BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)
2007 Number 4

In This Issue...

BMPs to Minimize Greenhouse Gas Emissions Associated with Fertilizer Use

Managing Crop Nitrogen for Weather

Manganese Nutrition of Glyphosate-Resistant and Conventional Soybeans

...and much more

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BETTER CROPS WITH PLANT FOOD

Vol. XCI (91) 2007, No. 4

Our cover: Traditional and modern rice farming methods are seen in the paddies of Hubei Province of China.
Photo by Dr. Fang Chen, IPNI

BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by the International Plant Nutrition Institute (IPNI). Periodicals postage paid at Norcross, GA, and at additional mailing offices (USPS 012-713). Subscription free on request to qualified individuals; others $8.00 per year or $2.00 per issue.
POSTMASTER: Send address changes to Better Crops with Plant Food, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone (770) 447-0335; fax (770) 448-0439. Website: www.ipni.net.

Better Crops with Plant Food is registered in Canada Post.
Publications mail agreement No. 40035026
Return undeliverable Canadian addresses to:
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The Government of Saskatchewan helps make this publication possible through its resource tax funding. We thank them for their support of this important educational project.

CONTENTS

A Research Agenda for Managing Crop Nitrogen for Weather

By Tom Bruulsema

Weather strongly influences N: its supply in and loss from the soil, and its crop-growth-driven demand. A recent soil science symposium identified opportunities for research leading to improvement of current crop N recommendation systems. The proceedings, titled Managing Crop Nitrogen for Weather (IPNI, 2007), describes several approaches to application of process-based models that hold promise for achieving this goal.

Farming has always depended on the weather. Since the dawn of agriculture, producers have had to adapt to it. While today's technologies allow a single producer to control a larger area of cropland than ever before, adapting to weather is just as important as it ever was. Weather impacts N dynamics at least as much as crop performance; arguably more, since it influences processes of N supply and loss from soils as well.

Decades of research into improved N management for crops have proven that there is no simple soil test that – on its own – can predict an optimum rate of N. Nevertheless, producers have improved their management of the nutrient. Between 1964 and 2006, partial factor productivity for N use in corn production in North America has increased from 42 to over 60 kg of corn per kg of N fertilizer applied (calculated using the method of Fixen and West, 2002). However, the current partial nutrient balance indicates an average recovery efficiency of less than 80% – that is, the N in grain harvested from the field amounts to 80% of the N in the applied fertilizers and manures – indicating considerable room for further improvement.

The reason many efforts to improve prediction of optimum rates have failed is that they have focused only on one specific tool at a time, be it a soil test, a plant indicator, or a weather-based predictor. The research effort that is needed must integrate these tools. Single-factor approaches do not lead to improved recommendations, because the factors determining N requirement are multiple.

Any approach that aims to come closer to optimum than current systems must account in a robust manner for the multiple factors affecting the demand for and supply of N (Stanford, 1973). Nitrogen demand associated with a specific crop yield potential is one of the three main components. The second is the supply function, most of which is directly influenced by management (applications of manure or fertilizer), but a substantial part is governed by biological mineralization and immobilization from native soil organic matter, and biological N fixation. The third component is the loss function, governed by weather processes that control water accumulating in and moving through soil, and the specific timing of these events interacting with the amount of N in the mobile nitrate form on any given day.

Few studies systematically partition variability in crop N response into the three components described above: crop N demand, soil N supply and soil N losses. Each of these three has both spatial and temporal components. Spatially, variability both within and among fields may be important. The main variation of interest is year-to-year or interannual. The two may interact with each other and thus be difficult to partition.

Managing crop N for weather requires site-specific approaches and flexible decision-making.

Process-based models that estimate mineralization, leaching, volatilization, and denitrification along with crop growth and development could contribute enormously to the rate decision at the critical point just prior to when crop N uptake begins. Agrometeorological information needs to be integrated into the decision-making process. The uptake of N for most crops, including corn, does not become rapid until several weeks after planting. By that time, probabilistic scenarios for that season's yield prospect can be better defined than they could have been prior to planting. A focused effort is required to develop prediction tools operating from process-based models that incorporate both past data and future probability scenarios.

