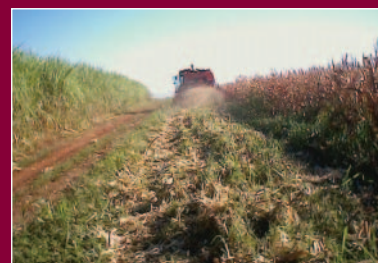# BETTER CROPS
WITH PLANT FOOD

2010 Number 2

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Integrating Crops and Tropical Pastures in Brazil

Zinc-Enriched Urea for Aromatic Rice in India

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BETTER CROPS
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Dr. Ji-yun Jin of IPNI Honored with 2010 IFA Norman Borlaug Award

The laureate of the 2010 International Fertilizer Industry Association (IFA) Norman Borlaug Award for excellence in crop nutrition knowledge transfer is Dr. Ji-yun Jin, Director of the IPNI China Program and Professor with the Institute of Agricultural Resources and Regional Planning at the Chinese Academy of Agricultural Sciences (CAAS) in Beijing. Since 1985, Dr. Jin has been working on ways to improve soil fertility and fertilizer management practices in order to increase crop productivity and farmers' incomes in China. He is also currently Professor of Plant Nutrition and Fertilization at CAAS and President of the Chinese Society of Plant Nutrition and Fertilizer Sciences.

Much of Dr. Jin's work has been devoted to developing knowledge transfer tools that can be used to pass the results of laboratory research on to farmers. The technologies developed by Dr. Jin have been widely disseminated through field demonstrations, farmer meetings, field inspection activities, brochures, leaflets, videos, TV, radio, posters, and websites. A television series on soil fertility management techniques developed by Dr. Jin was distributed through the China Central Agricultural Broadcasting School and CCTV agricultural channel. It is estimated that more than 400 million farmers are being influenced by these activities in support of technology transfer.

As Director of the IPNI China Program, Dr. Jin coordinates the efforts of a staff of soil scientists working in agronomic research and education throughout the People's Republic of China.

Dr. Jin is the 19th recipient of the IFA award, and the fourth Chinese national. He was nominated by Sinofert and selected by an independent jury. He graduated from Virginia Polytechnic Institute and State University in 1985

Dr. Ji-yun Jin

with a Ph.D. in soil science. He also received an M.S. in plant nutrition from CAAS. Dr. Jin will formally accept the award at the opening session of the IFA annual conference June 1 in Paris.

The IFA International Crop Nutrition Award was recently renamed the IFA Norman Borlaug Award in recognition of Dr. Borlaug's outstanding and tireless contribution to fighting hunger throughout the world. Effective knowledge transfer is needed for the wider adoption of improved nutrient management practices. This is the first time the award has been given to recognize excellence in crop nutrition knowledge transfer, or achievement in "last-mile" delivery.

For more about the award, visit the IFA website at: >www.fertilizer.org<. BC

Shamie Zingore Joins Staff of IPNI as Director of Africa Program

Dr. Shamie Zingore is joining the staff of the International Plant Nutrition Institute (IPNI) as Regional Director for Africa. He will be based in an office being established in Nairobi, Kenya, effective May 1.

"This announcement marks a major milestone for our organization and we are optimistic it will result in important progress for agriculture in Africa. Shamie Zingore has the right combination of education, research experience, and practical knowledge to get this new program up and running," said IPNI President Dr. Terry Roberts. "Our Board of Directors is firmly in support of this significant commitment for IPNI to adapt agronomic education and research that will succeed in Africa. Dr. Zingore will have a great opportunity to move forward in this effort."

Born in 1976 in north-east Zimbabwe, Dr. Zingore was brought up in Harare. He received his B.Sc. and Masters degrees in Soil Science at the University of Zimbabwe in 1999 and 2002, respectively. He worked for the Department of Soil Science and Agricultural Engineering as research assistant before studying for a Ph.D. at Wageningen University in The Netherlands, with support from the Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture (TSBF-CIAT). His Ph.D. dissertation was on integrated analysis of soil fertility management in African smallholder farming systems.

On completion of his Ph.D. in 2006, Dr. Zingore took a research position with TSBF-CIAT and led implementation of regional projects that developed principles for improving management of fertilizers and organic nutrient resources within complex and heterogeneous crop-livestock farming systems in sub-Saharan Africa. He worked extensively with farmer groups, input suppliers, and other stakeholders in agricultural research and development to develop innovations, build capacity, and promote

Dr. Shamie Zingore

information exchange on soil fertility management practices for enhancing productivity of agriculture in Africa. He has a strong interest in application of crop-soil models and decision support systems to improve recommendations for fertilizer and soil fertility management.

Dr. Zingore has an extensive list of publications in peer-reviewed international journals and in conference proceedings, and has also authored book chapters. BC

Managing Nitrogen Fertilizer for Economic Returns and Greenhouse Gas Reductions in Irrigated Cropping Systems

By David W. Archer and Ardell D. Halvorson

Research shows that increasing N fertilizer rates generally increase net greenhouse gas (GHG) emissions from irrigated cropping systems in Colorado. Applying N fertilizer at rates above the economic optimum increases net GHG emissions and reduces profitability. Results of this study show avoiding over-application of N fertilizer and combining careful N fertilizer management with appropriate changes in tillage and crop rotation practices can reduce net GHG emissions while maintaining profitability.

Greenhouse gas emissions from farming activities can be influenced by tillage and N fertilizer management decisions. While N fertilizer is important for increasing crop productivity, which can help maintain soil organic carbon (SOC) levels, N application generally increases nitrous oxide (N_2O) emissions from irrigated cropping systems in the Central Great Plains (Mosier et al., 2006; Halvorson et al., 2008, 2009). Additionally, N fertilizer use leads to indirect GHG emissions due to manufacturing and transportation of fertilizer to the farm. Tillage practices also influence GHG emissions, with greater tillage intensity generally associated with higher GHG emissions due to lower SOC storage and higher fuel use (Lal, 2004). There can be important interactions between N fertilizer and tillage management decisions, with higher N needed to minimize reductions in irrigated corn yield associated with no-till (NT) corn production (Maddux and Halvorson, 2008).

Tillage and N fertilizer decisions at the farm level are driven largely by economics. While management can lead to reductions in GHG emissions, producers are understandably unlikely to adopt management practices that are not profitable. This paper looks at the economic feasibility of reducing net GHG emissions using results from an irrigated cropping systems field study conducted near Fort Collins, Colorado. Cropping systems included conventional plow tillage continuous corn (CT-CC), no-till continuous corn (NT-CC), and no-till corn-soybean or dry bean (NT-CB). Nitrogen fertilizer rates applied to corn ranged from 0 to 220 lb N/A (0 to 246 kg N/ha) and rates applied to soybean or dry bean ranged from 0 to 50 lb N/A (0 to 56 kg N/ha). The highest N rate applied to corn varied with year (180, 200, and 220 lb N/A in 2002, 2003-2004, and 2005-2006, respectively). For the NT-CB system, corn was grown in 2002, 2004, and 2006, soybean was grown in 2003, and dry bean was grown in 2005. (See Halvorson et al., 2006; Halvorson and Reule, 2006; and Archer et al., 2008 for further details). Emissions of CH_4 and N_2O were measured from 2002-2006 for the 0, 60, 120, and 180+ lb N/A fertilizer rates in the CT-CC and NT-CC systems and for the 0 and high N rates in the NT-CB system using vented static chambers (see Mosier et al., 2006; Halvorson et al., 2008; and Alluvione et al., 2009 for details on GHG flux methodology).

Enterprise budgets were calculated for each system with costs calculated based on the operations and inputs used in the field study each year. Annual crop yield response to applied N was estimated using nonlinear regression and a logistic response function. Annual net returns were calculated using

Abbreviations and notes: N = nitrogen; CH_4 = methane; CO_2 = carbon dioxide.
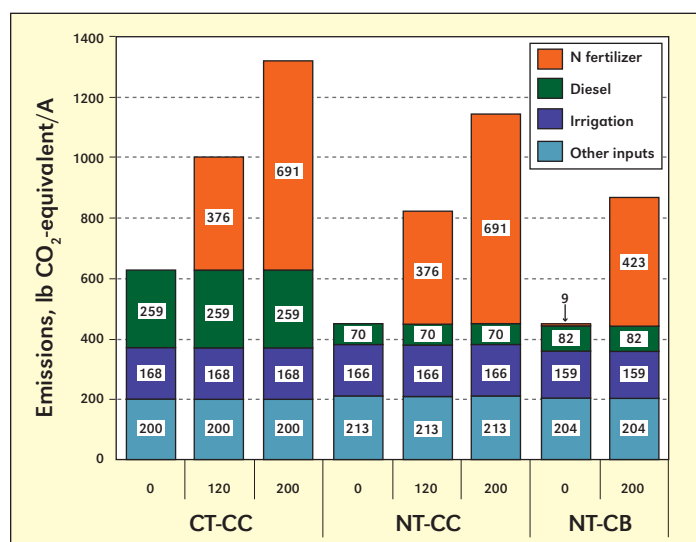
Figure 1. Average (2002-2006) greenhouse gas emissions from crop production activities (N fertilizer, diesel, irrigation, other inputs) for conventional-till continuous corn (CT-CC), no-till continuous corn (NT-CC), and no-till corn-bean (NT-CB) systems at 0, 120, and 200 lb N/A fertilizer application rates (corn year only).

the estimated annual crop yield response, assuming crop prices of $4.00/bu, $10.60/bu, and $23.80/cwt for corn, soybean, and dry bean, respectively, and N fertilizer price of $0.51/lb. Enterprise budgets did not include management or land costs, so net returns represent net returns to labor and management. The economic consequences of achieving GHG emission reductions were analyzed by combining the enterprise budget data with net global warming potential (GWP) calculated as CO_2 equivalents with 1 unit CH_4 = 23 units CO_2 and 1 unit N_2O = 296 units CO_2. Net GWP was calculated as the sum of CO_2 equivalents from irrigation, farm operations, N fertilizer production, soil N_2O emissions, and soil CH_4 emissions minus the annual increase in SOC. (See Archer et al., 2008, and Archer and Halvorson, 2010, for details on economic analysis and net GWP methodology).

Average emissions of GHG from production activities (irrigation, farm operations, N fertilizer production) are shown in **Figure 1**. At the highest N fertilizer rates, emissions associated with N fertilizer manufacture and transportation account for about half of the emissions from production activities. Excluding N fertilizer emissions, average production activity GHG emissions for the NT systems were 178 to 182 lb CO_2-equivalent/A lower under NT than under CT, primarily due to lower diesel fuel use. Average annual soil GHG
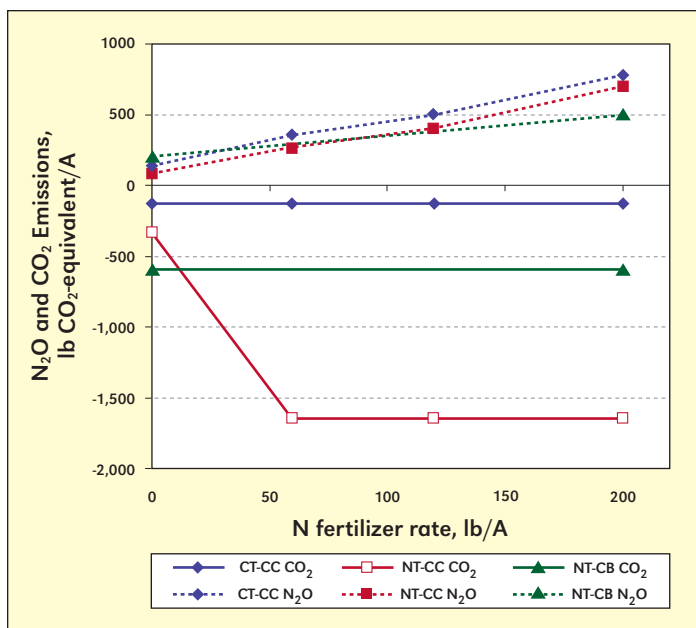
Figure 2. Average (2002-2006) CO_2 and N_2O soil emissions for conventional-till continuous corn (CT-CC), no-till continuous corn (NT-CC), and no-till corn-bean (NT-CB) systems as a function of N fertilizer application rate.

emissions used in calculating net GWP are shown in **Figure 2**. Annual emissions of CH_4 were negligible, ranging from 3 to 5 lb CO_2-equivalent/A (data not shown). Annual N_2O emissions increased with increasing N fertilizer rate (Mosier et al., 2006; Halvorson et al., 2008, 2009). All treatments increased SOC over time (1999-2007), so average annual soil CO_2 emissions for all treatments were negative (as measured by change in SOC). There were no significant differences in CO_2 emissions among N rates for CT-CC. Similarly, there were no differences in CO_2 emissions among N rates under NT-CB, so the average across all N rate treatments was used in calculating net GWP for CT-CC and NT-CB. Emissions of CO_2 were not significantly different among the 60, 120, and 200 lb N/A rates under NT-CC, but the CO_2 emissions at these rates were lower (greater SOC storage) than at the 0 lb N/A rate. Average annual CO_2 emissions were lower for NT-CC and NT-CB than under CT regardless of N fertilizer rate.

Net GWP emissions were calculated by adding emissions associated with production activities to soil GHG emissions. Combining net returns with net GWP shows some opportunities for managing GHG emissions while increasing profitability **(Figure 3)**. Excessive application of N fertilizer reduces profitability while increasing net GWP. For a producer growing CT-CC, the economic optimum N fertilizer rate in this study was 130 lb N/A. A producer applying 200 lb N/A would increase GHG emissions by 460 lb CO_2-equivalent/A while reducing profitability by $16/A compared to the economic optimum for the CT system. Reducing N fertilizer rates within a tillage-rotation system below the economic optimum could further reduce net GWP, but these reductions would come at a cost to the producer. However, switching from CT to either of the two NT systems offers opportunities to increase profitability while further decreasing net GWP. Comparing systems at the economic optimum N rates of this study, switching from CT-CC
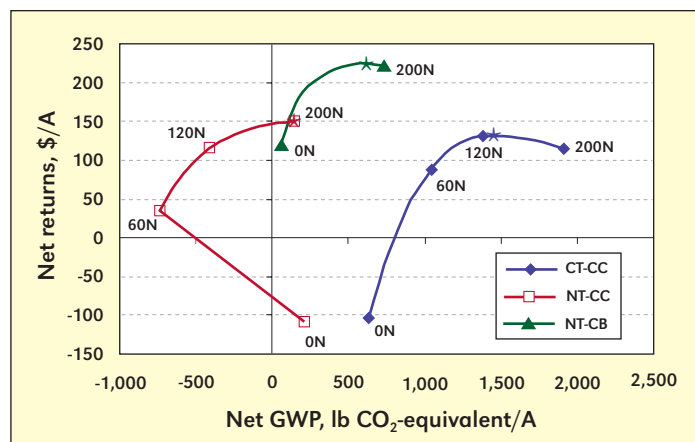
Figure 3. Relationship between average (2002-2006) net returns and average net global warming potential for conventional-till continuous corn (CT-CC), no-till continuous corn (NT-CC), and no-till corn-bean (NT-CB) systems. Point labels indicate N fertilizer application rates (lb N/A).

* Denotes economic optimum within each tillage-crop rotation system.

to NT-CC increases net returns by $19/A and reduces GWP by 1,310 lb CO_2-equivalent/A, while switching from CT-CC to NT-CB increases net returns by $92/A and reduces GWP by 830 lb CO_2-equivalent/A.

While GHG emissions tend to increase with increasing N fertilizer application rates, N fertilizer is necessary to maintain crop productivity and economic viability. For irrigated corn production in northeastern Colorado, our results indicate that GHG emissions can be reduced and profitability improved by avoiding over-application of N fertilizer. Further reductions in GHG emissions and increases in profitability could be realized by switching from CT to NT production systems. **BC**

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Zinc-Enriched Urea Improves Grain Yield and Quality of Aromatic Rice

By Gulab Singh Yadav, Dinesh Kumar, Y.S. Shivay, and Harmandeep Singh

Zinc-deficiency is widespread in the rice-growing tracts of northern India. The use of Zn-enriched prilled urea formulations assures better quality control than with Zn sulfate (ZnSO$_4$), which is being sold to farmers in India, but has quality issues. In this study, we found ZnSO$_4$ to be a better source to enrich prilled urea than Zn oxide (ZnO). For aromatic rice production, 1.0% Zn-enriched urea (ZnSO$_4$) was most effective in realizing higher grain yield and economic return.

In India, rice is the most important food crop, occupying 44 million (M) ha of land and producing 141 million metric tons (M t) of grain annually. But the per hectare yield of rice (3.21 t/ha) for India, though increasing marginally, is still well below the world's average yield of 4.15 t/ha. Furthermore, the aromatic rice varieties occupy a prime position in national and international markets due to their excellent quality characters, namely, aroma, fineness, and kernel length for cooking.

The use of macronutrients and micronutrients is important to increase aromatic rice yields and improve the quality of grains. Besides N, P, K, and S, Zn has gained maximum attention of late. The apparent reason for this is the overwhelming dominance of Zn deficiency in Indian soils and crops compared to other nutrients (Rattan et al., 1997). Increasing cropping intensity and accompanying changes in the soil and fertilizer management practices have lowered the Zn status of soils and its availability, especially in the Indo-Gangetic plains of India where rice-wheat cropping system is being practiced on a large-scale (Prasad, 2005).

