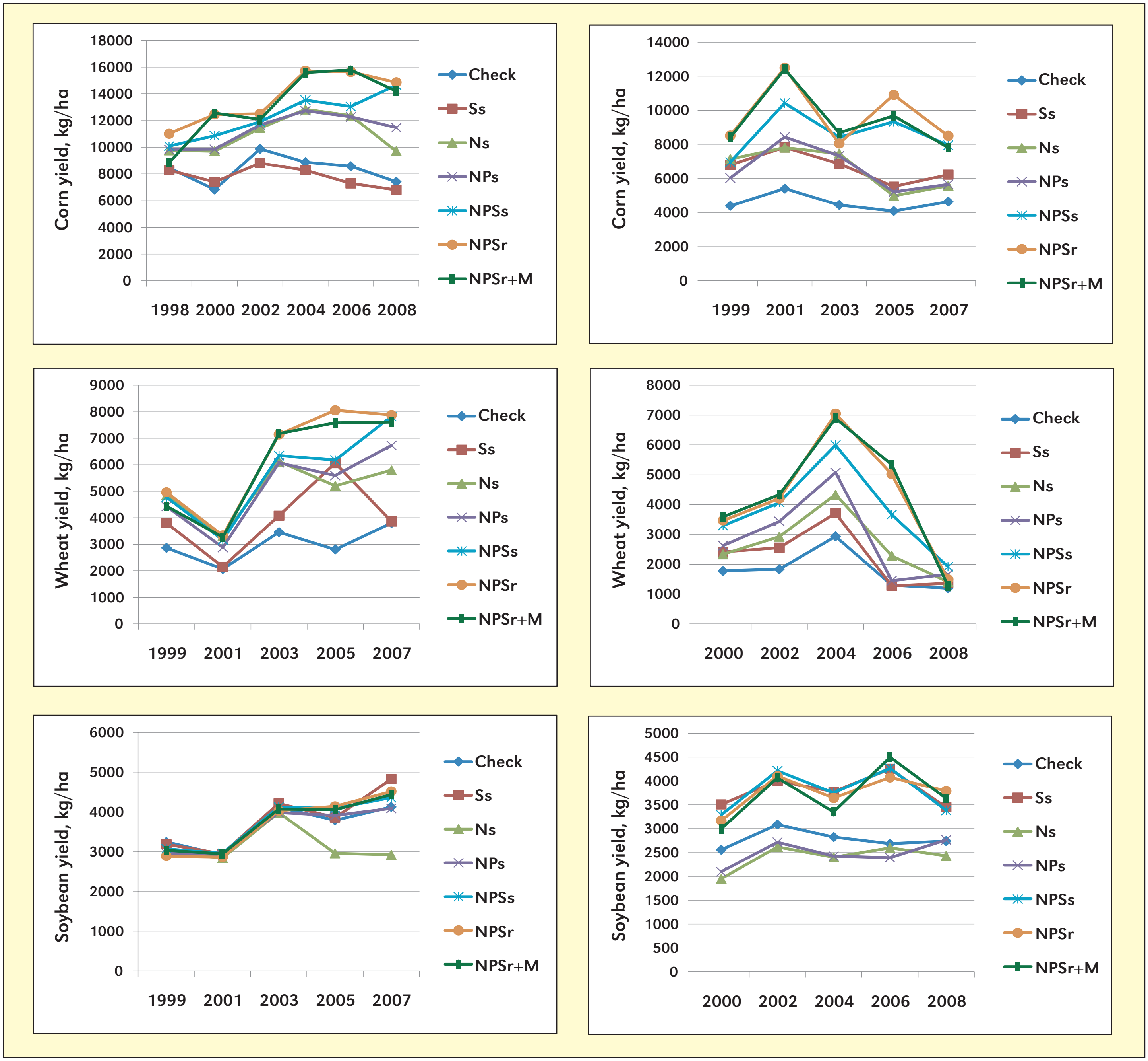

Figure 1. Grain yields of corn, wheat, and doublecropped soybean between 1998 and 2008 at Los Chañaritos (left column) and Don Osvaldo (right column).