Delaying applications until the last possible moment helps adapt N management to weather by reducing the time between application and crop uptake. Effectively, it transforms weather forecast probabilities into realities. Both probabilities and current realities need to be dealt with in adapting N management to weather.

However, a "just-in-time" approach to N management also needs to consider the probability of inclement field conditions preventing the timely application of a side-dress dose. Certain soil textures, particularly poorly-drained clay soils, may be most susceptible. The choice then becomes pre-plant with a controlled-release source (or an inhibitor to control transformation to nitrate), versus side-dress or split application, and that choice may be governed by soil texture. Sandier soils are accessible quite rapidly after wetting, so are more amenable

Abbreviations and notes for this article: N = nitrogen.

Table 1. Examples of crop and soil water models with potential application to weather-based N recommendations. More detail is available in IPNI (2007).			
Example	Crop N demand	Soil N supply	Soil N loss
HERMES (Kersebaum)	SUCROS (daily timestep; van Keulen et al., 1982)	Two-pool first order soil N mineralization	Soil water capacity model; Denitrification; Leaching
PMN (Melkonian and van Es)	Maize N model (daily timestep; Sinclair and Muchow, 1995)	Two-coefficient model of soil N mineralization	Soil water capacity model; Denitrification; Leaching
LEACHM-N (Hutson and Wagenet, 1992)	Non-interactive with weather	Single-coefficient model of soil N mineralization	Richards soil water flux + convection-dispersion for solute transport
DSSAT-CERES (Singh)	Crop growth and N uptake (maize and wheat; daily timestep)	Godwin & Singh, 1998	Leaching; Denitrification; Ammonia volatilization
SUNDIAL (Dailey)	Crop N uptake, soil N mineralization and losses (weekly timestep)	Soil N mineralization; Crop residue N	Leaching; Denitrification
Dryland wheat (Pan; Karamanos)	Growth based on soil water and anticipated rainfall (empirical)	Mineralization; Immobilization; Residual N	Leaching; Denitrification

to multiple applications, while the slower-drying clay soils are more likely to be better served with a controlled-release strategy. Decision support systems must consider not only the physiological needs of the crop, but also the practical realities of possibilities for management operations including soil conditions supporting application equipment.

Current recommendation systems for N application to corn are based mainly on factors that do not reflect weather. Several states and provinces have made recent advances in developing recommendation systems based on identified databases of crop response trials. The regional N rate guidelines for midwestern states including Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio and Wisconsin are based on factors including the price ratio between harvested corn and N fertilizer, previous crop, and to some extent the productivity of the soil, and are specific to each state. The Maximum Return to N (MRTN) is determined from quadratic-plateau response curves fitted to recent state-specific crop response data (Sawyer et al., 2006). In Ontario, a large database comprising over 600 site-years of corn N response trials was used in a similar manner to develop a set of recommendations comprising six factors: price ratio, yield goal, soil texture, previous crop, site heat unit rating, and application timing (www.gocorn.net). It is difficult, however, to adapt current local weather information to make further adjustments to these recommendations. For example, the pre-sidedress soil nitrate test (a soil test with some weather dependence) is advocated in some of these regions, but the producer is left with little guidance as to how to interpret the nitrate result in the context of the full set of other factors.

Computer models of crop growth predict growth and development of crops as a function of their soil and air environment. The primary driving variables are solar radiation, temperature, and water. The function of a model is to predict the outcome of numerous complex processes underlying a main process of interest. In the case of agronomy, the main interest is often the yield outcome. When variables under management control are included, the model can also serve to predict optimum input levels of such variables.

Moving the recommendation approach from single to multiple factors is likely to require some form of computer model to assist with the integration. **Table 1** lists some of the crop models referred to in the proceedings publication, *Managing Crop Nitrogen for Weather* (IPNI, 2007), and briefly describes the methods used for modeling each of the three fundamental process categories. There are many more models that could be implemented. Supplying accurate input data is a constant challenge with a modeling approach. When models are applied, it is important to critically evaluate each component to ensure a balanced representation of the important processes, and rigorously validate with data from on-farm research.