The recommendation for Zn, which is generally marketed as Zn sulfate heptahydrate (ZnSO$_4$•7H$_2$O), varies from 10 to 25 kg/ha/season, depending upon the crop, environmental, and soil conditions. One of the major issues that farmers in India are facing is the availability of good quality ZnSO$_4$. Therefore, a good quality Zn-enriched urea (ZEU) manufactured by a fertilizer company would be ideal. Government of India's Fertilizer Control Order (FCO) has a provision for manufacturing and coating of 2.0% Zn onto urea. But very limited scientifically-valid data are available on the evaluation of Zn-coated urea in aromatic rice. We conducted a field experiment at the Indian Agricultural Research Institute (IARI), New Delhi, during *kharif* (summer monsoon) seasons (July-October) of 2005 and 2006 to evaluate the effectiveness of Zn-enriched urea formulations on grain yield and quality of aromatic rice in a sandy clay loam soil. The experimental soil had low levels of available Zn (0.68 ppm). The critical level of DTPA extractable Zn for rice grown on alluvial soils in the rice-wheat belt of North India varies from 0.38 to 0.90 ppm soil (Takkar et al., 1997). The soil contained 0.53% organic C, 0.05% total N, 14.5 kg/ha available P and 247 kg/ha available K at the start of the experi-

View of research plots.

ment. The initial soil pH was 8.2. New Delhi has a semi-arid and sub-tropical climate with hot and dry summers and cold winters. The mean annual rainfall is about 710 mm, most of which (about 84%) is received between July and September.

In our experimental layout, there were a total of 10 treatments. Basic treatments consisted of eight combinations of two Zn-enrichment materials (ZnSO$_4$ and ZnO) and four levels of Zn-enrichment (0.5, 1.0, 1.5, and 2.0% w/w of prilled urea). In addition, there were two other treatments including a no Zn control (only PU) and ZnSO$_4$ at 5 kg Zn/ha (soil application)

Abbreviations and notes for this article: PU = prilled urea (common urea); Zn = zinc; ZEU = zinc-enriched urea; ZnO = zinc oxide; ZnSO$_4$ = zinc sulfate; DAT = days after transplanting; HRR = Head rice recovery; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; C = carbon; CD = Critical Difference, equivalent to Least Significant Difference; ppm = parts per million.

1.5% Zinc-enriched urea (ZnSO$_4$)
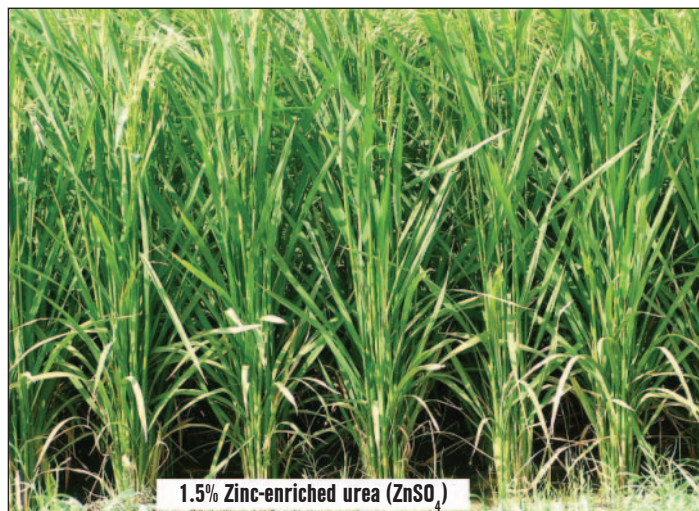
Plot showing rice with 1.5% Zn-enriched urea treatment (ZnSO$_4$).

Table 1. Grain yield, agronomic efficiency, and economic return of Zn use in aromatic rice as affected by Zn-enriched urea formulations.

Treatment	Zn rate, kg/ha	Grain yield across two years, t/ha	Agronomic efficiency of Zn, kg grain increase/kg Zn	Economic return,[1] Rs/Re invested in Zn
PU	0	3.98	–	–
0.5% ZEU (ZnO)	1.3	4.25	208	13.3
0.5% ZEU (ZnSO$_4$)	1.3	4.44	353	22.7
1.0% ZEU (ZnO)	2.6	4.46	185	11.9
1.0% ZEU (ZnSO$_4$)	2.6	4.66	261	16.8
1.5% ZEU (ZnO)	3.9	4.68	179	11.5
1.5% ZEU (ZnSO$_4$)	3.9	4.96	251	16.1
2.0% ZEU (ZnO)	5.2	4.95	186	11.9
2.0% ZEU (ZnSO$_4$)	5.2	5.14	223	14.3
PU + 25 kg ZnSO$_4$/ha soil application	5.3	5.18	226	14.5
CD (p=0.05)	–	0.47	–	–

[1]Taking GOI procurement price of fine paddy at Rs.6.10 per kg, and cost of Zn at Rs.95/kg. Minor changes in price of these commodities will not change the conclusion. US$1 is approximately equal to Rs.46.

Table 2. Effect of Zn-enriched urea formulations on grain quality of aromatic rice in second year of experimentation

Treatment	Zn rate, kg/ha	Hulling, %	Milling, %	Head rice recovery, %	Protein content, %
PU	0	70.2	63.7	52.4	6.6
0.5% ZEU (ZnO)	1.3	73.7	64.8	53.8	6.7
0.5% ZEU (ZnSO$_4$)	1.3	74.6	65.2	54.3	6.8
1.0% ZEU (ZnO)	2.6	74.8	65.6	54.5	6.9
1.0% ZEU (ZnSO$_4$)	2.6	75.6	66.3	55.1	7.0
1.5% ZEU (ZnO)	3.9	75.9	66.5	55.3	7.1
1.5% ZEU (ZnSO$_4$)	3.9	76.2	67.2	56.1	7.2
2.0% ZEU (ZnO)	5.2	76.3	67.8	57.2	7.3
2.0% ZEU (ZnSO$_4$)	5.2	78.5	69.3	58.3	7.6
PU + 25 kg ZnSO$_4$/ha soil application	5.3	75.8	66.2	55.2	7.2
CD (p=0.05)	-	2.6	2.7	2.1	0.6

+ prilled urea. In the soil application treatment, ZnSO$_4$ was applied on the soil surface (broadcast and incorporated), which is the general recommendation for rice in India (Rattan et al., 1997). The treatments were replicated thrice in a randomized block design. All plots received 120 kg N/ha as ZEU or PU. At final puddling, 60 kg P$_2$O$_5$/ha as single superphosphate and 40 kg K$_2$O/ha as KCl were broadcast. Nitrogen at 120 kg N/ha as PU or ZEU was band-applied in two equal splits – half at 10 DAT and the other half at panicle initiation (40 DAT). The ZEU supplied 1.3, 2.6, 3.9, and 5.2 kg Zn/ha for the 0.5, 1.0, 1.5, and 2.0% coatings, respectively. To make up for the short fall of N in ZEUs, calculated amounts of additional N as PU were added in plots receiving ZEUs. Two to three 25 day-old seedlings of basmati (aromatic) rice variety 'Pusa Sugandh 5'

were transplanted on hills at a row x plant spacing of 20 cm x 10 cm in the second week of July during 2005 and 2006.

The increase in grain yield in ZEU treatments over prilled urea ranged from 7.7% (0.5% ZEU-ZnO) to 35.9% (2.0% ZEU-ZS). A 0.5% Zn-enrichment of PU through ZnSO$_4$ or ZnO did not give a significant increase in grain yield over PU **(Table 1)**. However, a significant increase in grain yield over PU was obtained with 1.0, 1.5, and 2.0% Zn-enrichment either with ZnSO$_4$ or ZnO-enriched ureas and with soil application of ZnSO$_4$. Among the three higher levels of Zn enrichment (1.0, 1.5 and 2.0%), the highest grain yield was obtained at the 2.0% level. But the economic return was highest at the 1.0% level in the case of ZnSO$_4$, and at the 2.0% level in case of ZnO. Further, 1.0% ZEU (ZnSO$_4$) gave much higher economic return than 2.0% ZEU (ZnO).

In general, ZnSO$_4$-enriched urea was a better source than ZnO-enriched urea at the same level of Zn enrichment. This could be due to better solubility of ZnSO$_4$-enriched urea than of ZnO-enriched urea at the same level of Zn enrichment as observed by Nayyar et al. (1990). Slaton et al. (2005) also observed that Zn fertilizer source, averaged over application times, significantly affected grain yield of rice at all sites with Zn fertilization increasing yields by 12 to 180% compared with the unfertilized control.

Grain quality parameters were studied in year 2 of the study **(Table 2)**. Application of ZEUs improved the grain quality of rice significantly. In general, ZnSO$_4$-enriched urea had a higher percentage of hulling, milling, and head rice recovery (HRR) than ZnO-enriched urea at a same level of Zn-enrichment. For example, protein content and other quality parameters improved significantly with 1.5% ZEU (ZnSO$_4$), 2.0 % ZEU (ZnSO$_4$ or ZnO), and soil application of ZnSO$_4$. The lower levels of Zn-enrichment (0.5% or 1.0%) did not improve grain quality over the PU.

Conclusion

In this study, ZnSO$_4$ was a better source than ZnO for Zn-enrichment of prilled urea. A 1.0% coating may be sufficient for rice, with higher economic return per rupee invested in Zn. For improved grain quality, 1.5% Zn-enriched urea (ZnSO$_4$) may be more appropriate than other Zn formulations. **BC**

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Liming Requirement for Nitrogen Fertilizer-Induced Soil Acidity: A New Examination of AOAC Guidelines

By S.H. (Norman) Chien, R.L. Kallenbach, and M.M. Gearhart

Liming is a routine crop management practice on many agricultural soils and is partly a consequence of soil acidification by nitrification of N fertilizers. The Association of Official Analytical Chemists (AOAC) in 1934 adopted soil acidification values that suggest ammonium sulfate (AS) requires three times more lime to neutralize resultant soil acidity compared to ammonium nitrate (AN) or urea. This article reports on a critical examination of the value and discusses results of laboratory and 3-year greenhouse experiments with wheat-corn-wheat-corn-wheat grown to maturity in which the liming requirement for AS compared to urea and AN was approximately 25 to 47% less than the AOAC value. This report also discusses results from field trials where soils treated with AS, urea, or AN for tall fescue growth did not significantly decrease soil pH compared to the control over a 2- to 3-year period.

It is well-known that N fertilizers containing NH_4 can induce soil acidification by nitrification of NH_4 to NO_3, which produces hydrogen (H^+) ions. The degree of soil acidification, however, depends partly on N source. The following reactions represent three commonly used N fertilizers – AS, urea, and AN – in nitrification process (Adams, 1984):

$$(NH_4)_2SO_4 + 4\ O_2 \rightarrow 4\ H^+ + 2\ NO_3^- + 2\ H_2O \qquad (1)$$

$$(NH_2)_2CO + 4\ O_2 \rightarrow 2\ H^+ + 2\ NO_3^- + CO_2 + H_2O \qquad (2)$$

$$NH_4NO_3 + 2\ O_2 \rightarrow 2\ H^+ + 2\ NO_3^- + H_2O \qquad (3)$$
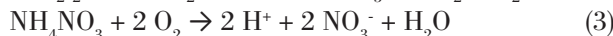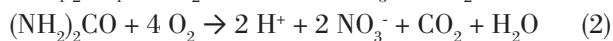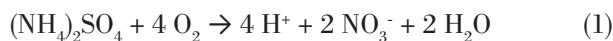
Since all three N sources contain 2 moles of N, theoretically the acidity produced by AS should be *twice* that produced by urea or AN based on the same amount of N applied. However, Pierre (1928a,b) reported that the actual acidity that would develop from urea and AN would be only 50% of the theoretical prediction for urea and AN and 75% for AS. Therefore, the predicted acidity from AS would be *three times* (3X) that from AN or urea. In 1934, the AOAC adopted Pierre's prediction and stated that the lime requirement to neutralize soil acidity induced by AS is 3X higher than the lime requirement for AN or urea. This statement has been cited extensively over the years, but until recently was not critically examined and validated in literature.

This article presents results from 1) a long-term greenhouse experiment conducted from 2001 to 2003 with a consecutive cropping system of wheat-corn-wheat-corn-wheat grown to maturity on three soils with about the same soil pH, but varying widely in soil texture, and 2) a field study (2005-2007) examining different N sources for tall fescue pastures at two sites. The main objective was to re-examine the recommended AOAC values for Relative Lime Requirement (RLR) for AS, with respect to urea and AN.

In the greenhouse study, three topsoils (0 to 6 in.) were compared: Sharkey (Chromic Epiaquerts) with pH = 6.0 and clay = 64%; Decatur (Rhodic Paledults) with pH = 7.3 and clay = 33%; and Greenville (Rhodic Kandiults), pH 6.6 and clay = 17%. Prior to planting, Sharkey, Decatur, and Greenville were incubated with KOH, HCl, and water, respectively, to narrow the range of soil pH to the range of 6.4 to 6.6. The AS, urea, and AN were incorporated below a 20-in. depth in 35 or 48 lb pots to eliminate possible NH_3 volatilization losses from urea. The N rates applied were 90 lb N/A for the first two wheat crops and 180 lb N/A for the corn crop and the

last wheat crop because of depletion of soil N. All other nutrients were applied at adequate levels for plant growth. Three replicates for each treatment including the check were made within a randomized block design. Total dry-matter yield of corn (because of erratic grain yield under greenhouse conditions) and wheat grain yield and soil pH were measured after each harvest. Soil samples were collected after the fourth or last crops and analyzed for RLR by two methods: 1) extraction with a weak buffer 1 *M* Ca-acetate solution (pH 8.0) and back titration with 0.01 *M* NaOH to pH 8.0, and 2) incubation at various rates of $CaCO_3$, as described by Chien et al. (2008). Equation [1] was used to calculate RLR in the first method:

$$RLR = [(V_{AS} - V_{Check})\ /\ (V_{AN\ or\ urea} - V_{Check})] \qquad [eq.\ 1]$$

where V is the volume of NaOH used in back titration to pH 8.0.

Equation [2] was used to calculate RLR in the second method:

$$RLR = (Q_{AS})\ /\ (Q_{AN\ or\ urea}) \qquad [eq.\ 2]$$

where Q is the quantity of $CaCO_3$ required to reach pH 6.2 (Sharkey soil) or pH 6.34 (Greenville soil) by AS, AN, and urea, based on the regression equations.

In the field study, established tall fescue was fertilized with 75 lb N/A from AS, urea, and AN in mid-March at the Southwest Research and Education Center near Mt. Vernon, Missouri, and at Bradford Research and Extension Center near Columbia. The soil series is a Dapue silt loam (pH 5.8) (Fluventic Hapludolls) at Mt. Vernon and a Leonard silt loam (pH 7.1) (Vertic Epiaqualfs) at Columbia. The clay contents of these two soils were estimated to be 20 to 30% based on the soil texture chart of the Soil Survey Staff (1960). Fourteen different N sources were tested in 2005, 2006, and 2007 at Mt. Vernon and in 2006 and 2007 at Columbia. Soil P and K levels were maintained at adequate levels for plant growth. Each treatment, including the check, was replicated five times. For the purpose of this report, only the data of AS, urea, and AN were extracted from the results.

Because all N sources were incorporated into the soils in the greenhouse study, there were no significant yield differences among AS, urea, and AN after each crop, indicating N availability of AS, urea, and AN was about the same to corn and wheat (data not shown). Soil pH after each crop followed the order of AS < urea = AN < check, according to the reactions (1), (2), and (3). Soil pH also kept decreasing compared to the check as higher N rates were applied. One example of the changes in soil pH (ΔpH) after each crop is shown in **Table 1** for Greenville soil.

Table 1. Changes in soil pH (ΔpH) as related to total accumulated N rate applied from three N sources to Greenville soil.

| Total N rate, lb N/A | Crop | ΔpH[1] | | |
		AS	Urea	AN
90	Wheat	0.22	0.05	0.05
270	Corn	0.49	0.14	0.11
360	Wheat	0.62	0.15	0.16
540	Corn	0.89	0.25	0.31
720	Wheat	1.03	0.28	0.26

[1] ΔpH = (pH of check) – (pH of N source) measured at soil to water ratio = 1:1.