In general, crop yields were usually higher at Los Chañaritos than at Don Osvaldo (**Figure 1**). This could be attributed to weather differences among cropping seasons, and a better soil condition at the establishment of the demonstration at Los Chañaritos than at Don Osvaldo.

Corn and wheat responded to the application of N, P, and

Corn during the 2005/06 season at Don Osvaldo; from left to right, the treatments are: Check, NPSs, and NPSr.

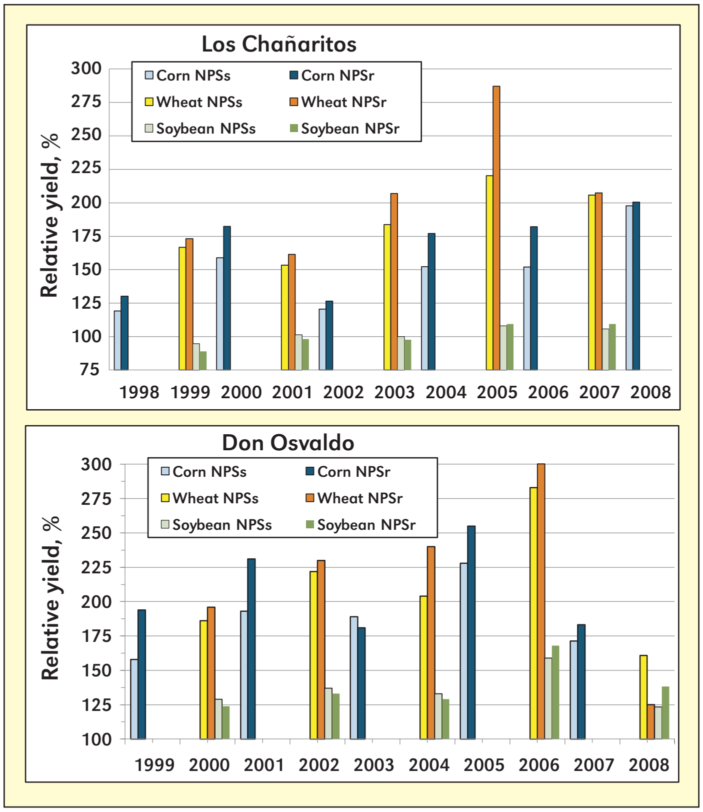

Figure 2. Relative grain yield of NPSs and NPSr treatments with respect to the Check treatment for corn, wheat, and doublecropped soybean between 1998 and 2008 at Los Chañaritos (top chart) and Don Osvaldo (bottom chart).