A research agenda to further the development of integrated model-based N recommendations should include:

- Participatory research with producers and advisers to test feasibility of integrated N management tools, using on-farm weather monitoring;
- Development of models that address the weather's impact on crop growth, soil N supply, and soil N losses;
- Further exploration of datasets of past response research, assembling the necessary soil and weather data to run models to estimate the movement and transformation of soil N;
- Increased use of real-time remote-sensed data to detect N status of plants and gauge need for additional N application;
- Development of simplified means to characterize soil physical properties that impact water and nutrient movement in soil for practical management, using principles from the sciences of soil physics and agro-meteorology;
- Spatial analysis and description of nitrate transport and transformation within agricultural fields;
- Identifying genetic traits influencing the physiology of crop growth, to select genotypes that capture more of the nutrients made available through the season by mineralization.
- Field validation of soil-crop-water-nutrient models.

- Increased accessibility of real-time weather data.

Spatial and temporal variation need to be addressed together. The complex interactions that stand out in several of the studies reported in IPNI (2007) show that spatial variations in soil properties affect optimal N rates in a complex manner. It can be postulated that a highly site-specific approach to managing N will not be effective without an eye to the weather, and that attempts to make weather-specific recommendations will also fail if there is no eye to the soil and its spatial variability.

Managing crop N for weather requires site-specific approaches and flexible decision-making. These aspects are difficult to accommodate in regulatory approaches to nutrient management, and indeed are a limitation in nutrient management plans established on cycles of several years. While nutrient management plans have value in tactical planning, it is important that they allow flexibility in day-to-day implementation to suit changing weather conditions. Nutrient management must adapt more closely to changeable weather. Systems allowing producers to make data-driven decisions more rapidly may have advantages over regulatory approaches in improving the efficient use of N. BC

Dr. Bruulsema is IPNI North American Program Northeastern Regional Director; e-mail tom.bruulsema@ipni.net.

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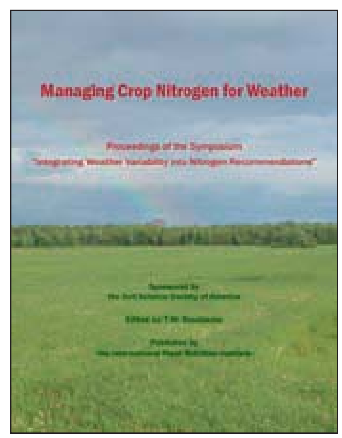
Proceedings of the Symposium "Integrating Weather Variability into Nitrogen Recommendations"



The weather controls a great deal of the crop response to N. The contents of a new publication titled *Managing Crop Nitrogen for Weather*, based on the proceedings of a symposium at the 2006 meeting of the Soil Science Society of America (SSSA), provide details of experimental data and experiences of those engaged in efforts to improve prediction of crop N needs in response to weather conditions.

The papers contained in this new 132-page publication were originally presented at the Symposium "Integrating Weather Variability into Nitrogen Recommendations." Thirteen of the original presentations from the Symposium are contained in the publication, plus abstracts of others. The authors are from several different countries and are recognized scientific authorities on their topics. The International Plant Nutrition Institute (IPNI) published the proceedings.

The publication is paper-bound, 8½ x 11 in., and contains some color. It is available for purchase from IPNI for US$50.00 plus shipping/handling.

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Trends Indicated by Nutrient Analysis of Cotton Tissue

By Brenda R. Cleveland and Mario Cervantes

Cotton leaf tissue analyses at the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) laboratory reflect improved cotton N management the last few years. Yet, there are many fields where farmers and crop advisers have opportunities to significantly improve K nutrition.

Use of plant tissue analysis as a monitoring tool is the best way to ensure optimal fertilization of upland cotton (*Gossypium hirsutum*). By detecting nutrient deficiencies before symptoms appear, growers have the opportunity to prevent irrecoverable losses in yield and quality. Growers who rely on visual symptoms forfeit this safeguard.

The Agronomic Division of NCDA&CS has provided its plant tissue analysis service to growers throughout the state since 1973 and recently has made it available to growers nationwide.