Table 2. RLR values of AS with respect to urea and AN for soil samples as determined by two methods.

| Soil | Soil titration method after corn (2000) | | Soil incubation method after wheat (2001) | | Over-all average | Clay content, % |
	AS/Urea	AS/AN	AS/Urea	AS/AN		
Sharkey	1.55	1.54	1.60	1.64	1.58	64
Decatur	2.08	2.14	2.16	1.92	2.07	33
Greenville	2.22	1.93	2.39	2.45	2.25	17

Table 3. Late May forage yield of tall fescue fertilized with different N sources.

| | Mt. Vernon | | | Columbia | |
| | 2005 | 2006 | 2007 | 2006 | 2007 |
N source	lb/A				
AN	8,080	3,972	3,674	4,601	4,826
Urea	7,779	3,680	3,139	4,037	4,716
AS	8,832	3,987	4,183	4,407	4,915
Check (No N)	4,231	1,653	1,565	1,688	2,166
LSD (p = 0.05)	1,023	626	420	790	553

Table 4. Final soil pH of plots treated with different sources of N fertilizers for three (Mt. Vernon) or two (Columbia) successive springs. Each N source was applied in mid-March at 75 lb N/A to the same plots each year.

| N source | Mt. Vernon | Columbia |
	Soil pH	
AN	5.92	6.92
Urea	5.86	6.92
AS	5.62	6.76
Check (No N)	5.84	6.96
LSD (p = 0.05)	NS	NS

The results of the RLR values obtained by the titration and soil incubation methods for the soil samples treated with AS, urea, and AN are shown in **Table 2**. The over-all average RLR values are 1.58, 2.07, and 2.25 times higher for AS with respect to urea and AN for Sharkey, Decatur, and Greenville soils, respectively. These values are below the AOAC value (3.00) and represent 47%, 31%, and 25% less than the AOAC value, respectively. The Sharkey value is also less than the theoretical value (2.00) as predicted from reactions (1), (2) and (3), while the RLR values of Decatur and Greenville soils are close to the theoretical value. Thus, the results do not support liming guideline adopted by the AOAC that states AS requires 3.0 times more lime than urea and AN to neutralize soil acidity induced by nitrification of N fertilizers. In this study, Sharkey soil had very high clay content (64%), and therefore, its ΔpH value was less than that of Decatur and Greenville (data not shown). Data in **Table 2** show that the liming requirement to neutralize soil acidity induced by nitrification does not depend only on N source, but also on the soil clay content (soil texture) or pH-buffering capacity. **Table 2** shows that the over-all RLR value of AS with respect to urea and AN increased with decreasing soil clay content. This is a factor that is not considered in the AOAC recommendation for liming the acidified soils that are induced by N fertilizers containing NH_4^+-N.

The field data of forage show only the initial harvest responded to N applied. Between 60 and 80% of the annual dry matter was harvested at the initial sampling date in May and few treatment differences were measured in the two subsequent harvests. Thus, the yields shown are only for the initial harvest each year **(Table 3)**. Ammonium sulfate ranked at the top for nearly all harvests and locations. At Mt. Vernon, AS produced over 1,000 lb/A more forage than that fertilized with urea in the spring of 2005 and 2007 and produced more forage than AN in 2007. Urea and AN produced equal amounts of forage in every case except one: yields from plots fertilized with urea produced about 500 lb/A less than AN in Mt. Vernon in 2007. In each case, precipitation was not recorded for 3 to 6 days

after fertilizers were applied in mid-March.

The final soil pH for each location is shown in **Table 4**. Although AS tended to lower soil pH more than other treatments did at both locations, there were no significant differences based on LSD (p = 0.05). Neither urea nor AN lowered soil pH as compared to the check. Thus, there appeared to be no need for liming in Mt. Vernon soil treated with a total accumulated N rate of 215 lb N/A for tall fescue growth after 3 years from AS, urea, or AN.

These results suggest that the AOAC standard that states AS requires 3X more lime than urea and AN to neutralize soil acidification induced by nitrification of N sources should not be universally accepted. Other than N source, factors such as initial soil pH, soil texture, soil pH buffering capacity, soil moisture, accumulated total N rate applied, method of N placement, climate, or even crop species, should also be considered. Further work, especially field trials, is needed to delineate all these factors and make a better recommendation of liming requirements for soils treated with N fertilizers. **BC**

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IPNI Crop Nutrient Deficiency Photo Contest—2010

The 2010 edition of IPNI's annual photo contest on crop nutrient deficiencies is now accepting entries. Crop consultants, researchers, extension workers, teachers, students, photographers, and others from around the world are invited to submit their best documented examples in four nutrient-based categories: Nitrogen (N), Phosphorus (P), Potassium (K), and Other (including secondary and micronutrients). Participants will have the chance to win cash prizes and their efforts will be highlighted in the first issue of *Better Crops with Plant Food* released in 2011. We extend our appreciation to all past entrants, our congratulations to our growing list of winners, and good luck to those able to participate throughout 2010.

As in past contests, some specific supporting information is required for all entries, including:

- The entrant's name, affiliation, and contact information.
- The crop and growth stage, location, and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors, and additional details that may be related to the deficiency.

Participants are limited to one entry per category (i.e., one individual is able to have an entry in each of four categories). Cash prize awards are offered in each of the four categories as follows: • First place = US$150 • Second place = US$75 • and a Grand Prize of US$200 will be offered for the best overall photo entry.

Entries are encouraged from farm fields and research plots planted in all regions of the world. However, entries can only be submitted electronically as high resolution digital files to the organization's website, at >www.ipni.net/photocontest<.

Photos and supporting information can be submitted until December 15, 2010. Results will be announced in January of 2011 after winners are notified. All winning entries will be posted on our website and featured in *Better Crops with Plant Food*.

For questions or additional information, you may contact:

Mr. Gavin Sulewski, IPNI, Agronomic and Technical Support Specialist, e-mail: gsulewski@ipni.net, phone: 1-306-652-3535 BC

How Potassium Nutrition Can Suppress Soybean Aphids

By Tom Bruulsema, Christina DiFonzo, and Claudio Gratton

The soybean aphid has become the most important insect pest of soybeans in the Northeast and Midwest regions of North America. It often damages soybean plants that are K-deficient more than those that are not. Recent research in Wisconsin and Michigan has found that K-deficient soybeans can in some, but not all, instances suffer more from aphids than soybeans without K limitation, and that the causes may be related to amino acid composition of the phloem sap.

The soybean aphid, *Aphis glycines* Matsumura, is an invasive species that was first discovered in the United States in 2000. On-farm visits and observations in Wisconsin and Michigan indicated that many of the soybean fields most heavily infested with soybean aphids were also exhibiting symptoms of K deficiency. This article summarizes results from recent research conducted to examine the association between aphids and K, in order to determine the appropriate role of plant nutrition in the management of the aphid pest.

Wisconsin, 2001-2002

In a controlled field experiment in which K fertilizer had been applied at different levels, soybean leaf K and yield increased with increasing soil test K **(Table 1)**, but no differ-

Photo by Claudio Gratton

Close-up photo of an individual aphid (*Aphis glycines* Matsumura).

Table 1. Soybean leaf K and yield increased with increasing soil test K in a field experiment in Arlington, Wisconsin (means of 2 years, 2001-2002; adapted from Myers et al., 2005).

Soil test K[1], ppm	Leaf K, %	Soybean yield, bu/A Sprayed	Unsprayed
60	0.76	33	26
93	1.2	47	38
114	1.43	52	41

[1]Soil test K in Wisconsin is by the Bray-1 extractant. Values below 80 and above 100 are considered low and high, respectively.

ences were observed in aphid populations (Myers et al., 2005). Repeated foliar insecticide sprays reduced aphid populations and increased yields, but there was no interaction between spray and K on either parameter.

Yet, aphid populations were very high in both years in this experiment, substantially higher than those in farm fields. For example, in 2002 peak abundance in the unsprayed plots eclipsed 1,600 aphids per plant, compared to an average peak abundance of 280 in a survey of southern Wisconsin fields. It is possible that owing to the close proximity (< 3 ft.) and small size (10 by 23 ft.) of the plots, severe K deficiencies attracted and supported large aphid populations that led to colonization of plants both deficient and sufficient in K. Thus the design of this experiment may have hindered the ability to detect the observed effects that appear to be operational at the whole-field scale.

Abbreviations and notes: K = potassium; P = phosphorus; N = nitrogen; S = sulfur; ppm = parts per million; CEC = cation exchange capacity.

Table 2. Aphids in a 2003 lab study grew more rapidly on soybean leaves with less K (adapted from Myers et al., 2005).

Soil test K, ppm	Leaf K, ppm	Petiole sap K, ppm	Aphid Fecundity, nymphs/adult	Population growth rate
60	0.55	1,000	68	0.48
160	1.68	2,493	49	0.42

Wisconsin, 2003

A laboratory experiment examined performance of aphids on leaf material collected from healthy and visually K-deficient soybean plants growing in an experimental field in Arlington, Wisconsin, in 2003. The number of nymphs per adult and the population increase rate were substantially higher on the leaves low in K **(Table 2)**. This effect indicates that K-deficient soybeans provide for greater potential expansion rates of aphid populations. These controlled laboratory conditions, however, do not allow expression of factors such as natural predators and parasites that would be operational in the field.

The mechanism for this effect was not identified, but others have noted that aphids are dependent on soluble amino acids for their nutrition, and that K deficiency can cause increased concentration of such amino acids in plant tissue.

Wisconsin, 2004

In 2004, a year with low aphid pest pressure, soybean aphid populations were monitored in 34 production soybean fields across Wisconsin, ranging in soil test K from 80 to over 200 ppm (Myers and Gratton, 2006). These fields included some soils of sandier texture, whose critical level for soil test K (upper limit of the "low" range) is as low as 60 ppm. Across these fields, aphid population growth rate was negatively correlated

Table 3. Leaf K and soybean yield were increased, and aphid infestations were decreased, by addition of muriate of potash to bring soil test K to 113 and 142 ppm, in an open field trial in 2004 in Arlington, WI. (adapted from Myers and Gratton, 2006).

Soil test K, ppm	Leaf K, %	Clip-cage aphids		Natural aphids/plant		Soybean yield, bu/A
		Fecundity, nymphs/adult	Population growth rate	19-Aug	26-Aug	
60	1.5	42	0.31	107	251	24
113	2.4	27	0.28	56	72	47
142	2.4	26	0.27	54	72	46

Potassium deficient (left); healthy leaf.

Aphid infestation on a soybean leaf.

Photos by Claudio Gratton

Table 4. Surveys conducted in Michigan found higher numbers of naturally-occurring aphids in K-deficient field areas in 2003 but not in 2004 (Walter and DiFonzo, 2007).

Within-field area surveyed	2003		2004	
	Soil test K, ppm	Aphids/leaf	Soil test K, ppm	Aphids/leaf
K-deficient	15-65	174	28-83	3
Symptomless	22-83	103	38-83	3

[1]Ammonium acetate extractable K; critical levels 75-100 ppm.

Table 5. Aphid populations in a K-deficient commercial soybean field in 2004. Exclusion cages were infested with one aphid per plant on 28 May. Initial soil test K was 67 ppm[1] (Walter and DiFonzo, 2007).

KCl applied, lb K_2O/A	Clip cage 14-Jul		Exclusion cage	
			30-Jun	15-Jul
	Age at first nymph	Nymphs /adult	Aphids/plant	
0	8.8	88	703	6,858
140	11	71	233	2,315

[1]Critical level for this soil (CEC of 8.6 meq/100g) is 96 ppm.

with soil K and P and leaf K, N, P, and S. However, peak aphid densities were positively correlated with the same suite of soil and leaf nutrients.

In the same year, a controlled K response trial in field plots showed that medium and higher soil test K levels decreased aphid reproductive rates, slowed rates of population increases, and lowered peak abundance of naturally occurring aphid populations **(Table 3)**. Clip-cages placed on leaves of intact plants allowed the study of reproduction of single aphids placed on single leaves in a small enclosure, isolated from other aphids and protected from predators and escape, but in the field environment.

The reasons why aphid populations were reduced by higher K levels in 2004 **(Table 3)**, but not in 2001 and 2002 **(Table 1)** are not clear. It may be related to the lower pest pressure in 2004 which made it possible for the effects of plant nutrition on aphids to be detected without high overall aphid numbers swamping out any effects. Plot size in 2004 was the same as in the earlier studies.

Michigan, 2003-2004

In mid-August of both 2003 and 2004, five to eight commercial soybean fields in southwest Michigan showing symptoms of K deficiency were surveyed (Walter and DiFonzo, 2007). Within each field, pairs of samples were selected such that one was in the center of an area of severe visual symptoms, and the other was in a nearby symptomless area. At each of the areas, soils, plant phloem, and aphid populations were sampled. Soil test K levels were found to be lower in areas showing symptoms in both years. In 2003, an outbreak year, aphid density was higher in the K-deficient sample areas **(Table 4)**. In 2004, aphid populations were too low to detect differences in density.

In 2004, in a commercial soybean field with low soil test K in Van Buren County, Michigan, a field trial was established containing five plots, each 20 by 120 ft., with and without application of potash fertilizer at a rate of 140 lb of K_2O/A. Clip cages and exclusion cages were used to monitor reproductive performance of aphids. A clip cage was a small predator-proof enclosure clipped to a leaf to measure the growth and reproduction of individual aphids. Exclusion cages were 6 x 6 ft., covering 10 plants each, and prevented predation on the introduced aphids, but allowed escape of any aphids which morphed into alate (flying) form.

The first set of clip cages, installed on 10 June, showed no differences in aphid reproductive performance. The second set, installed 14 July, produced nymphs earlier and in greater numbers on soybeans that had not received K fertilizer **(Table 5)**. In the exclusion cages, significantly higher populations of aphids were observed on the zero-K treatment from 30 June onward.

Samples of phloem sap were analyzed from all studies conducted in Michigan in 2003 and 2004. The sampling method measured the ratios of 18 common amino acids in the sap, but not the total amounts. The relative proportion of the amino acid asparagine was found to correlate negatively with soil test K, while the other amino acids showed no relationship. That is, asparagines levels in plant sap increased as soil K tests decreased: at a soil test K level of 120 ppm, asparagine comprised 3 to 10% of the total amino acids but increased to 8 to 20% when soil tests were at 20 ppm.

Asparagine may play a critical role in relieving N-limitation of aphids. Weibull (1988) noted that sap from the most aphid-resistant accessions of oat and barley contained relatively low

Soybean leaves showing symptoms of K deficiency.

Predator-proof cages used to measure population growth rate of aphids on K-deficient and K-amended soybean, southwest Michigan, July 2003.

levels of asparagine. Richards and Berner (1954) reported that K deficiency caused higher asparagine content in barley leaves. Barker and Bradfield (1963) reported that higher levels of K in a nutrient solution resulted in reduced concentrations of free amino acids, especially asparagine, in young corn seedlings.

Aphids are thought to obtain all of their dietary N from amino acids translocated in the phloem sap. Aphids are not known to use proteinases as part of their nutritional digestion, probably because high levels of proteinase inhibitors and extremely low protein concentrations in typical phloem sap make plant proteins a poor N source. Godfrey and Hutchmacher (1999) reported that K applied on California cotton at 100 to 200 lb K_2O/A had a "moderate negative effect on both the generation time and the fecundity of the aphid." So, as plants become more stressed due to K-deficient soils, their response is to release more free amino acids such as asparagine into the phloem to counterbalance osmotic imbalances in plants. However, aphids can take advantage of these free-flowing and easy-to-digest N-containing compounds to develop faster and produce more offspring per female. This results in faster aphid population growth and ultimately higher population densities on soybean which further exacerbates yield loss.

Conclusions

In both Wisconsin and Michigan, low soil K was associated with increased aphid populations only at the low end of the range of soil K in production fields, and well below the K levels recommended for soybean production. Soil test summaries conducted in 2005 for these two states indicate a median soil test K of 125 to 149 ppm, and that only about 10 to 15% of soils are expected to test below 80 ppm.

While these results from Wisconsin and Michigan show a strong "bottom-up" effect of soybean K nutrition on the soybean aphid, it does not imply that adequate K is a reliable control for aphids. Aphid populations are also affected by natural enemies such as Asian lady beetles, and by natural parasites. Both are examples of "top-down" factors that may be more or less important, depending on the year and the site, than "bottom-up" factors such as host plant nutrition. Aphid infestations can still occur when K nutrition is adequate.

However, preventing deficiencies provides at least one
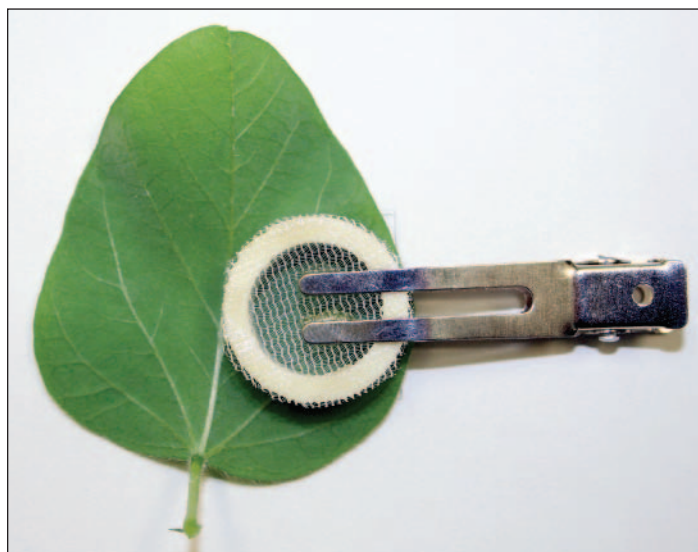
A clip cage to measure growth and development of single aphids.

degree of protection or insurance against yield loss from these potentially damaging and disease-transmitting insects. From a practical standpoint, this means that soybean growers should manage soil K levels in their fields as part of their integrated pest management plan for the soybean aphid. BC

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Benefits of Integrating Crops and Tropical Pastures as Systems of Production

By Carlos A.C. Crusciol, Rogério P. Soratto, Emerson Borghi, and Gustavo P. Mateus

Dry winter seasons prevent farmers from successful adoption of sustainable no-till systems. The consortium (intercropping) of cereals with tropical forages has been successfully adopted in several regions of Brazil as a means to protect the soil and obtain higher yields and higher economic return. This article discusses the main conditions of this consortium and its advantages, including improvement of nutrient use efficiency.