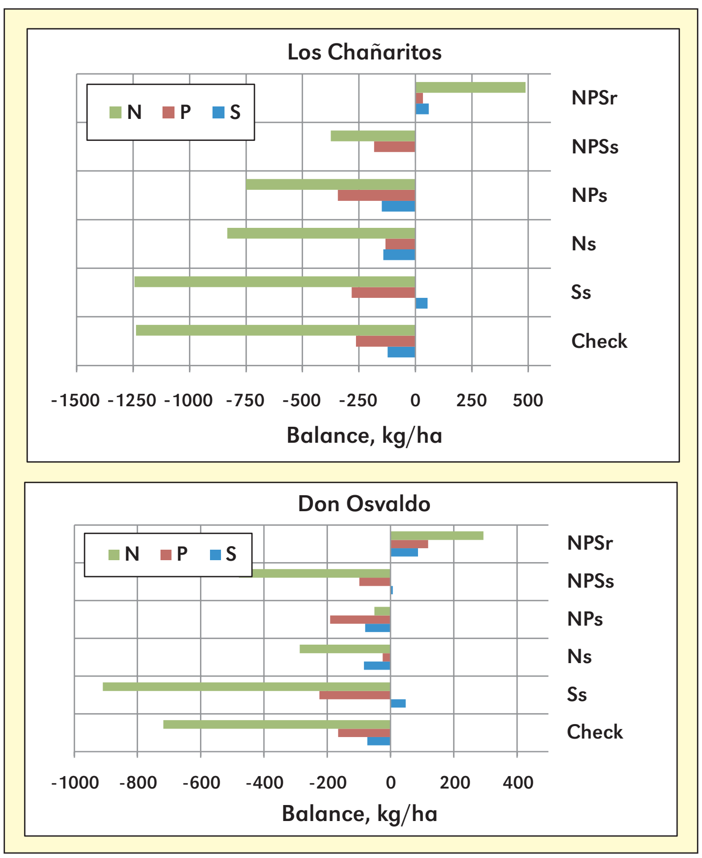

Figure 3. Nutrient balances for the seven treatments at the end of the 2008/09 cropping season at Los Chañaritos (top chart) and Don Osvaldo (bottom chart).

Table 3. Soil organic matter, Bray-1 P, and pH (0 to 18 cm) at Los Chañaritos on August 2004 (after the first six cropping seasons).

Treatment	Organic matter, %	Bray-1 P, mg/kg	pH, 1:2.5
Check	3.1	8	6.4
NPSs	3.3	18	6.3
NPSr	3.1	21	6.2

S at both sites, with the highest yields for the NPSr treatment. For soybean, the treatments without S resulted in the lowest grain yields at Don Osvaldo. At Los Chañaritos, differences in soybean yields were observed only in the last seasons (2005/2006 and 2007/2008), with the lowest yield for the N treatment. No responses were observed with application of Mg, Zn, B, and/or Cu (NPSr vs. NPSr+M treatments).

In general, grain yields of the fertilized treatments tended to increase while the Check treatments maintained similar grain yields along the years **(Figure 1)**. At both field sites, the relative grain yield differences between the Check and the NPSs and NPSr treatments, and between both NPS treat-

Soybean at Don Osvaldo 2006/07, showing response to S. NPs treatment is in the foreground and NPSs treatment in the background.

ments, have increased through the seasons **(Figure 2)**. This improvement in grain yields, by maintaining or building-up soil fertility, would also provide for a better soil condition by supplying more C through greater crop residue production and root growth and development, and, thus, a greater microbial population growth and activity.

Nutrient balances were estimated as the difference between nutrient removal by the grain and fertilizer nutrient application. For soybean, it was considered that 50% of grain N removal is provided by biological N fixation. Thus, the corresponding amount was subtracted from the grain N removal. The S balances were positive for the Ss, NPSs, and NPSr treatments at both sites, indicating that S rates have been overestimated **(Figure 3)**. At both sites, N and P balances were positive for the NPSr treatments. Regular NPS rates used by farmers in the region, equivalent to those of treatments NPSs or NPs, would result in soil N and P negative balances of 28 to 83 and 3 to 18 kg/ha per cropping season, respectively. These negative balances have resulted in widespread and severe

NPS deficiencies in most of the fields under annual cropping in the Pampas.

The differences in P balances among the Check, NPSs, and NPSr treatments might explain the differences on soil Bray-1 P (0 to 18 cm) determined on August 2004 at Los Chañaritos **(Table 3)**. No major differences among these treatments were observed for soil organic matter and pH. Soil organic matter was slightly higher for NPSs than for the Check or NPSr. Soil pH tended to decrease as fertilizer rates increased for NPSs and NPSr, compared to the Check.

In summary, NPS applications at grain removal rates resulted in high crop yields while maintaining or improving soil nutrient balances and, thus, soil fertility conditions. Further evaluations of specific soil properties and a longer evaluation period are needed to confirm the conclusions of the first 10 years of these on-farm demonstrations. On-farm testing would contribute to a more rapid and widespread adoption of crop and soil nutrient management guidelines developed at research centers. BC

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From left, Dr. García and Dr. Paul Fixen of IPNI are shown with Mr. Gudelj, Mr. Ghio, and Mr. Boll at the corn demonstration at Don Osvaldo.

Wheat at Los Chañaritos 2007/08; check plot at the left and NPSr at right.