Plant tissue reports can be either predictive or diagnostic. Predictive reports are generated when samples are submitted to monitor nutrient status for the purpose of adjusting fertilization for optimum yield and quality. NCDA&CS encourages establishing a cotton monitoring program. It is best to manage a cotton fertilization program based on the results of tissue samples collected routinely over a period of several weeks to monitor trends and fine tune nutritional needs. "Predictive" samples are collected from fields that represent average conditions at approximately the same time each week, beginning one to two weeks prior to bloom and continuing through the third or fourth week of bloom. The sample contains at least 25 to 30 of the most recently mature and healthy-looking leaves from main stems (usually the leaf at the 4th node from the plant terminal). Petioles are detached from the leaf blade before leaving the field for analysis of leaf blade nutrient concentrations (N, P, K, S, Ca, Mg, Fe, Mn, Zn, Cu, and B) and petiole NO_3-N concentration.

"Diagnostic" reports are generated when samples are submitted to help understand an existing problem. When plants exhibit discoloration or abnormal growth, tissue testing can demonstrate whether the problem is nutrient related. The plant analysis report provides recommendations for corrective action as needed.

In the period from 1999 to 2006, North Carolina grew an average of 868,000 acres of cotton per year, and NCDA&CS analyzed nearly 21,000 cotton tissue samples. A summary of data from this 8-year period shows general trends in cotton nutrition.

Plant tissue nutrient analysis and monitoring can identify deficiencies and opportunities for corrective action.

The sample contains at least 20 of the most recently mature and healthy-looking leaves from main stems, usually the leaf at the 4th node from the plant terminal.

Nitrogen Status

Leaf blade N provides information on N availability and uptake for the week or 2 weeks prior to sampling. NCDA&CS, through experience and research, has established that a concentration of 3.5 to 4.5% N in the leaf blade is associated with optimal growth and yield. Overall, during the period summarized, 9% of all cotton samples contained too little N; 27% contained sufficient N; and 64% contained too much N (**Table 1**). The percentage of cotton samples with insufficient N ranged from a low of 3% in 1999 and 2002 to a high of 19% in 2006. Samples with sufficient N ranged from a low of 17% in 1999 to a high of 39% in 2001. Samples with too much N decreased to 50% in 2006, from a high of 80% in 1999. A decrease in excess application of N is favorable since excess N is an environmental concern because of the danger for leaching and runoff.

Table 1. Nitrogen sufficiency status (% of cotton leaf blade samples).

	1999	2000	2001	2002	2003	2004	2005	2006	All
Low	3	6	12	3	15	12	12	19	9
Sufficient	17	22	39	17	30	37	30	31	27
High	80	72	49	80	55	51	57	50	64

Abbreviations and notes for this article: N = nitrogen; NO_3 = nitrate; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Fe = iron; Mn = manganese; Zn = zinc; Cu = copper; B = boron; ppm = parts per million.

Excessive N nutrition is also an economic concern because of the increasing price of most N fertilizers in recent years, and the challenges associated with cotton defoliation difficulty and regrowth. The average N concentration has fallen from 5.1% in 1999 to 4.4% in 2006 (**Table 2**). These data appear to indicate a trend toward improved N management.

In cotton, sufficiency ranges for K depend on growth stage. As the bolls develop and the crop matures, K concentration decreases in the leaf blade as it is allocated to the developing boll. From the early vegetative stage to early bloom (<5 weeks after full bloom), the desired K range within the tissue of most recently mature leaves is 1.5 to 3.0%. From late bloom (>5 weeks after full bloom) through maturity, the desired range is 0.75 to 1.5% K.

During early vegetative growth through early bloom, most samples (70 to 80%) contained sufficient levels of K (**Table 3**). The remaining samples were nearly always low in K. Samples testing high in K were very rare. From 1999 to 2006, the NCDA&CS documented a slight increase in the percentage of early cotton tissue samples with K deficiency. The yearly average K concentration ranged from 1.7 to 2.0% (**Table 2**). When plant tissue K is low, recommendations for remedial action are based upon soil K levels, environmental conditions and crop yield potential. Additional K is typically made as a soil application.

Table 2. Average and ranges in cotton leaf blade nutrient concentrations (%).