Obtaining more sustainable agricultural production systems is facilitated when utilizing effective crop rotations adapted to the region. In Brazil, no-till has been successfully used as a means to obtain more sustainable systems due mainly to its benefits to the soil and at the same time because it provides conditions for higher crop yields with time.

The correct implementation and evolution of no-till in tropical areas should follow certain basic principles. Two of the most important are to avoid tilling the soil and to establish crop sequences leading to higher amounts of straw at the surface for soil protection. The first principle is farmer dependent. The second is difficult to achieve in several regions of Brazil, and also the world, where the winter season is unfavorable in terms of climatic conditions. This is because the low temperature and low water availability does not favor good plant development and, consequently, good dry matter production.

In recent years, an alternative has been implemented to increase dry matter production and straw at the soil surface in these areas. It consists of a consortium of grain crops with tropical pastures, especially *Brachiaria brizantha* or *Panicum maximum*, during the summer, with the forages evolving to produce good dry-matter yield during the winter. These pastures have vigorous and deep roots and high tolerance to water stress, developing well in climatic conditions where the great majority of other cover crops would fail. In this system the pasture is managed with the annual crop until the main crop is harvested, at which time it continues to grow for good forage production **(Figure 1)**. The inclusion of tropical forages in the cropping system, besides leading to higher amounts of straw at the soil surface all year long, creates conditions for

Figure 1. *Brachiaria brizantha* cv. Marandú seeded with corn in different stages of the consortium: (A) before corn harvesting time, (B) at corn harvesting, (C) soon after corn harvesting, and (D) some days after corn harvesting.

Photo credits: Emerson Borghi (A and B) and Rogério Soratto (C and D)

improved soil properties (physical, chemical, and biological) and also for more favorable nutrient cycling, resulting in better plant nutrition, development, and yield.

The consortium of annual crops, especially corn or sorghum, with tropical forages is possibly due to the relevant difference in the rate of biomass accumulation among cereals and forage crops, with forages presenting lower rates of accumulation in early stages of development. Consequently, the crops of corn and sorghum become established with no necessity, in most cases, to use herbicides to retard the forage development.

Advantages to the Soil and Plant Development of Integrating Crops and Pastures

Research has already shown many agronomic advantages in the consortium of annual crops and tropical pastures. There are proven positive impacts related to straw production, nutrient cycling and removal, weed development, and soil physical, chemical, and biological quality. Average yields of up to 12 metric tons/ha (t/ha) of pasture straw, 7 months after harvesting, are frequently obtained leading to favorable soil protection, especially when corn is included in the crop sequence. These

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; CEC = cation exchange capacity; H = hydrogen; Al = aluminum; AN = ammonium nitrate.
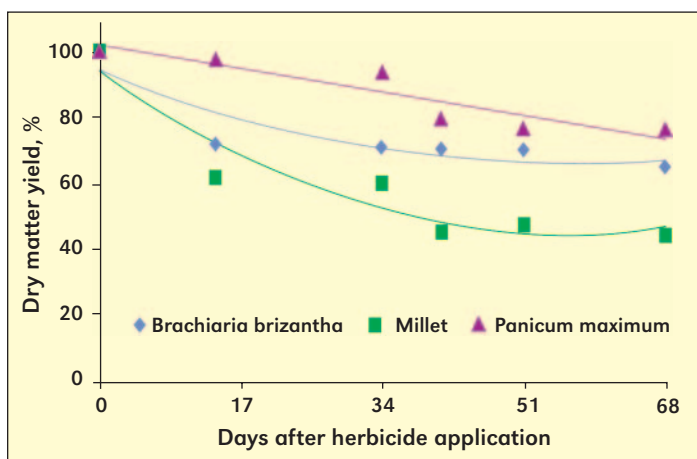
Figure 2. Persistence of forage grasses in no-till system in Botucatu, São Paulo (Crusciol, 2007).

values are much higher than the average 2.5 t/ha obtained in the same 7 months with a single corn crop.

Besides high dry-matter yield, one of the main characteristics conferring success to the use of perennial forages in grain production systems under no-till, in regions of dry winter, is its higher persistence in the soil. As an example, **Figure 2** shows that 51 days after herbicide application, only 50% of the straw from millet remained in the soil, while around 70% to 80% remained when using *Brachiaria brizantha* or *Panicum maximum* (Crusciol, 2007). In the same study, it was observed that these two tropical forages retained similar amounts of nutrients, preventing them from natural losses. These amounts were always higher than the amounts retained by millet. For example, 68 days after herbicide application the amount of N in the straw remaining in the soil was 43%, 22%, and 48% for the systems including *Brachiaria*, millet, and *Panicum*, respectively.

The higher and more resistant amounts of straw provided by the tropical forages also control the development of weeds that can negatively interfere with the plant development and final yield. Borghi et al. (2008) evaluated the occurrence of weeds before desiccation in an area, as a function of cropping system, and noticed that the control of weeds was much higher (up to 99% of control) when using *Brachiaria* in consortium with corn, as compared to corn cultivation only.

In terms of soil quality, a study by Crusciol et al. (2006) showed that the cultivation of *Brachiaria* in consortium with corn improved the soil fertility with higher final values of organic matter, soil pH, P, K, Ca, Mg, CEC, and base saturation and lower values of H + Al and P adsorption. The soil physical quality is also improved with the use of forages in these production systems, with studies showing more structured soil particles, higher soil aeration, lower levels of soil resistance, lower temperature at soil surface and more water availability to the plants. All these changes are favorable to plant growth.

One of the main advantages of utilizing these cropping system relays is the higher nutrient use efficiency with time. With more adequate soil conditions, and with improved soil nutrient cycling, plants are able to capture and utilize nutrients more efficiently. **Figure 3** shows an example. In this study, corn partial factor productivity (amount of grain produced per unit of fertilizer applied) was up to 20% higher when utilizing *Brachiaria* or *Panicum* in the cropping system.

Figure 3. Corn partial factor productivity as influenced by grass forages (*Brachiaria brizantha* cv. Marandú or *Panicum maximum* cv. Mombaça) and time of consortium establishment (Crusciol, 2009). Fertilizer was 320 kg/ha 8-28-16 for corn, applied at seeding, plus 375 kg/ha AN applied as top-dressing. Yields (kg/ha) appear in parentheses above bars. Data are average of 3 years.
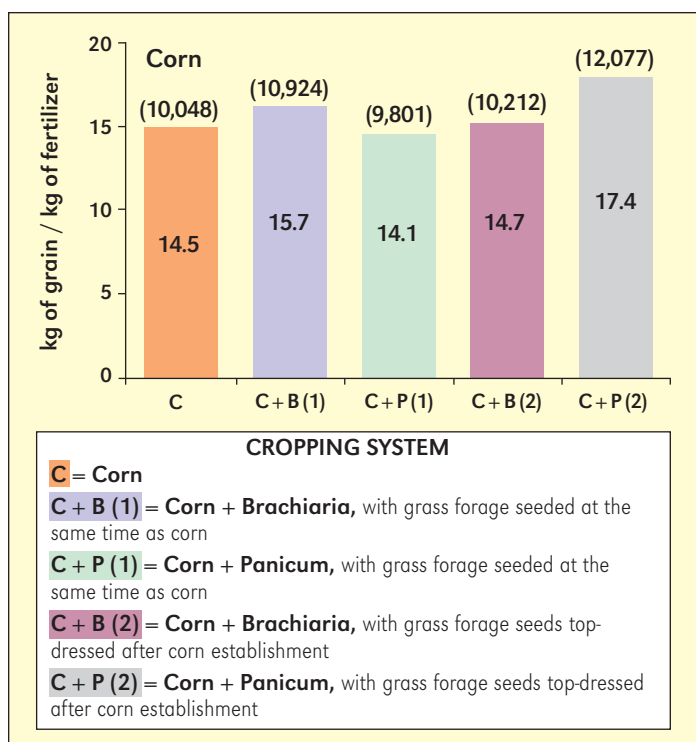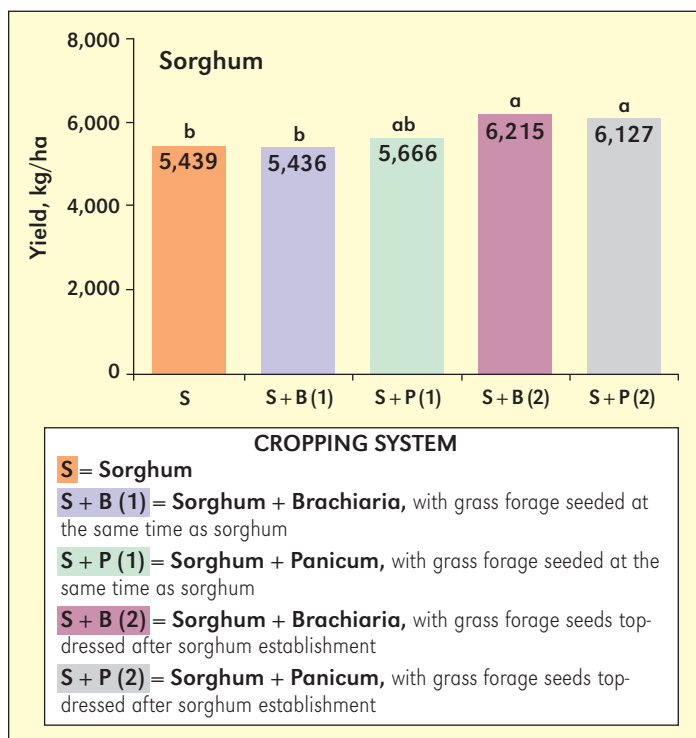

Figure 4. Yields of sorghum influenced by grass forages (*Brachiaria brizantha* cv. Marandú or *Panicum maximum* cv. Mombaça) and timing of consortium establishment (3-year average). Averages followed by the same letter do not statistically differ at 5% probability (Sousa et al., 2006).
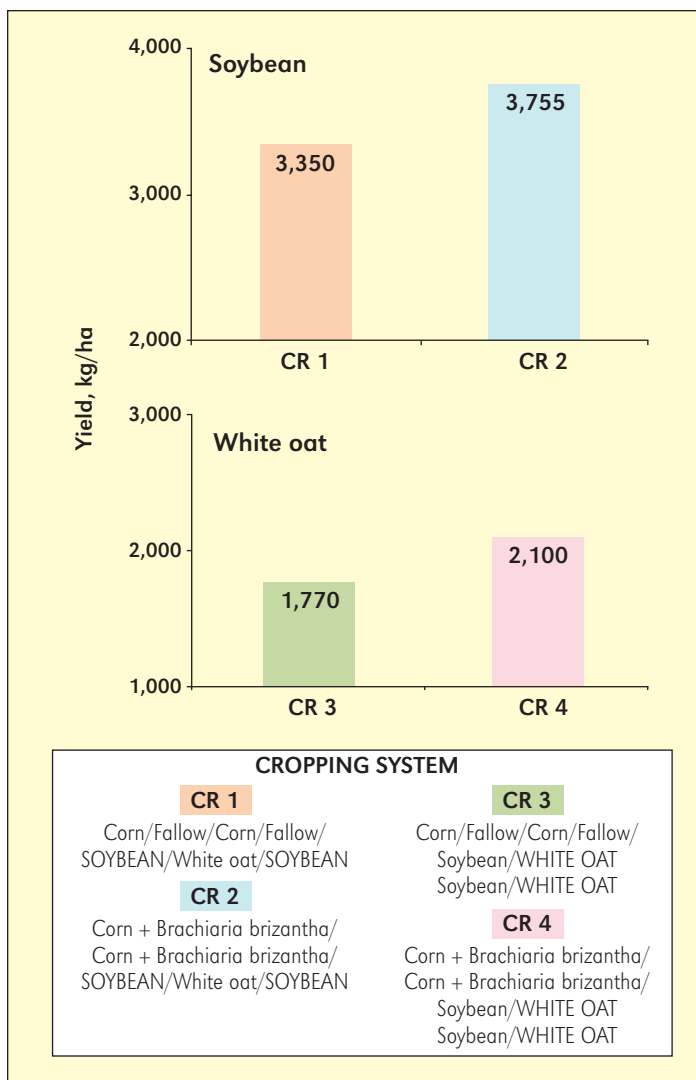
Figure 5. Yield of soybean and white oats with or without the addition of *Brachiaria brizantha* cv. Marandú in the cropping system; 2-year average (Crusciol, 2009).

Important Agronomic Aspects to be Considered

The success of these cropping systems depends greatly on several interactions with other factors affecting plant development. Some of the most important aspects that farmers have to consider follow.

Seed and Herbicide There is a clear interaction between the time to add forage seeds to the soil and the need for herbicide to control the forage development. Simultaneous seeding of forage in the corn furrow and also at the soil surface between furrows can reduce the grain yield when not utilizing the herbicide to retard forage development. However, when forage seeds are added in only one place, such as furrow or soil surface, the pasture does not interfere with final cereal yields.

Variety Cycle An important decision is related to the type of cereal variety regarding the crop cycle (very early, early, medium or long). Research has shown that very early and early cereal cycle seeds should be utilized to increase the cereal yields. It seems that the short cereal cycle leads to less impact in yields by diminishing the period of competition among both plant species. New specific varieties of cereals and tropical pastures are in development for these cropping systems.

Nitrogen Recommendation Due to the higher amounts of straw at soil surface, and also a possible competition between crops, it may be necessary to increase the amounts of N applied as compared to local official recommendations.

Consortium with Soybean The consortium between forage and soybean has to be carefully planned. Seeding this legume and the forage too close in time may lead to an aggressive development of the pasture, which can reduce the final soybean yield. For this type of consortium, it is necessary to adopt one of these two options: (1) apply herbicide in sub rates as to decrease the forage development or (2) seed the forage when the soybean crop is at stage R5 - R6. The first option may lead to soybean developing much faster, interfering with later light availability to the forage. Consequently, the sub rates have to be carefully planned.

Cereal Yield Increases by Integrating Crop and Forage Production

As a consequence of soil and plant amelioration by the consortium of tropical forages with annual crops, the yields have been improving when the system of production is established and managed properly. The increase in yields can be noticed early during the consortium (example in **Figure 4**) but are remarkably higher in future annual crops (example in **Figure 5**). **Figure 4** shows a positive effect in sorghum yield in consortium with *Brachiaria* or *Panicum*, with, in this case, the forage seeds top dressed to the soil surface only when the plants of sorghum had already established. **Figure 5** shows the effect of previous crop rotations in the yields of soybean and white oats, with a clear trend for higher yields with the inclusion of *Brachiaria* in the cropping system.

Differences in yield are economical and attest that these systems should be considered as an alternative in no-till areas with dry winter seasons. As an example of economic feasibility, in one of the farms of Peeters' agro company, there was 100% increase in profit due to the adoption of a cropping system alternating soybean, corn second crop, and *Brachiaria* grass in one year with cotton in the other year, as opposed to cotton every year. It is believed that similar cropping systems can be expanded to other areas of the world. **BC**

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Fertilizer Bands and Dual Effects of Nitrogen on Young Corn Plants

By Jun Zhang, Alfred M. Blackmer, Tracy M. Blackmer, and Peter M. Kyveryga

Applications of N fertilizer that relieve temporary deficiencies of N in young corn plants can advance plant growth stage as well as accelerate rate of growth within growth stages. This article summarizes main points of the manuscript recently published in _Communications in Soil Science and Plant Analysis_ and describes how fertilizer bands applied prior to planting can advance growth stage of corn plants. Further discussion is focused on the practical importance of this effect.

Recent studies show that early season applications of N that relieve temporary deficiencies of N in corn seedlings can accelerate plant growth stage as well as result in taller and greener plants (Zhang et al., 2007, 2008a, 2010). In a recent review, Nafziger (2006) referenced studies showing that differences in plant age and size reduced corn yield because of interplant competition.

Whereas the apparent effect of N fertilization on plant height and leaf color has been widely recognized, the potential effect of N fertilization on accelerating growth stage has not been recognized and makes it difficult to diagnose deficiencies of N. These effects have been commonly observed when bands of fertilizer N are applied diagonally to corn rows before fields are planted (Blackmer, 2001).

We report observations showing that pre-plant applications of fertilizer N in bands diagonal to corn rows can advance growth stages of the plants near the bands and discuss the importance of these effects. The primary point addressed is that the practical importance and basic significance of the effect has not been recognized.

Study Area and Plant Grouping

The observations were made in a field in a corn-soybean rotation and managed by a producer using his normal practices. A week before planting corn in late April, anhydrous ammonia was injected at a rate of 106 kg N/ha (95 lb N/A) in bands about 15° diagonal to corn rows. An additional 112 kg N/ha (100 lb N/A) was injected as a urea-ammonium-nitrate solution between corn rows on June 10. Four categories were formed according to heights and positions of corn plants relative to the tracks of the pre-plant fertilization. Representative plants were categorized as Group 1 including the tallest plants directly over the fertilizer bands, Group 2 including taller plants on the transitional portion but not directly over the bands, Group 3 including shorter plants between the bands, and Group 4 including the shortest plants far from the bands.