Conversion Factors for U.S. System and Metric Units

Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others…depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields in Illinois would use units of pounds per acre (lb/A) for fertilizer rates and bushels (bu) for yields; an article on rice production in Southeast Asia would use kilograms (kg), hectares (ha), and other metric units.

Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

To convert Col. 1 into Col. 2, multiply by:	Column 1	Column 2	To convert Col. 2 into Col. 1, multiply by:
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
	Area		
2.471	hectare, ha	acre, A	0.405
	Volume		
1.057	liter, L	quart (liquid), qt	0.946
	Mass		
1.102	tonne[1] (metric, 1,000 kg)	short ton (U.S. 2,000 lb)	0.9072
0.035	gram, g	ounce	28.35
	Yield or Rate		
0.446	tonne/ha	ton/A	2.242
0.891	kg/ha	lb/A	1.12
0.159	kg/ha	bu/A, corn (grain)	62.7
0.149	kg/ha	bu/A, wheat or soybeans	67.2

[1]The spelling as "tonne" indicates metric ton (1,000 kg). Spelling as "ton" indicates the U.S. short ton (2,000 lb). When used as a unit of measure, tonne or ton may be abbreviated, as in 9 t/ha. A metric expression assumes t=tonne; a U.S. expression assumes t=ton.

Precision Technology for Right Nutrient Management

Managing nutrients right – right source, right rate, right time, and right place – may be best accomplished with the *right tools*. Various technologies are available to aid farmers and their advisers in decisions related to nutrient management, from soil sampling to fertilizer application to yield measurement. Farmers use these tools to enhance their ability to fine-tune nutrient management decisions and develop the right site-specific nutrient management plan for each field. The farmer and the farmer's employees, management and agronomic advisers, and input suppliers all are part of a team, each contributing to the decision process in different ways.

Right management means site-specific management. Making decisions on source, rate, timing, and placement with information collected on the specific field helps produce efficient, economical, and environmentally appropriate nutrient management plans. Costs of being wrong are much greater under today's costs for inputs and today's crop prices. That means the price paid for technology to fine-tune those decisions is easier to justify.

The price for the technology need not be great. Costs have gone down for many of the tools, so the components of site-specific management technology do not require as much investment. Employing global positioning system (GPS) technology to geo-reference input and yield data is a good first step. Most fertilizer and chemical dealers now have GPS-guided application equipment. Harvesting equipment now comes with GPS as a standard…or easily added… feature. The main system can usually be transferred to planting equipment for collecting geo-referenced planting data, starter fertilizer application, and other inputs. With proper controllers, variable-rate application of inputs can be added to the management plan. Each of these steps can be added over time, increasing the value of the initial investment. GPS guidance helps avoid costly skips and overlaps, saving on input costs for seed, fertilizer, and pesticides. Reduced operator stress and fatigue are major added benefits.

Geo-referenced records are a key element. On-board sensors, monitors, and controllers make huge amounts of data available to help farmers and their advisers refine the management system. To best utilize the information collected on the farm, a geographic information system (GIS) is important. GIS is a powerful tool for managing and analyzing large amounts of geo-referenced data…the kinds of data generated by modern agriculture's tools and practices. Decision-support services for farmers, consultants, and input suppliers help interpret the GIS data for better-informed decisions. GIS-based records enable all members of the management team to have access to the details for each field, so that they can help choose the right sources, rates, timing, and placement for best results.

Early efforts to assemble such a comprehensive, shared data management system had limited success, but there is a resurgence of interest. The software and communication systems have improved. New outside databases, such as digitized soil surveys and weather information, are now available to complement the farmer's data for use in decision-support tools. More farmers with more data leads toward the "critical mass" of customers needed to sustain a support service offering, either as an independent operation or as an add-on support service offering by an input supplier. Managing and interpreting those data often require outside help. Farmers can glean much more benefit by sharing the data with their adviser partners. Programs being implemented by seed, fertilizer, and chemical companies, or by technology data service providers, may be the answer to the growing information management needs of 21st century farmers…helping them to put the right nutrient source on at the right rate at the right time in the right place.

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