	1999	2000	2001	2002	2003	2004	2005	2006
N								
Average	5.1	4.9	4.5	5.0	4.6	4.5	4.6	4.4
Min	1.5	0.7	1.5	0.7	1.4	1.2	1.8	1.1
Max	9.0	8.2	7.6	7.5	7.9	8.1	7.0	7.8
K, early vegetative through early bloom growth stage								
Average	2.0	2.0	1.7	1.8	1.8	1.8	1.7	1.8
Min	0.6	0.6	0.5	0.7	0.6	0.8	0.5	0.8
Max	7.1	7.9	5.6	4.0	9.7	5.0	3.0	3.5
K, late bloom to maturity growth stage								
Average	1.7	1.7	1.5	1.7	1.5	1.5	1.5	1.5
Min	0.5	0.3	0.5	0.6	0.3	0.2	0.1	0.2
Max	3.9	4.1	3.6	4.9	3.0	3.1	2.6	6.4
P								
Average	0.35	0.34	0.31	0.33	0.37	0.36	0.34	0.34
Min	0.07	0.09	0.13	0.11	0.15	0.16	0.14	0.10
Max	1.0	0.86	0.87	0.17	0.89	0.88	0.72	0.8
S								
Average	0.60	0.51	0.47	0.55	0.46	0.56	0.50	0.48
Min	0.14	0.07	0.10	0.08	0.10	0.12	0.11	0.08
Max	2.08	1.48	1.33	1.51	1.39	1.57	1.43	1.20

From late bloom to maturity, most samples (96 to 99%) had sufficient to high K levels (**Table 3**). K was rarely low. The yearly average K concentration ranged from 1.5 to 1.7%, generally above the established sufficiency range (**Table 2**).

The desired range for P within the tissue of the most recent mature leaves is 0.20 to 0.65%. P levels were rarely low. Typically, 98 to 99% of all samples fell within the desired range in most years (**Table 3**). The yearly average P concentration ranged from 0.31 to 0.37% (**Table 2**). The sufficiency range for S in cotton tissue is 0.25 to 1.0%. Samples with low or high S levels were not commonplace during the specified period (**Table 3**). In 2003 and 2006, 7% of the samples tested low for S. The yearly average S concentration ranged from 0.46 to 0.60% (**Table 2**).

Table 3. Cotton leaf blade K, P, and S sufficiency status (% of samples).

	1999	2000	2001	2002	2003	2004	2005	2006
K (early vegetative growth to early bloom)								
Low	17	13	31	19	25	23	24	25
Sufficient	81	85	69	80	74	76	76	74
K (late bloom to maturity)								
Sufficient	31	30	51	25	54	51	47	50
High	68	70	47	74	45	48	51	48
P								
Low	1	1	4	2	1	1	2	3
Sufficient	97	98	96	98	98	99	98	94
S								
Low	1	4	5	2	7	3	3	7
Sufficient	93	95	94	95	91	93	95	92

NCDA&CS tissue analyses also measure concentrations of Ca, Mg, Fe, Mn, Zn, Cu, and B. The desired concentration ranges for these nutrients are: 1.25 to 3.0% Ca; 0.25 to 0.50% Mg; 50 to 250 ppm Fe; 20 to 350 ppm Mn; 20 to 40 ppm Zn; 5 to 25 ppm Cu; and 20 to 60 ppm B. As a rule, fewer than 10% of the samples analyzed tested low in these nutrients.

Conclusion

Even ideal fertilizer management, based on soil testing and research-based fertilizer recommendations, cannot overcome all factors that affect growth and yield. Plant tissue nutrient analysis and monitoring can identify deficiencies and opportunities for corrective nutrient addition, during the current season or before the next crop. A well-nourished plant has a greater ability to withstand stresses from various environmental pressures. Routine cotton tissue analysis provides nutritional information essential to efficiently manage fertilizer for optimum growth and yield, especially in times of increased fertilizer costs and environmental concerns. BC

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Svetlana Ivanova Joins Staff of IPNI as Eastern Europe and Central Asia Group Coordinator

Dr. Svetlana Ivanova

Dr. Svetlana Ivanova has joined the IPNI staff as Eastern Europe and Central Asia Group Coordinator, effective August 1, 2007. She is based in Moscow, Russia, and has responsibility for establishment and oversight of the agronomic programs of IPNI in Russia and other Former Soviet Union countries, including Central Asia.

"This announcement marks a significant step toward realizing one of the key objectives of IPNI," said Dr. Terry L. Roberts, IPNI President. "Dr. Ivanova has the credentials and qualifications along with a unique background that will be an excellent match for this new role."