Height Measurement

Starting from June 14, corn heights were measured from the soil surface to the height of the uppermost collars on individual plants at 5-day intervals until the topmost leaf collar reached its terminal height. Permanent records of key events were made by taking photographs of the relevant part of the plants with a measuring tape in the background to indicate height above ground. Approximately 2,500 digital photographs were taken.

Abbreviations and notes for this article: N = nitrogen; CMR = chlorophyll meter reading.
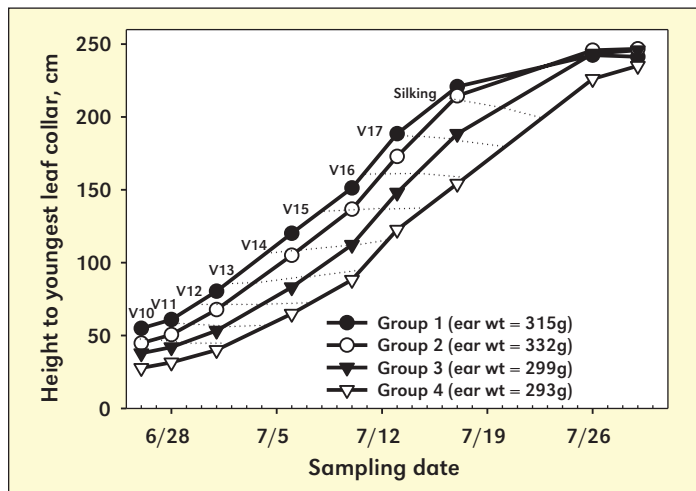
Figure 1. Temporal pattern of corn heights in four groups formed to present their relative position to the fertilizer bands. Groups 1 and 2 represent the tall plants directly over the fertilizer bands and on the transitional portion, respectively. Groups 3 and 4 represent the short plants between and far from the fertilizer bands, respectively.

Chlorophyll Measurement

Chlorophyll contents were measured by using a Minolta SPAD-502 meter and recorded as chlorophyll meter readings (CMRs) from June 26 through July 28 (corresponding to the growth stages V8 through R2 as described by Ritchie et al., 1986) at approximately 5-day intervals. The youngest fully expanded leaf was used for measurements until the tassels emerged; thereafter the ear-leaf was measured. All readings were taken halfway between the stalk and leaf tip and along the leaf margin. The mean of four individual CMRs on each leaf was calculated.

Data Analyses

The baseline measurement of corn heights on June 26 and the relative positions of those plants to fertilizer bands were used to group plants into four categories. The same approach of averaging was applied to leaf CMR measurements. The four categories clearly showed effects of anhydrous bands on plants in the test area.

Results

1. Plant heights clearly indicated the location of fertilizer bands and the differentiation of growth stages.

The plants in each of the four groups followed the same pattern of growth as normally expected, i.e., relatively slow in the seedling stage, relatively rapid during the period of "grand

Figure 2. Corn plants as viewed aside on seven dates (height indicated by a measuring tape) in the four groups representing the range in initial heights observed from first measurement.

growth," and a slow down as plants ended the vegetative stages of growth and entered the reproductive stages (Ritchie et al., 1986; Zhang et al., 2008b, 2009).

The initial plant heights measured on June 26 showed significant differences among the four groups **(Figure 1)**. The difference gradually increased as plants further developed and showed a maximum lag of 66.5 cm (26 in.) of height between Group 1 a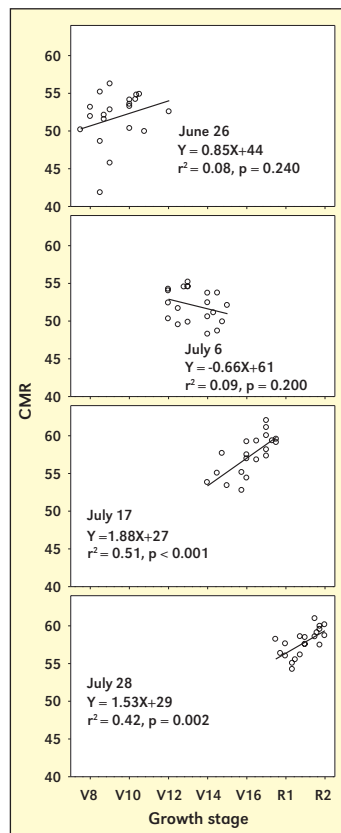nd Group 4 on July 17. The R1 stage as indicated by the emergence of silk started earlier on the plants over fertilizer bands than on the plants between fertilizer bands. This stage also started earlier on taller plants than on shorter plants. The emergence of silks seemed very sensitive to the plant heights as defined in this study. Most plants entered the R1 stage at an approximate height of 200 cm (79 in.) in this study.

Plant heights corresponding to different landscape positions across fertilizer bands were related to growth stages within each date **(Figure 2)**. These relationships suggest that much of the variability in corn height with respect to the position of fertilizer bands could be linked to differences in growth stage. Regression analysis showed that the initial corn heights had great effect (p < 0.01) on plant heights throughout the growing season until all plants approached their terminal heights by July 28. Analysis of variance showed that the overall effects of fertilizer bands on plant heights were statistically significant (p < 0.05) during this period. Toward the end of the season, differences in plant heights among the four groups were minimized, likely due to all plant roots eventually reaching the fertilizer bands, making earlier season growth and development differences less apparent on final ear weight **(Figure 1)**.

2. The greenness of corn leaves varied due to leaf position prior to silk emergence; thereafter it was linearly related to plant growth stages.

Leaf greenness as indicated by CMRs was solely measured on the uppermost developed leaves on June 26 and July 6 **(Figure 3)**. The statistically insignificant relationship (p > 0.05) between CMRs and growth stages measured at these dates suggests that CMRs measured on the uppermost developed leaves were greatly influenced by the change of leaves as plants advanced in growth. Thereafter, CMRs taken on the ear-leaf provided a reliable indication of growth stages.

3. Linear association of plant height and leaf greenness varied by growth stages.

The observed corn heights and leaf CMRs on July 6 and July 28 were poorly correlated (p > 0.05) **(Figure 4)**. Coefficients of variation for plant heights were about 3 to 4 times greater than for CMRs (data not shown). Almost all plants approached their maximum heights by July 28 and the coefficient of variation subsequently reduced to 3%.

Figure 3. Relationships between CMR and growth stages on four different dates.

Figure 4. Relationships between corn heights and CMR measured on four different dates.

Summary

When bands of pre-plant fertilizer are applied diagonally to rows of plants, variation in the amount of time for roots to grow enough to reach the bands results in a situation where adjacent plants within each row show effects that vary in a predictable sinusoidal pattern. Plants farther from the bands may have delayed development early in the season. This delayed development carries through much of the season. ▣

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Corn plants show when their roots first reach bands created by injection of anhydrous ammonia.

Learning from Long-term Experiments – What Do They Teach Us?

By Rob Norton, Roger Perris, and Roger Armstrong

Established in 1916, the Longerenong long-term rotation provides a platform for evaluating long-term trends in farming systems and soil health over a period of many years. Longerenong rotation 1 (LR1) gives us essentially the same message as other long-term agronomic experiments. The message is that rotations can be sustained and productive provided the challenges of diseases, weeds, soil structure, and nutrient replacement are met.

Long-term agronomic experiments (LTAE) reflect new ideas and practices in farming systems. The longest running experiments were established at Rothamsted in the United Kingdom (UK) in 1843, and seven are still running today (Rassmussen et al., 1998). There are only 10 others of these classical (more than 50 years) experiments across the globe, including LR1 in Australia.

LR1 is Australia's longest running annual cropping system experiment, established in 1916 on a self-mulching, alkaline Grey Vertosol near Horsham in southeastern Australia. Average annual rainfall is about 420 mm. LR1 sought to identify what crop sequences would provide improved yields and over time it has became a platform for other research such as on the use of superphosphate. The experiment compares seven cropping rotations and although not spatially replicated, each cropping phase is present every year. The rotations are continuous

LR1 has a history of providing lessons to farmers and scientists. This photograph was taken at the annual field day in 1930.

wheat (WWW), wheat/fallow (WF), wheat/oats grazed/fallow (WOgF), wheat/barley/peas (WBP), wheat/oats/peas (WOP), wheat/oats grazed/fallow (WOgF) and wheat/oats/oats grazed/fallow (WOOgF). The crops receive no fertilizer N, 10 kg P/ha on cereals, and 5 kg P/ha on other harvested crops. Crop establishment, weed control, and crop protection activities follow district practice. In the soil, N and P are present in a range of forms that have different availabilities to plants. Most of the soil N is present in organic forms which are mineralised to nitrate which is the form that plants can take up. Applied P is partitioned into a range of soil pools with different plant availability, due to differences in desorbtion, dissolution, and

Abbreviations and notes: N = nitrogen; P = phosphorus; C = carbon; N_2 = atmospheric N.
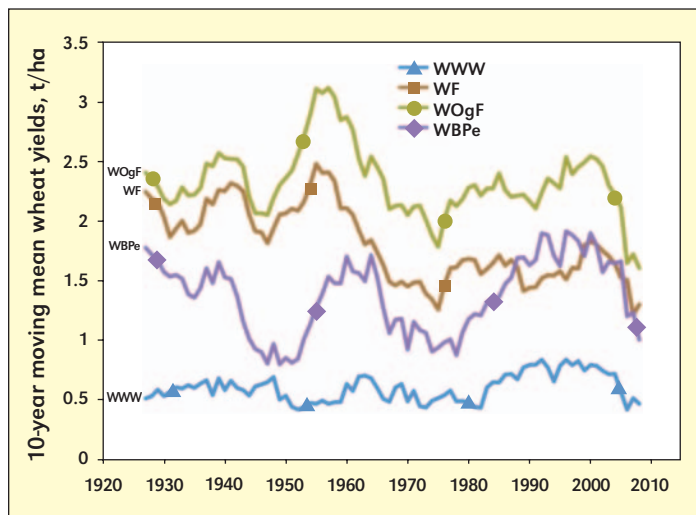

Figure 1. Grain yields of four of the seven rotations from LR1. Data presented are the 10-year moving means for the wheat phases of the rotations for the period 1916 to 2008.

mineralisation rates that contribute to plant P nutrition. Soil tests can distinguish the more available P (e.g. resin, bicarbonate, and sodium hydroxide extractable) forms in the soil (Hedley et al., 1982). Understanding the fate of this applied P helps us predict future P strategies.

The 90+ years of this experiment have given several lessons about grain yields, nutrient removals, and sustainability.

Lesson 1– Yields can be sustained over long periods

The mean wheat yields over the period of the experiment are shown in **Figure 1**. There are phases in these trends and the most recent recovery, starting in 1975, is co-incident with the use of herbicides on this experiment (Hannah and O'Leary 1995). Over the past 10 years, the rotation experiment has been challenged by the root nematode *Pratylenchus* and infestations of the weed bromegrass, but the downward trend seen in **Figure 1** since about 2000 is a result of low rainfall over that time. The only rotation that did not trend downwards is the WWW, which was already low yielding.

The highest producing rotation (WBP) from LR1 produced two and a half times the energy equivalence of the WWW rotation (2.22 t/ha/y glucose equivalence versus 0.87 t/ha/y glucose equivalence). Glucose equivalence is the energy content of the grain and provides a way to compare yields of different crops with different energy densities. Over the past 90 years, the WBP has produced 1.52 t/ha of wheat, 1.53 t/ha peas, and 1.57 t/ha barley in its 3-year cycle. At current grain

Table 1. Apparent mass balances for N and P for the seven rotations of LR1 (1986-2008).

Rotation treatment 1986-2006	Average wheat yield, t/ha	P balance, Δ kg P/ha/y	N balance, Δ kg N/ha/y
Continuous wheat	0.64±0.52	7.3	-7.3
Wheat:fallow	1.50±0.76	0.9	-11.8
Wheat:grazed oats:fallow	2.05±0.97	-0.3	-10.6
Wheat:barley:peas	1.46±1.31	3.2	2.9
Wheat:oats:peas	1.39±1.24	1.2	1.8
Wheat:oats:fallow	1.86±0.95	3.0	-13.9
Wheat:oats:grazed oats:fallow	2.11±0.96	-0.1	-12.1

Longerenong College open day in 1930, putting new cultivars in front of farmers.

Table 2. Soil N, C, bicarbonate extractable P (Olsen P), total P, and selected P fractions as a percentage of total P for rotations of LR1 and the adjacent uncropped fenceline, when sampled in 2005.

	WWW	WF	WOgF	WBP	WOP	WOF	WOOgF	Fence-line
Total soil N %	0.070	0.056	0.063	0.085	0.087	0.061	0.066	0.162
C: N ratio	13.3	16.2	14.9	13.0	12.9	13.9	13.8	13.1
Total P, mg/kg	486	367	307	341	329	330	322	295
Bicarbonate Ext. P, mg/kg	69	52	40	40	47	66	50	18
% HCl P	39	25	18	25	22	23	19	7
% Residual P	35	43	47	49	52	50	61	75

prices, this is the most profitable rotation. Although damaging to soil structure, the inclusion of a fallow phase into the rotations gave lower yield variability than continually cropped rotations, especially in these years of low rainfall over the past decade **(Table 1)**.

Weed and disease control strategies both require biological diversity in the farming system. Crop rotation is fundamental to ensure sustainable production systems with each phase acting as a tool to support and enhance the following crops by providing disease breaks, opportunities for alternative weed control strategies, and/or improving soil conditions.

Lesson 2 – Nutrient balances need to be addressed

Long-term production does come at a cost, though. **Table 1** shows the N and P balance for LR1 over the past 25 years. This period was chosen because the experiment was altered a little in 1984 and since then south-eastern Australia has experienced a long period of below average rainfall.

Grain yield has been recorded each year and grain protein (N) in recent years. However, seed P content has not been measured, but estimated from other experiments. To develop a nutrient balance for this experiment, the apparent balance of N or P was calculated on an annual basis as:

N balance = N applied as fertilizer + N fixed by legumes − N removed in grain

or P balance = P applied as fertilizer - P removed in grain

No estimates were made for free living N fixation, non-biological N inputs, N leaching, N volatilization, or N lost in soil erosion. The N_2 fixation for the pea phases were estimated using the peak biomass for peas from the pea grain yield, as-suming a harvest index of 0.3, then converting this peak biomass to N fixed by using the conversion of 25 kg N/tonne of biomass (Peoples et al. 2001). Grain N removal was estimated by the grain N content multiplied by the yield of peas, barley, or wheat. Both the grazed oats and the crop stubbles were retained within the plots. Grain P content was estimated from grain P contents taken in 2005, but the actual grain P contents may differ in response to different soil P levels.

Table 1 shows an average N removal of 12 kg N/ha/y from 1984 where no pulse was included and a slightly positive N balance where the rotation included peas.

There was no baseline soil archived when the experiment was established 90 years ago, and so a "fenceline" sample was taken in an uncultivated area adjacent to the site. The soil N and C values (top 10 cm) measured then are in general agreement with the estimated N decline from the mass balances. While it is not possible to fully analyze these data due to the nature of the experimental design, there is an indication that C:N ratios are higher for rotations that

Longerenong College was one of the first places in southeastern Australia to trial superphosphate for grain production.

have fallows, reflecting the gradual decline in the amount and nature of the organic matter present.

Table 1 also shows the P balance for the various rotations at LR1. Tang et al. (2006) reported P fractionation of the soils from this experiment and a summary of some of these results is given in **Table 2**. All rotations show a positive P balance except for the two grazed oat rotations. The total amount of P and the less available acid-soluble P fraction increased in all rotations, especially in the continuous wheat which also had the highest P balance. The regular P applications used as part of the cropping practices in this experiment increased

Roger Perris (left) in LR1 plots with second year agronomy students from The University of Melbourne.

Google Earth/DigitalGlobe view of LR1 showing the plot layout. All plots were originally one acre each. In 1986, they were split, with the southern half using the latest cultivars while the northern half retained the traditional variety Ghurkha wheat.

the total P content of the soil, while the relative proportion of P in the "plant available" pools decreased.
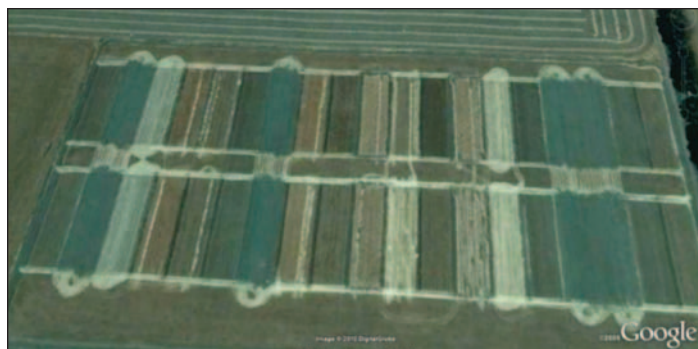
Where is the N coming from? Unfortunately, LR1 had no soil samples archived from the beginning, but we can look at fenceline soils as a measure of "native" soil levels. **Table 2** shows the soil N and C levels. It is possible to estimate the annual decline in soil N from these data, if we assume the starting point was the fenceline soil. These values are largely consistent with the mass balance estimates and indicate that the decline in N is basically derived from the mineralization of organic matter. The conclusion then is that to access N in rotations, soil organic matter needs to be oxidized, and N from the soil comes at a cost to soil C. We need to consider the converse of this statement, which is that if we wish to sequester C in soils, N (and P) will need to be supplied.