A native of Moscow, she graduated with honors in 1995 and received her Ph.D. in 1999, all at the Lomonosov' Moscow State University. Her Ph.D. thesis examined the changes in the buffer capacity of forest podzolic soils to acids and alkalis under influence of simulated acid precipitations. From 1999 to 2001, Dr. Ivanova was a research scientist in the Institute of Oceanology (Russian Academy of Science). She worked as a corporate agronomist from 2001 to 2002 in Moscow. Since September 2002 she was employed with JSC "Uralkali", based in Berezniki as a senior technical expert. Starting in 2004, Dr. Ivanova worked as coordinator of the China program of the International Potash Institute (IPI).

Throughout her career, Dr. Ivanova has been active in community and professional organizations, including recent service as a member of several task forces of the Agriculture Committee of the International Fertilizer Industry Association (IFA). Her resume also includes an impressive list of scientific publications as well as technical reports and presentations. BC

IPNI Crop Nutrient Deficiency Photo Contest—2007

While the classic symptoms of crop nutrient deficiencies are not as common in fields as they were in the past, they do still occur. To encourage field observation and increase understanding of crop nutrient deficiencies and other conditions, the International Plant Nutrition Institute (IPNI) is sponsoring a photo contest during 2007.

"We hope this competition will appeal to practitioners working in actual production fields," said IPNI President Dr. Terry Roberts. "Researchers working under controlled plot conditions are also welcome to submit entries. We encourage crop advisers, field scouts, and others to photograph and document deficiencies in crops."

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.

There are four categories in the competition: Nitrogen (N), Phosphorus (P), Potassium (K), and Other. Entries are limited to one per category (one individual could 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
- Third place = US$50

Photos and supporting information can be submitted until the end of calendar year 2007 (December 31, 2007) and winners will be announced in January of 2008. Winners will be notified and results will be posted at the website.

Entries are encouraged from 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<**. For questions or additional information, please contact:

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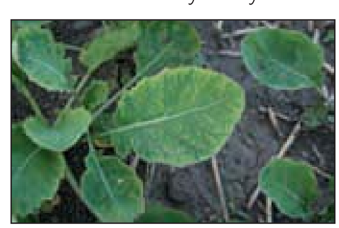
Shown at right are some photos as examples of deficiency symptoms. BC

Nitrogen deficiency in corn.

Phosphorus deficiency in cotton.

Potassium deficiency in soybeans.



Sulfur deficiency in canola.

Luís Prochnow Joins Staff of IPNI as Brazil Program Director

Dr. Luís Ignácio Prochnow

Dr. Luís Ignácio Prochnow joined the staff of IPNI on October 15 and will become Brazil Program Director effective December 1, 2007. Dr. T. Yamada, who has served as Brazil Program Director since 1977, is retiring effective November 30, 2007.

Dr. Prochnow will based at the established IPNI office in Piracicaba, São Paulo, with responsibility for the agronomic programs of the Institute in Brazil. He is currently Professor of Soil Fertility, Fertilizers and Crop Nutrition, in the Department of Soil and Plant Nutrition, University of São Paulo (ESALQ/USP), also located in Piracicaba.

Dr. T. Yamada

"We are very happy that Dr. Prochnow has agreed to accept this position. There are tremendous opportunities for agriculture in Brazil and he has an exceptional insight and knowledge base," said IPNI President Dr.Terry Roberts. "Dr. Prochnow plans a smooth transition and has ideas for further building the IPNI Brazil Program in the future."

After receiving his B.S. in Agronomy from the University of the State of Sao Paulo in 1985, Dr. Prochnow worked for a private laboratory until 1990, and then at Sao Paulo West University before receiving his masters degree in 1992. He then joined ESALQ/USP as a Professor and completed his Ph.D. in 1996. From 1999 to 2001, Dr. Prochnow was a Visiting Scientist at the International Fertilizer Development Center (IFDC) before returning to ESALQ/USP.

During his professional career, Dr. Prochnow has established an impressive record of achievement in crop management and field extension work, as well as coordination of graduate students' programs, research projects, training events, laboratory operations, and other leadership responsibilities. He has considerable international technical experience and an extensive list of peer-reviewed publications. Dr. Prochnow has been recognized with important honors and awards. BC

IPNI Announces Munir Mohammad Rusan as Middle East Consulting Director

Dr. Munir Mohammad Rusan

Dr. Munir J. Mohammad Rusan of Jordan University of Science and Technology (JUST) has agreed to represent IPNI as Middle East Consulting Director in 2007. The priorities of his work plan will be the initiation of projects in the region to promote balanced fertilization and organization of a workshop or training course on fertigation and fertilizer use in the Middle East.

"This new arrangement is unique for IPNI and we are honored to have this talented and respected scientist joining in our efforts," said Dr. Terry L. Roberts, IPNI President. "His diverse experience and knowledge of the Middle East region will be valuable in achieving these early goals."

Dr. Mohammad Rusan is Full Professor and Dean of the Faculty of Agriculture at JUST, located at Irbid. He received his Ph.D. in Soil Fertility and Plant Nutrition in 1994 at Washington State University, Pullman, in 1994, and also received his M.S. degree there in Soil Chemistry in 1986. He earned his B.S. degree in Agronomy in 1980 at Moscow University, Russia.

Previously in his career, Dr. Mohammad Rusan was Dean, Faculty of Natural Resources and Environment, Hashemite University, Zarqa, Jordan, from 2003 to 2005. From 2000 to 2005 he was National Coordinator (part time) for the Fertigation Research Program and Technology Transfer of Fertigation, Ministry of Agriculture, Jordan. He has also served as Regional Coordinator for the International Potash Institute (IPI). His resume includes involvement in numerous international organizations, extensive teaching activities, research projects, and public service. BC

Effect of Long-Term Fertilization on the Persistence of Cypermethrin in Soil

By Xie Wenjun, Zhou Jianmin, Chen Xiaoqin, and Wang Huoyan

Soils from a long-term fertilization field experiment were used to assess the impact of fertilizer treatment on pesticide (cypermethrin) dissipation in soil. Five fertilization treatments included: organic manure (OM), NPK fertilizer, PK fertilizer, NK fertilizer, and no fertilizer (control). The half-life for cypermethrin under NK application was significantly longer compared to the other treatments.

Currently, there is interest in the relationship between the biodegradation of pesticides and fertilization. Many studies have shown that the addition of organic manure and N and P fertilizers can affect pesticide degradation in soils (Topp et al., 1996; Han et al., 2003; Caracciolo et al, 2005). However, little is known about the interaction between long-term fertilization and pesticide dissipation. This study investigated cypermethrin dissipation in soils under five different long-term fertilization treatments.

Cypermethrin is a pyrethroid insecticide used to control certain insect pests. It is increasingly used for agriculture and commercial pest control, given that organochlorine and some organophosphate products are being phased out. Cypermethrin has been found in soils, sediments, and even foodstuffs, and recent studies have shown that cypermethrin possesses carcinogenic and co-carcinogenic potential and endocrine activities (Tyler et al., 2000; Shukla et al., 2002). These health impacts, combined with cypermethrin's high toxicity to aquatic life (Solomon et al., 2001), places great significance of the study of cypermethrin's behavior and fate in the environment.

Beginning in September of 1989, a long-term field experiment was established to determine the influence of mineral fertilizer and organic manure on soil fertility, with a crop rotation of wheat and maize. The site was part of the Key Experimental Station for Ecological Agriculture, Fengqiu County, Henan Province. The soil in this area was derived from alluvial sediments of the Yellow River, and is classified as aquic inceptisol. It has a sandy loam texture (about 9% clay, 22% silt). This study involved five treatments including N, P, and K (NPK); N and K without P (NK); P and K without N (PK); organic compost was applied without inorganic fertilizers (OM); and no fertilization (control). The application rates of N, P, and K, if applied, were the same in all treatments at 150 kg N/ha, 75 kg P_2O_5/ha, and 150 kg K_2O/ha for winter wheat; and 150 kg N/ha, 60 kg P_2O_5/ha, and 150 kg K_2O/ha for maize. Soil samples were collected from the surface layer (0 to 20 cm in depth) of each plot in April, 2005. The soil was sieved through a 2 mm screen to remove the roots and stored at 4 °C in plastic bags until analyzed.