Where is the P going? It is clear that the long-term P applications have raised the total amount of soil P, basically in accord with input and outputs presented in **Table 1**. The soil P fractions differ in their availability to crops and these results show that almost all the applied P is now in the low availability pool (Residual and Acid P). Tang et al. (2006) took soil from these rotations and tested the crop response to P in a glasshouse. This showed a positive response to additional P which is not what would be expected from the Olsen soil P test values. The conclusion is that on these alkaline soils, the fixation processes are rapid and current commercial soil tests are not very reliable indicators of potential P response, and indeed the responses differed among a range of crops used to test response. Those authors also concluded that the key to improving P use efficiency is to match P fertilizer applications to crop P removal on these soils.

Soil C levels The effect of mineralizing N is to reduce C so that soil C levels have declined. With the current interest in C sequestration, LTAEs such as LR1 can provide unique real world data on soil C stocks under different farming systems. In 1916, when the experiment was established, such a question would not have been thought of and now as part of a new research project, this site will be used to measure soil C stocks to depth and accounting for soil bulk density.

Conclusion

At the most fundamental level, LTAEs provide us with reassurance that cropping and pasture systems can operate for many decades and depending on the strategies adopted, continue to produce food and fibre with resource protection. While cropping and pasture systems computer simulation models can help refine information, they do require real world data to calibrate against. Conclusions based on 10 to 20 years of experimental data can be quite different to those based on 50 years of data. Long-term agronomic experiments have provided us with understanding about the trends in productivity associated with different crop sequences and tillage operations. Since their inception, we now use LTAE's to help identify factors affecting sustainability and environmental quality as well as species impacts in response to change.

While we know a lot about the effect of systems on soil health ("knowns"), there are things we have not yet parameterised ("known unknowns", such as soil C). There are other things we have not even considered. Dealing with "unknown unknowns" is difficult to cost and plan for, but having well planned and suitably resourced long-term experiments can play a vital role in such studies. As Rassmussen et al. (1998) indicated, "We need continuity with the past to better predict the future." **BC**

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Magnesium: A Forgotten Element in Crop Production

By Ismail Cakmak and Atilla M. Yazici

Magnesium nutrition of plants is frequently overlooked and shortages will adversely impact plant growth. Many essential plant functions require adequate Mg supplies, the most visible being its role in root formation, chlorophyll, and photosynthesis. Many less visible reactions are also dependent on an adequate supply of Mg. This review briefly summarizes some of the essential roles of Mg for plants.

Magnesium has a number of key functions in plants. Particular metabolic processes and reactions that are influenced by Mg include: 1) photophosphorylation (such as ATP formation in chloroplasts), 2) photosynthetic carbon dioxide (CO_2) fixation, 3) protein synthesis, 4) chlorophyll formation, 5) phloem loading, 6) partitioning and utilization of photoassimilates, 7) generation of reactive oxygen species, and 8) photooxidation in leaf tissues. Consequently, many critical physiological and biochemical processes in plants are adversely affected by Mg deficiency, leading to impairments in growth and yield. In most cases, the involvement of Mg in metabolic processes relies on Mg activating numerous enzymes. An important Mg-activated enzyme is the ribulose-1,5-bisphosphate (RuBP) carboxylase, which is a key enzyme in the photosynthesis process and the most abundant enzyme on earth.

Leaf yellowing in the form of interveinal chlorosis on older leaves is one of the typical symptoms of Mg deficiency stress **(Figure 1)**. It is reported that up to 35% of the total Mg in plants is bound in chloroplasts **(Figure 2)**. However, the ap-
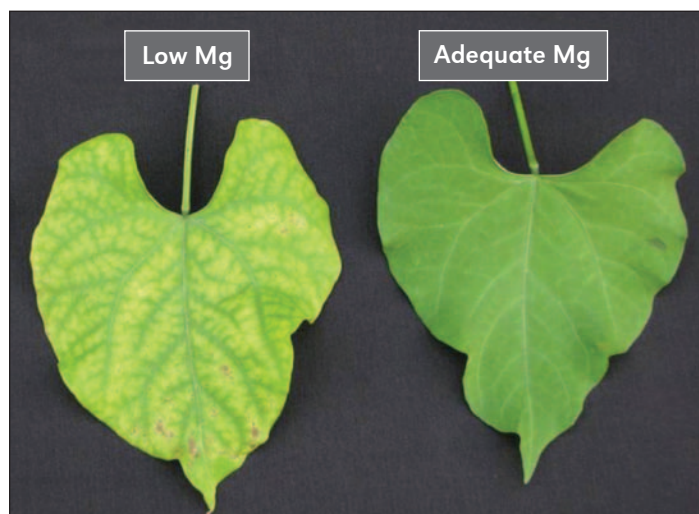

Figure 1. Magnesium deficiency symptoms on common bean leaves, left.

pearance of Mg deficiency symptoms is highly dependent on light intensity. High light intensity increases the development of interveinal chlorosis, together with some reddish spots on the leaf blade **(Figure 3)**. Therefore, the well-documented differences between plant species in the expression of visual Mg deficiency symptoms and also in critical deficiency concentrations of Mg in the leaf tissue may be related to the light intensity in a particular growth environment.

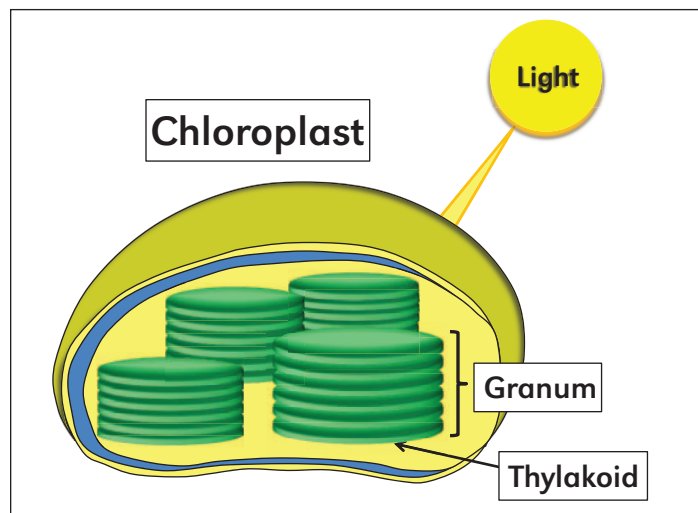The leaf damage that occurs in Mg-deficient plants exposed

Abbreviations and notes: Mg = magnesium; N = nitrogen; P = phosphorus; K = potassium; Al = aluminum; Ca = calcium; ATP = adenosine triphosphate.

Figure 2. Chloroplasts are the organelles that host thylakoids, the Mg-containing compartments where light energy is converted to chemical energy through the process of photosynthesis.

to high light intensity has been ascribed to enhanced generation of damaging highly reactive oxygen species in chloroplasts at the expense of inhibited photosynthetic CO_2 fixation. Plants growing under conditions of high light intensity appear to have a higher requirement for Mg than the plants grown under lower light intensity.

Magnesium Deficiency Is a Growing Problem

Despite the well-known role of Mg for various critical functions, there is surprisingly little research activity on the role of Mg nutrition in crop production and quality. Hence, Mg is often considered a "forgotten element". However, Mg deficiency is increasingly becoming an important limiting factor in intensive crop production systems, especially in soils fertilized only with N, P, and K. In particular, Mg depletion in soils is a growing concern for high-productivity agriculture.

Due to its potential for leaching in highly weathered soils and the interaction with Al, Mg deficiency is a critical concern in acid soils. One of the well-documented plant adaptation mechanisms to acid soils is the release of organic acid anions from roots. Organic acid anions released from roots will chelate toxic Al ions and form Al-organic acid complexes that are no longer phytotoxic. It is well-documented that Mg is required for effective release of organic acid anions from roots to modify an Al-toxic rhizosphere (Yang et al., 2007). Like Mg, Ca is also important in alleviating Al toxicity in acid soils. However, Mg can be protective against Al toxicity when added in micromolar levels, while Ca exerts its protective role in millimolar concentrations (Silva et al., 2001). This result indicates Mg has very specific benefits in protecting against Al toxicity.
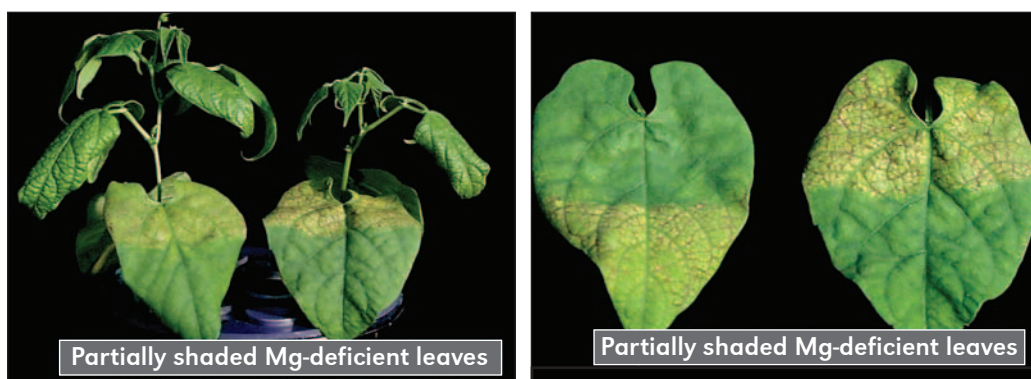
Figure 3. Symptoms of leaf chlorosis in Mg-deficient bean plants grown at high light intensity. The green portion of the leaves was partially shaded with filter paper. With an adequate Mg supply, high light did not cause any leaf chlorosis (Cakmak and Kirkby, 2008).

Early Reaction to Mg Deficiency

In view of diverse functions of Mg in plants, a question arises as to which function or structure is affected first under Mg deficiency. The most common answer was chlorophyll level, or photosynthesis, or protein synthesis. There are a few studies published previously by Cakmak et al. (1994) in common bean, Hermans et al. (2004) in sugar beet, and Hermans and Verbruggen (2005) in Arabidopsis that provide a clear and convincing answer to that question, as discussed below in this short review paper.

Hermans et al. (2004) grew sugarbeets with either a low or an adequate Mg supply and analyzed 1) plant growth, 2) photosynthetic CO_2 fixation, 3) chlorophyll concentrations, 4) photosynthetic electron transport and 5) leaf concentration of sucrose. The results obtained were clear: before any noticeable or significant change occurred in the first four measurements, there was a large accumulation of sucrose in the fully expanded leaves of the Mg-deficient plants. Magnesium-deficient leaves accumulated up to 4-fold more sucrose when compared to the Mg-adequate leaves, indicating a severe inhibition in sucrose transport out of the Mg-deficient leaves.

Cakmak (1994 a,b) studied the role of Mg nutrition in 1) shoot and root growth, 2) concentration and distribution of carbohydrates among root and shoot organs, and 3) phloem export of sucrose in bean plants. Results showed pronounced inhibition of root growth before any noticeable change in shoot growth and chlorophyll concentration. Consequently, the shoot: root ratio for both bean and wheat plants increased in Mg-deficient plants **(Figure 4)**. This early negative effect of Mg deficiency on root growth before the development of visible leaf chlorosis is a critical issue for growers because of the importance of a good root system for plant production. Therefore, special attention should be given to the Mg nutritional status of plants before the development of any visible deficiency symptoms.

Accumulation of carbohydrates in fully-expanded leaves is a common phenomenon with Mg-

deficient plants. At the beginning of Mg deficiency and under severe Mg deficiency, Cakmak (1994 a, b) found that older leaves contained 3.5-fold and 9-fold more sucrose, respectively, compared to the Mg-adequate plants. Magnesium-deficient leaves also contained elevated amounts of starch and reducing sugars. In bean plants grown with a low Mg supply for 12 days, only 1% of the total plant carbohydrates were found in roots, whereas in the Mg-adequate plants, this value was 16%. All these results clearly indicate a severe inhibition in phloem export of sugars out of Mg-deficient leaves.

Phloem exudates were collected from bean plants with low and adequate Mg supply to study the role of Mg nutrition on the movement of sucrose out of the leaf. Magnesium deficiency resulted in severe and very early inhibition of the phloem transport of sucrose **(Figure 5)**. There was an inverse relationship between sucrose concentration in leaf tissues and the sucrose export rate in phloem during the 12 days of Mg-deficiency treatment. The inhibitory effect of Mg deficiency on sucrose transport via phloem occurred before any adverse effect on shoot growth. Re-supplying Mg to the deficient plants restored the phloem export of sucrose within 12 hours.

These results strongly suggest that the effect of Mg on phloem loading of sucrose is specific and not related to any secondary effect. The mechanism by which Mg deficiency affects phloem loading of sucrose is still not fully understood, but it appears to be related to the low concentrations of the Mg-ATP complex at the phloem loading sites. It is widely believed that Mg-ATP is required for a proper function of H^+-ATPase, an enzyme that provides energy for the phloem loading process and maintains sucrose transport into phloem cells.

Practical Importance of Early Mg Deficiency

High carbohydrate accumulation coupled with inhibited phloem export of sucrose from Mg-deficient leaves show the importance of maintaining adequate Mg nutrition of plants
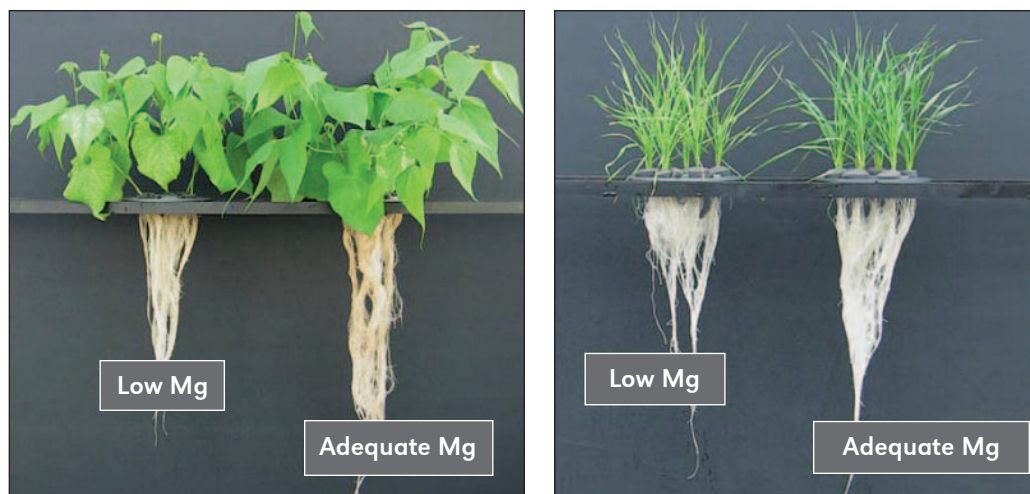

Figure 4. Growth of common bean (left) and wheat (right) plants with low and adequate Mg nutrition.

during periods of intensive carbohydrate transport from leaves to the growing cells. Sufficient Mg is required for maximizing the carbohydrate transport into sink organs (such as roots and seeds) to promote high yields. Maintenance of adequate Mg nutrition at the late growth stages is also essential for minimizing generation of harmful reactive oxygen species and photooxidative damage in chloroplasts. The application of late-season Mg through fertilization or foliar sprays may be useful in some circumstances. The impairment in root growth due to Mg deficiency may have also serious impacts on uptake of mineral nutrients and water, especially under marginal soil conditions.

Producing plant-based biomass as a renewable energy source is a growing and promising alternative to fossil fuel. But the productivity of these systems is directly dependent on 1) the capacity of plants to fix CO_2 into organic carbon (C) through photosynthesis, 2) translocation of the assimilated C from source into sink organs, and 3) utilization of assimilated C in the sink organs for growth. All of these steps are specifically controlled by Mg. Therefore, attention must be directed to the Mg nutritional status of biofuel plants in order to achieve high biomass production and partitioning of the assimilated C in the desired plants organs (such as grains or roots).

Magnesium has long been noted for its essential role in chlorophyll formation and photosynthesis. However, growing evidence shows that sink organs (such as growing roots and developing seeds) are also severely affected by Mg deficiency. For too long, Mg has been a forgotten element for crop production, but its vital role is increasingly being recognized in plant nutrition. BC

Acknowledgment

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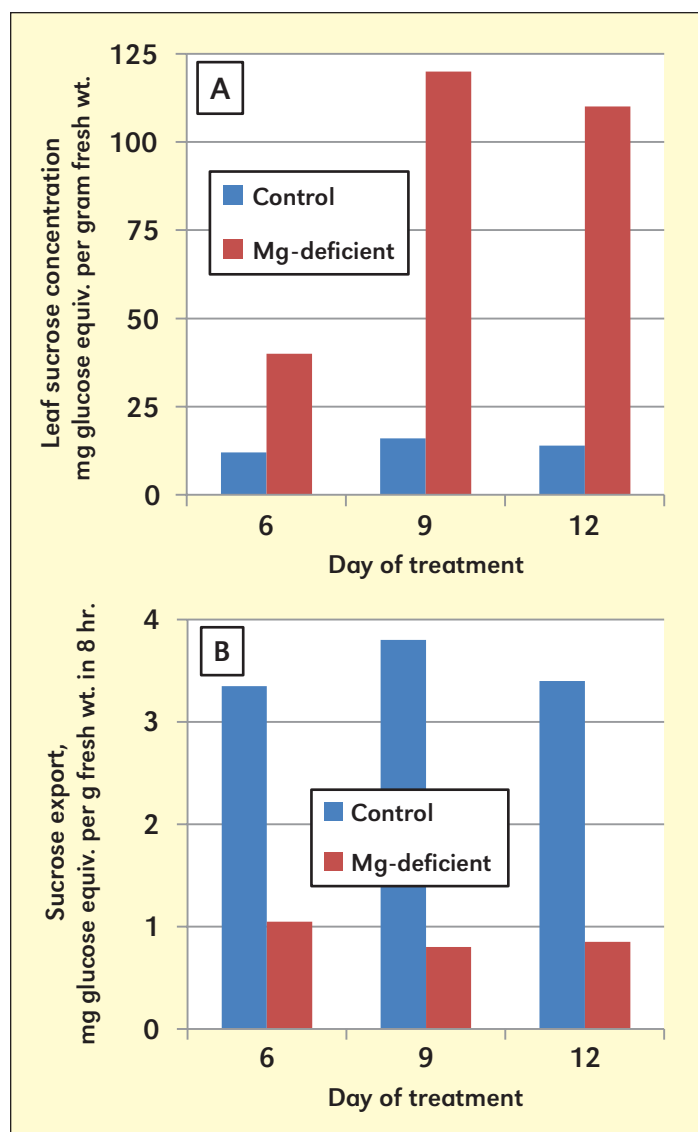Hermans, C., G.N. Johnson, R.J. Strasser, and N. Verbruggen. 2004.

Figure 5. Leaf sucrose concentration (A) and sucrose export rate (B) in bean plants grown with adequate Mg (control) or deficient Mg for 12 days (Cakmak et al., 1994b)

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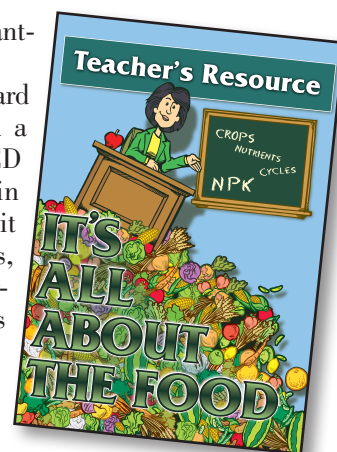
Soil and Fertilizer Magnesium

By Robert Mikkelsen

Magnesium (Mg) is an essential plant nutrient that is too frequently overlooked. Although weathering of primary and secondary minerals may provide adequate Mg in some soils, there are some soils that benefit from Mg additions. There are various soluble and slowly soluble Mg sources available to meet crop demands.

12
Mg
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Magnesium is a common constituent in many minerals, comprising 2% of the Earth's crust. It is also a common component in seawater (1,300 ppm). Magnesium is present in the divalent Mg^{2+} form in nature, but can be processed into a pure metal. Since metal Mg is one-third lighter than aluminum (Al), it is commonly used in lightweight alloys for aircraft and automobiles. In the powder or ribbon form, metallic Mg burns when exposed to air. China is the largest producer of Mg metal, although the USA and the former Soviet Union (FSU) also produce significant amounts.

The importance of Mg for human and plant nutrition has been well established. This article will review the behavior of Mg in rocks and soils, and describe some of the common Mg sources used for plant nutrition.

Magnesium in Primary and Secondary Minerals

Several ferromagnesian minerals (such as olivine, pyroxene, amphibole, and mica) are major Mg sources in basic igneous rocks. Secondary minerals, including carbonates... for example, dolomite [$MgCO_3 \cdot CaCO_3$], magnesite [$MgCO_3$], talc [$Mg_3Si_4O_{10}(OH)_2$], and the serpentine group [$Mg_3Si_2O_5(OH)_4$] ...are derived from these primary minerals.

When serpentine is present in large amounts, it gives rise to the term "serpentine soil." In these ultramafic serpentine soils, high Mg concentrations lead to poor plant growth and poor soil physical conditions. Undesirably high concentrations of nickel may also occur in these soils.

These primary and secondary minerals are important sources of Mg for plant nutrition, especially in unfertilized soil. But plant-available Mg concentrations cannot be accurately predicted based only on the parent material composition due to differences in mineral weathering rates and leaching. In some cases, the contribution of minerals to meeting the entire crop demand for Mg during a single growing season is insufficient to prevent plant and animal deficiencies.

Non-Exchangeable and Exchangeable Magnesium

Magnesium is located both <u>in</u> clay minerals and associated with cation exchange sites <u>on</u> clay surfaces. Clays such as chlorite, vermiculite, and montmorillonite have undergone intermediate weathering and still contain some Mg as part of their internal crystal structure. The Mg release rate from these clays is generally slow. Illite clays may also contain Mg, but their release rate is even slower. The details of clay weathering and mineralogy are available elsewhere.

The gradual release of non-exchangeable Mg has been demonstrated in a variety of conditions, but the amount of Mg dissolved from these minerals is often small compared with the amounts required to sustain high crop yields for multiple

Abbreviations and notes: N = nitrogen; Ca = calcium; K = potassium; S = sulfur; ppm = parts per million.
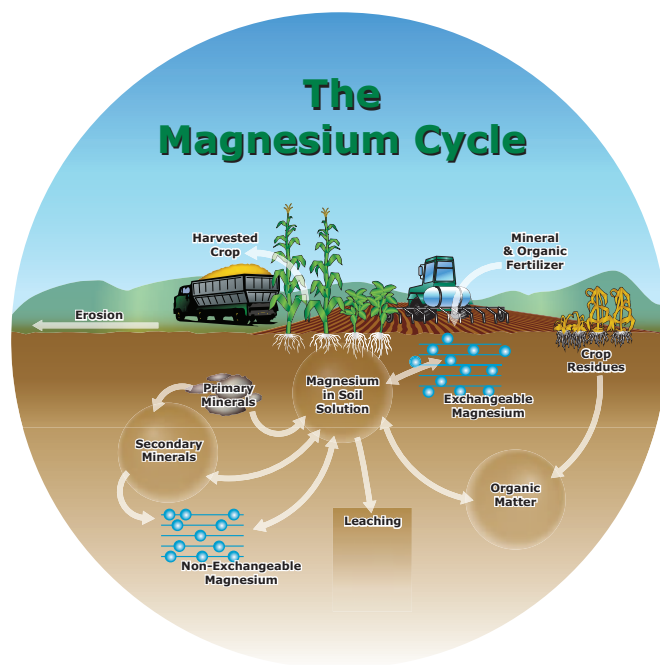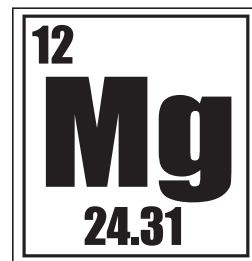

Figure 1. Magnesium cycling in agricultural soils.

years. This non-exchangeable Mg may be coming from the octahedral clay layers as well as the interlayer material. In low-productivity agriculture, this slow release of Mg may be sufficient to replenish the soil solution and meet plant nutritional demands.

In alkaline to slightly acidic soils, Mg is usually second in abundance to Ca on cation exchange sites. Magnesium ions generally resemble Ca in their behavior in ion exchange reactions. These cation exchange reactions are generally reversible, where even strongly adsorbed cations can be typically replaced by manipulation of the soil solution.

To become soluble, Mg adsorbed on a clay particle must be replaced by a cation present in the soil solution. Cation exchange reactions are stoichiometric, meaning that the charge balance must be maintained. For example, two K^+ ions are required to replace a single Mg^{2+} ion. The exchange reactions are very rapid, but the limiting step is usually the diffusion of the cation to or from the colloid exchange site.

Certain clays, such as vermiculite, have a special affinity for soluble Mg. The hydrated Mg ion fits well between the partially expanded sheets of vermiculite, making this clay an excellent Mg scavenger.

An excessively large proportion of Mg on the cation exchange sites can lead to degradation of the soil physical condition. Since Mg cations have a larger hydrated radius than Ca, the attractive forces that tend to aggregate soil colloids in typical conditions are diminished with an over-abundance of

Mg. A high proportion of Mg on soil exchange sites results in dispersion of clay particles, leading to decreased porosity and reduced infiltration rates typically found in serpentine soils.

Pathways of Magnesium Loss

When removal of Mg from the soil is greater than the release rate of Mg from mineral sources and fertilizer additions, Mg concentrations in solution and on the exchange sites will decline. This low-Mg situation is most frequently observed on sandy soil with low exchangeable Mg, soils receiving repeated applications of calcitic limestone, and due to a competition with other cations, such as K. Long-term sustainability requires balancing the Mg supply with removal from crop harvest, leaching, and runoff.

Crop removal A wide range of Mg crop removal data exists in published literature, depending on the soil Mg supply, growing conditions, the specific plant species, and yield levels. For example, a high-yielding crop of sugarbeets may take up as much as 80 lb Mg/A, and high-yielding forages and corn silage may remove 50 lb Mg/A. In general, cereal crops remove smaller amounts of Mg at harvest compared with root crops and many fruit crops. Of all the pathways of loss, removal of abundant crops at harvest is the desired outcome.

Leaching Losses Loss of soil cations through leaching can result in significant decline in nutrient availability over time. The extent of Mg loss from the rootzone to lower soil horizons will vary greatly depending on the soil properties, the amount of water passing through the soil, and local conditions. In some circumstances, leaching losses as low as a few pounds of Mg/A/yr are reported. However in other conditions, losses exceeding 100 lb Mg/A/yr are not unusual.

Fertilization with other cations, such as K^+ and Ca^{2+}, frequently leads to enhanced Mg solubility in the soil as they exchange on the clay sites and ultimately make Mg more susceptible to leaching. Decreases in exchangeable Mg are often correlated with the amount of salts added as fertilizer or soil amendments. In soils where Ca and Mg are leached following repeated K fertilization, an undesirable enrichment of K on the cation exchange sites can result. Leaching losses of nitrate accelerate Mg loss, especially under urine and dung spots in pasture.

Erosional Loss The soil surface is the zone that generally contains the most organic matter and essential plant nutrients. Runoff water leaving the field may carry with it valuable organic matter and nutrients associated with the eroding clay. Minimizing water runoff from fields by use of conservation techniques such as vegetative buffers or irrigation tailwater return will help reduce losses of Mg, as well as protect adjacent surface water.

Interactions Magnesium deficiencies are not uncommon in low pH, sandy soils where Al dominates the soil cation exchange sites. Magnesium assimilation is also depressed in the presence of Al^{3+}, which has a detrimental effect on root growth as well as through a competitive cation effect for root uptake.

High exchangeable K concentrations can have an adverse effect on Mg availability for plants. The competition between these two cations for root uptake appears to be the primary cause, although high K may also impair Mg translocation within the plant. Low forage Mg concentrations following K fertilization have been linked with low Mg in the blood of
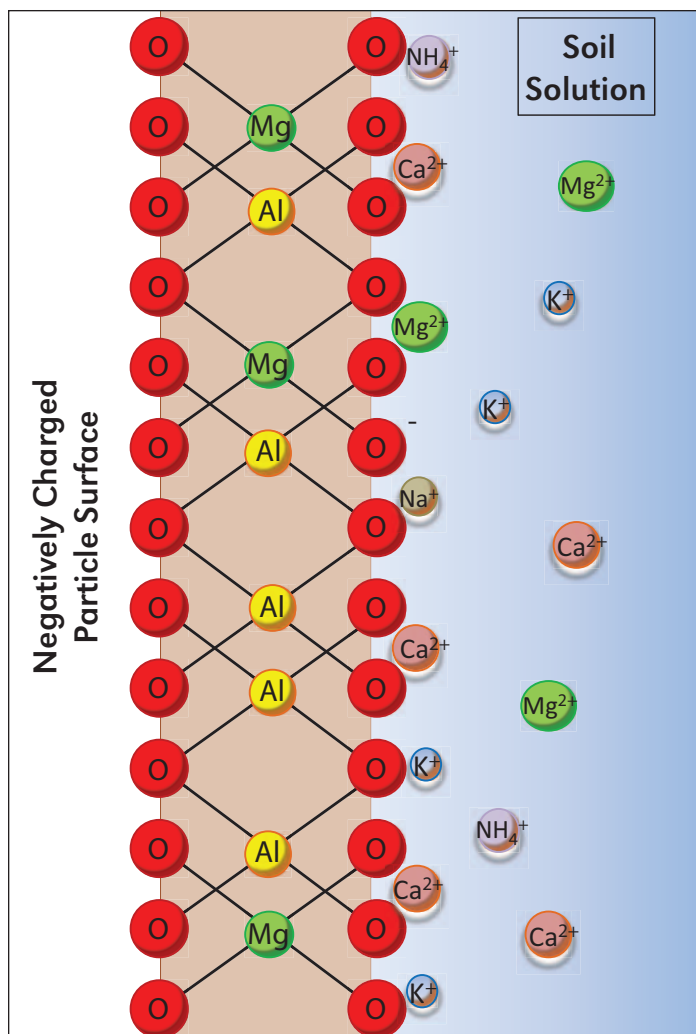

Figure 2. Common 2:1 clays contain Mg as a constituent of their clay structure, in the interlayer region, and as exchangeable cations on the clay edges.

grazing animals (called grass tetany) where it is essential for certain enzyme and metabolic reactions.

Magnesium Sources

There are many excellent sources of Mg that can meet crop demands. Surface placement of the soluble Mg sources is usually satisfactory, but incorporation of the less-soluble Mg materials into the soil is recommended. Since there are no serious environmental issues associated with agricultural uses of Mg, no special precautions are needed. Contributions of Mg in rainfall are generally less than one lb/A/yr.

Common Mg fertilizers are typically divided into two classes: soluble sources and semi-soluble sources. The particle size of semi-soluble Mg sources in large part determines the rate of dissolution, while this factor is not significant for the soluble sources.

Soluble Mg Sources (with approximate solubility at 25°C)

Kieserite – $MgSO_4 \cdot H_2O$; 17% Mg –   Kieserite is the monohydrate of magnesium sulfate, produced primarily from mines located in Germany. As a carrier of both Mg and S, kieserite finds multiple applications in agriculture and industry (360 g/L)

Kainite – $MgSO_4 \cdot KCl \cdot 3H_2O$; 9% Mg –   Kainite is the mixed salt of magnesium sulfate and potassium chloride. It is

IPNI Awards Available to Graduate Students and Scientists in 2010

Each year, IPNI offers the Scholar Award to honor and encourage deserving graduate students, and also the IPNI Science Award to recognize and promote distinguished contributions by scientists.

"We receive very favorable reaction to these awards each year and they clearly have many positive benefits," said IPNI President Dr. Terry Roberts. "It is important to encourage talented young people in their studies of agronomic and soil sciences, while established scientists also deserve recognition for career accomplishments. These awards are made possible by our member companies and are evidence of their respect for science."

The Scholar Award requires students who are candidates for either a M.S. or Ph.D. degree in agronomy, soil science, or related fields to submit an application and supporting information by June 30. Individual graduate students in any country where an IPNI program exists are eligible. Only a limited number of recipients are selected for the award, worth US$2,000 each. The application process is available online only. Recipients are announced in September.

The Science Award goes to one individual each year, based on outstanding achievements in research, extension, or education which focus on efficient and effective management of plant nutrients and their positive interaction in fully integrated crop production, enhancing yield potential and/or crop quality. It requires that a nomination form (no self-nomination) and supporting letters be submitted by mail before September 30. The Award announcement is December 1. It includes a monetary prize of US$5,000.

More information about past winners of these awards, plus details on qualifications and requirements for both awards, can be found at the IPNI website: >www.ipni.net/awards<. BC

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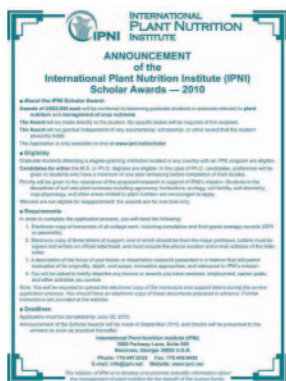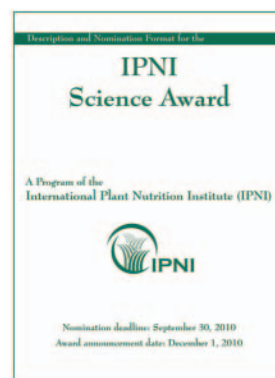
most commonly used as a K source, but is useful where both Mg and K are required (variable solubility).

Langbeinite – $2MgSO_4 \cdot K_2SO_4$; 11% Mg – A widely used source of Mg, as well as K and S, this mineral is an excellent multi-nutrient source. While totally soluble, langbeinite is slower to dissolve than some Mg sources and not typically delivered through irrigation systems (240 g/L).

Magnesium Chloride – $MgCl_2$; 25% Mg – Generally sold as a liquid due to its high solubility, this material is frequently used as a component in fluid fertilizers (560 g/L).

Magnesium Nitrate – $Mg(NO_3)_2 \cdot 6H_2O$; 9% Mg – Widely used in the horticultural industry to supply Mg in a form that also provides a soluble N source (1,250 g/L).

Magnesium Sulfate (Epsom salt) – $MgSO_4 \cdot 7H_2O$, 9% Mg – Epsom salt derives its name from naturally occurring geologic deposits in Epsom, England. It is a common mineral and a byproduct from various brines that makes an excellent Mg source. It is similar to Kieserite, except it contains seven water molecules associated with the $MgSO_4$ (357 g/L).

Schoenite – $K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$; 6% Mg – Although more commonly used as a K source, it is also a useful soluble Mg fertilizer material (330 g/L).

Animal Wastes and Composts The concentration of Mg in these organic materials is low compared with mineral sources. However, high application rates can supply significant quantities of Mg to the soil. Magnesium in these materials is generally considered to be totally plant available within a growing season.

Foliar Sprays These may contain one or more of the soluble Mg materials discussed above. Specialty materials containing EDTA, lignosulfonate, and other complexing agents may be used with soluble Mg sources to improve foliar uptake. Leaf sprays are effective at correcting Mg deficiency, but they generally must be repeated to maintain maximum plant growth and are usually considered a temporary resolution before the soil can be modified.

Semi-Soluble Mg Sources

Dolomite – $MgCO_3 \cdot CaCO_3$; 6 to 20% Mg – Depending on the geologic source, the concentration of Mg will vary considerably. Pure dolomite contains 40 to 45% $MgCO_3$ and 54 to 58% $CaCO_3$. However a concentration of 15 to 20% $MgCO_3$ (4 to 6% Mg) is common for material called "dolomitic limestone". Dolomite is often the least expensive common source of Mg, but may be slow to dissolve, especially where soil acidity is lacking.

Hydrated dolomite – $MgO \cdot CaO/MgO \cdot Ca(OH)_2$; 18 to 20% Mg – This product is made by heating dolomitic lime (calcined) to form MgO and CaO. It is then hydrated to form dolomitic hydrated lime, which may contain only hydrated calcium oxide or it may also contain hydrated magnesium oxide. These compounds dissolve faster than untreated dolomite.

Magnesium oxide – MgO; 56% Mg – Composed of only magnesium and oxygen, it is formed by heating $MgCO_3$ to drive off carbon dioxide. It contains the highest concentration of Mg of common fertilizers, but is rather insoluble. Applying in advance of plant demand and using a fine particle size will help make this nutrient source useful for plant growth.

Struvite – $MgNH_4PO_4 \cdot 6H_2O$; 10% Mg – Struvite is produced primarily during the recovery of P in wastewater from animal manure and municipal treatment plants. While slow to dissolve, struvite also provides a valuable supply of N and P, nutrients not found in other Mg-containing fertilizers

Crop fertilization practices continue to intensify with the demand for high yields. Magnesium is an essential plant nutrient that is frequently overlooked and may be limiting plant growth. Soil testing should be used to identify potential deficiencies, and there are many excellent Mg sources available for farmers when needed. BC

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Characteristics of Nutrient Uptake by Grape

By Yan´an Tong, Wenjuan Ma, Yimin Gao, and Shulan Zhang

Nutrient uptake was examined in an intensive year-round study of a 7-year old grape orchard in Fufeng County in order to guide nutrient management for grape production in Shaanxi Province. Macronutrient accumulation was identified according to plant development stage, which provides insight into the periods of peak nutrient demand and appropriate timings of fertilizer application.

Grape is considered a major cash crop in Shaanxi. Most recently available statistics place its total area at 17,700 ha and its total grape production at 220,000 metric tons (t). Nutrient uptake by grape has not been as intensively studied as cereal crops and previous studies in grape have mainly focused on yield/quality responses to fertilizer applications (Abha et al., 1995; Li et al., 1995; Zhou et al., 2002). Thus, the nutrient requirement of grape has not been clear, which restricts the implementation of science-based nutrient management in the crop. The objective of this study was to investigate N, P, and K uptake and its distribution in grape plant parts during an entire growing season.

The study was conducted in Fufeng County, located on the western reaches of the Guanzhong Plain. The soil type for the selected grape orchard was Eum-orthic anthrosols (using Chinese Soil Taxonomy). According to routine soil analysis methods described in Lu (2000), soil organic matter, total N, Olsen-P, and exchangeable K (ammonium acetate extractable) were 9.9 g/kg, 1.05 g N/kg, 7.8 mg P/kg, and 120 mg K/kg. Grape plants were selected from a 7-year old Red-Globe grape orchard planted at a row spacing of 1 m with 2.5 m between each plant. Red-Globe is a table grape variety introduced from North America. It has long s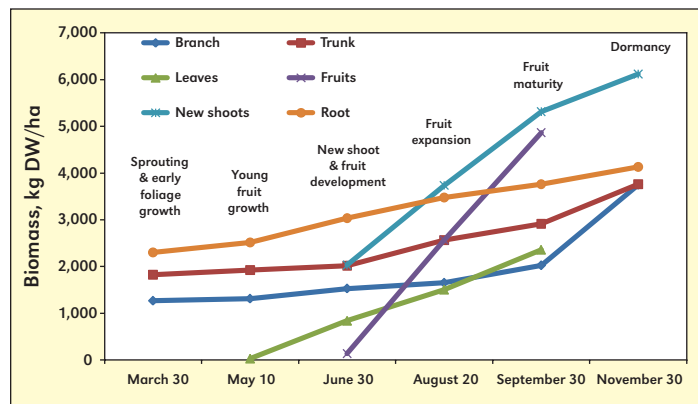helf life, is easy to transport, and is suited to planting in arid or semiarid areas with trellises. Grapes (fruit) in this orchard were first harvested 3 years after planting. Average annual fertilizer rate applied during the last 3 years before sampling, and the year of sampling, was 635 kg N/ha, 308 kg P_2O_5/ha, and 216 kg K_2O/ha. In this traditional system, fertilizers were applied within a band 20 cm deep and 60 to 70 cm around the tree. All P and K fertilizers and 50% of the N fertilizer were applied basally in September after grape harvest; 30% of the N was applied in March and the remainder in June, during the start of new shoot growth and fruit development.

Samples were taken from three typical plants at six different

Red-Globe is a table grape variety introduced from North America. It has a long shelf life, is easy to transport, and is suited to planting in arid or semi arid areas with trellises. Samples were taken from this orchard for analysis.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Figure 1. Changes in biomass of different plant parts during growing period of grape plants.

growing stages including: March 30 (sprouting and early foliage growth), May 10 (young fruit growth), June 30 (new shoot growth and fruit development), August 20 (fruit expansion), September 30 (fruit maturity), and November 30 (dormancy). At each sampling, fruits, leaves, new tops, branches, trunks, and roots were separated. Root samples included all within a radius of 50 cm around the trunk and a 100 cm depth. Enzymatic activity within all plant samples was destroyed by oven heating at 100 to 105 °C for 15 minutes. Samples were dried to a constant weight at 70 to 80 °C, ground, and digested in concentrated sulfuric acid (Lu, 2000). The solutions were analyzed for N and P by Flow Injection Analyzer (Emteryd, 1991), and K was determined by flame photometry (Lu, 2000).

Biomass, measured as dry matter weight (DW), of the main trunks and roots gradually accumulated from March to November **(Figure 1).** The biomass of branches also increased at a gradual rate before harvest, but this was followed by a period of more rapid growth. Leaf biomass accumulated rapidly from May to September. New shoots grew most rapidly between June 30 and September 30 which coincided with the period of rapid fruit development. Total average biomass of grape plants, not

Researchers gathered whole plant samples throughout the season to determine biomass and nutrient accumulation within each plant part. Students are shown cutting branches for samples.

including fruits, increased from 5,391 to 17,760 kg DW/ha between March 30 and November 30.

Grape plants accumulated an average of over 102 kg N/ha between March 30 and November 30 (**Table 1**). This N was fairly evenly distributed between fruit (31.6%) and leaves (34.3%), while new shoots received 27.5% of total annual plant N uptake. Established plant parts including branches, trunks, and roots accumulated a small amount of N. The total N that remained in the plant after harvest was 34.1% of total N uptake, while the remainder was removed with the leaves and harvested fruit.

Nutrient removal in grape leaves and fruit represented about 66% of total annual plant demand for N, 45% for P, and 58% for K.

Grape plants accumulated 33 kg P_2O_5/ha during the growing season (**Table 2**); 36.1% of this was distributed to fruit, followed by new shoots which received 27.5% of total P uptake. Results also showed that 45.4% of total plant P uptake was removed by leaves and fruit, while 54.5% remained in the grape plant.

Total annual K accumulation amounted to over 140 kg K_2O/ha (**Table 3**), which was mainly distributed between fruit (45.8%) and new shoots (22.5%). Fruit and leaves removed 58% of total K uptake, thus 42% of the total remained in the plant.

This study highlights three distinct stages for nutrient uptake by grape plants, including: 1) the period between sprouting/early foliage growth and new shoot/fruit development; 2) the period between early fruit development and fruit expansion; and 3) the period after fruit expansion up to fruit maturity. These respective periods saw 38%, 28.7%, and 28.8% of the total N accumulation, 22.4%, 29.4%, and 31.2% of P accumulation, and 26.2%, 45.7%, and 16.6% of K accumulation. Given these seasonal distributions, it can be generally stated that while soil N supply is equally critical throughout the entire growth phase of grape plants, it is particularly important for soil P supply to increase gradually and extend throughout the entire fruit production phase. Lastly, K supply must meet maximum plant demand that occurs just prior to fruit expansion.

Table 4 compares this study's results for NPK requirements of 1,000 kg of Red-Globe grape fruit with previous work using other varieties (National Investigation and Cooperation Network on Grape, 1993; Qin et al., 2001; Zhang and Ma, 2006). Regardless of the variation between studies, all agree that grape plants require significant quantities of K followed by N then P. Although it is currently difficult to quantify fertilizer recommendations for grape orchards by soil testing, the site's nutrient balance can be monitored and annual nutrient removal by

Table 1. Nitrogen accumulation and distribution (kg N/ha) in various parts of grape plants.

Plant part	March 30	May 10	June 30	Aug. 20	Sept. 30	Nov. 30	Net accumulated N
Leaves	-	2.9	18.8	30.1	35.1	-	35.1
Fruits	-	-	6.2	20.4	32.3	-	32.3
New shoots	-	-	20.1	21.8	28.1	28.1	28.1
Branch	4.4	4.9	5.3	5.9	6.2	7.0	2.6
Trunk	5.7	5.7	5.8	6.2	6.6	7.2	1.5
Roots	20.2	17.7	13.0	14.2	19.8	22.9	2.7
Total plant	30.3	31.2	69.2	98.6	128.1	65.2	102.3

Note: Net accumulated N in leaves, fruits, and new shoots equal to total accumulated in the last sampling. Net accumulated N in branches, trunks and roots equal to N accumulation in the last sampling value minus N accumulation in the first sampling value.

Table 2. Phosphorus accumulation and distribution (kg P_2O_5/ha) in various parts of grape plants.

Plant part	March 30	May 10	June 30	Aug. 20	Sept. 30	Nov. 30	Net accumulated P_2O_5
Leaves	-	0.1	2.3	2.9	3.1	-	3.1
Fruits	-	-	0.3	5.4	11.9	-	11.9
New shoots	-	-	4.7	7.7	8.3	9.1	9.1
Branch	1.0	1.4	2.0	1.2	1.2	4.5	3.5
Trunk	0.7	0.6	1.1	1.1	1.1	2.3	1.6
Roots	9.2	8.2	7.9	9.7	12.7	13.0	3.8
Total plant	10.9	10.3	18.3	28.0	38.3	28.9	33.0

Table 3. Potassium accumulation and distribution (kg K_2O/ha) in various parts of grape plants.

Plant part	March 30	May 10	June 30	Aug. 20	Sept. 30	Nov. 30	Net accumulated K_2O
Leaves	-	0.4	12.3	13.6	17.2	-	17.2
Fruits	-	-	2.6	43.0	64.3	-	64.3
New shoots	-	-	20.7	34.4	28.3	31.6	31.6
Branch	7.0	5.6	4.9	8.1	8.8	15.4	8.4
Trunk	7.3	6.2	6.2	11.4	12.5	14.4	7.1
Roots	19.7	20.0	24.1	24.5	27.2	31.5	11.8
Total plant	34.0	32.2	70.8	135.0	158.3	92.9	140.4

Table 4. Nutrient requirement to produce 1,000 kg grapes.

Cultivars	Plant age, yrs.	N	P_2O_5	K_2O	N: P_2O_5: K_2O
		Nutrient requirement, kg/1,000 kg grape			
Red-Globe	7	4.05	1.84	7.80	1:0.32:1.37
Ju Feng[1]	6	3.91	2.31	5.26	1:0.59:1.35
Shuangyou[2]	12	8.44	12.76	13.13	1:0.39:1.15
Cabernet Sauvignon[3]	5	5.95	3.95	7.68	1:0.66:1.29

[1] National Investigation and Cooperation Network on Grape, 1993
[2] Qin et al., 2001
[3] Zhang and Ma, 2006

To achieve a more complete assessment of seasonal nutrient distribution, below-ground plant parts were considered. Although annual accumulation of N in roots was relatively minor, amounts for P and K were more significant. This is an example of roots for sampling

senesced leaves and harvested fruits can be supplemented by applying appropriate amounts of nutrients. Assuming that two-thirds of accumulated nutrients are derived from fertilizer and using fertilizer N, P, and K use efficiencies of 50%, 40%, and 50%, respectively, the recommended application rate would be 136-55-187 kg $N-P_2O_5-K_2O$/ha. According to the characteristics of nutrient uptake during the growing season, fertilizer N should be split evenly between the three stages of nutrient demand described above. About 50% of this P recommendation should be supplied prior to fruit expansion

and 70% of K recommendation should be applied prior to the flourishing of new shoot growth.

As is indicated, the recommended rates of N, P, and K in this study are significantly lower than those that have been traditionally used, especially in the case of N and P. Although this suggests N and P have been overused for grape production in Shaanxi, it still needs to be confirmed whether this new recommendation, rationalized according to seasonal crop demand, can sustain high yielding grape production and soil nutrient balances. BC

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Conversion Factors for U.S. System and Metric

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.

We clearly see that plant growth suffers when there are low amounts of nutrients in the soil, when the nutrients are not sufficiently soluble, or if nutrients do not move to the roots. In our quest to grow abundant and healthy crops, it is easy to overlook all of the complex chemical and biological activity occurring around the plant roots that make nutrients available for uptake.

The availability of plant nutrients for roots is controlled by factors such as soil properties, root characteristics, and interactions with surrounding microorganisms. Traditional soil testing techniques measure the availability of nutrients in the general soil, but this may differ from the nutrient concentration in the immediate vicinity of the root (the rhizosphere). Nutrients with restricted mobility in the soil (such as P, K, zinc, iron, manganese, and copper), may be in adequate supply in the bulk soil, but their concentration may be low near the root if the transport is too slow to replenish the nutrients entering the root.

Focusing on P as an example, supplying this nutrient to the root includes several complicated mechanisms. This involves excretion of organic acids, increased root hair formation, and enzyme release.

• Release of Organic Acids: When soil P supplies are low, many plants excrete a wide range of organic compounds to increase the availability of relatively insoluble compounds, such as some calcium phosphate minerals. The organic acids have a role in dissolving nutrients (due to pH) and providing an excellent growth substrate for soil microorganisms.

Most soils have populations of microorganisms that are capable of dissolving P-containing minerals, so addition of an organic substrate may encourage their growth in low-P conditions. Mycorrhizal fungi also form complex relationships with most plant species, where the fungi provide various benefits for the plant, including improved nutrition, in exchange for carbohydrate for fungal maintenance and growth.

• Changes in Root Structure: Plants growing in a low-P soil tend to direct more of their photosyntate carbohydrates to root development and often have more fine roots with a small diameter, resulting in a larger surface area. A large root surface area allows plants to access more of the soil and scavenge any soluble phosphate that may be present.

• Enzyme Release: In low-P conditions, plants generally increase the production of enzymes that enhance the rate of P release from soil organic matter, especially from phytate. Phytase, the enzyme responsible for phytate hydrolysis, is primarily released by microorganisms, which indirectly improves the P availability for nearby roots.

These root modifications occur as a result of low soil P availability, requiring plants to devote additional energy to the roots and away from above-ground growth. The excretion of organic compounds from roots can consume as much as half of all the carbon allocated to the root system, although this number is highly variable. The energy costs of mycorrhizal associations with various plant species ranges from 4 to 20% of the daily net photosynthesis. Plant geneticists are looking for ways to make plant roots more efficient at recovering nutrients from the soil. While we wait for improved plant genetics, there are many practical things that can be done to get the maximum benefit from added nutrients. Place nutrients in the soil in the proper form and in the correct place so plant roots can support abundant yields of high-quality products.

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