Researchers Dr. Chen (left) and Dr. Wang at work in laboratory.

Soil pH, organic carbon, total N, total P, available N, available P, and available K were determined as described by Lu (2000). All treatments were assessed using fresh soil samples equivalent to 20 g of dry soil and the water content in the soil was adjusted to 60% of soil water-holding capacity.

Three replicates of soil from each treatment were amended with cypermethrin (purity >96%, Sigma) and dissolved in acetone (0.5 mL) to obtain a pesticide concentration of 10 mg/kg. Next, the pesticide was distributed homogeneously. The soils amended with cypermethrin were placed in beakers, covered with perforated aluminum foil to ensure gas exchange, and then incubated at 25°C. Soil moisture content was maintained constant throughout the entire incubation period. After 4, 7, 14, 21, and 28 days, soil samples were collected to determine the residue concentrations. The analyses of cypermethrin residues in soils were performed using an Aglient 6820 gas chromatograph equipped with an electron capture detector and an HP-5 MS capillary column based

Table 1. Effect of long-term different fertilization on soil physicochemical properties

Treatments	pH (H_2O)	SOC [a], g/kg	Total N, g/kg	Total P, g/kg	Available N, mg/kg	Available P, mg/kg	Available K, mg/kg
OM	8.03c [b]	8.0 a	0.9 a	0.6 b	30.6 b	45.3 a	171.9 c
NPK	8.26 bc	5.4 b	0.6 b	0.6 b	37.2 b	24.8 c	147.0 b
PK	8.43 ab	4.5 c	0.5bc	0.7 a	11.2 c	35.3 b	231.1 a
NK	8.38 b	3.6 d	0.5 c	0.5 c	44.9 a	1.3 d	235.7 a
Control	8.51 a	4.0 d	0.4 c	0.5 c	12.8 c	2.0 d	57.1 d

[a] SOC: Soil organic carbon.
[b] Values followed by different letters within a column are significantly different at $p<0.05$ (LSD, n=3).

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

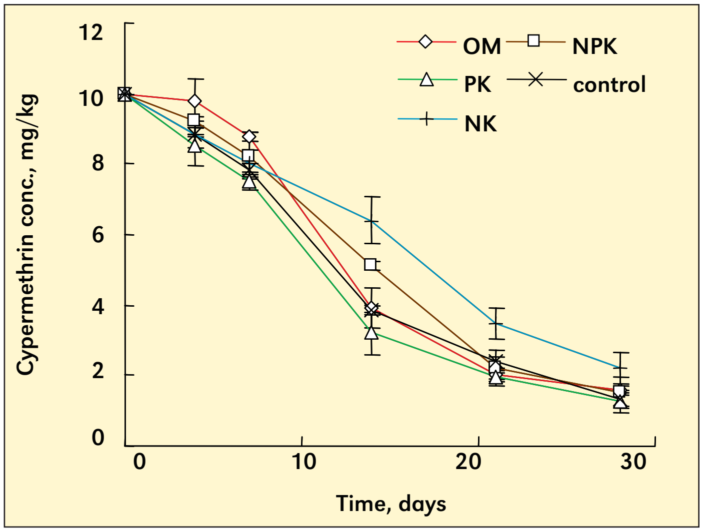


Figure 1. Cypermethrin degradation in treatments during incubation. The vertical bars represent the standard errors.

on the method reported by Sannino et al. (2003).

Soil physicochemical properties varied significantly after applying different fertilizers over a long period of time (**Table 1**). The OM treatment had the highest organic carbon, available P, and total N contents, but the lowest pH. The lowest total and available N, P, or K contents were found in the treatments that omitted N, P, or K. Overall, higher soil N, P, and organic carbon contents were observed in treatments receiving OM or NPK.

Cypermethrin dissipation in non-sterilized soils over a 28 day period is shown in **Figure 1**. In the first 4 days, cypermethrin dissipated slowly. Dissipation was especially slow within the OM treatment compared to other treatments. From day 4 to day 21, cypermethrin dissipated faster, and with the exception of the NK treatment, more than 80% had transformed in the soils by the end of the incubation period. The dissipation patterns of cypermethrin fit first order kinetics, $C = C_0e^{-kt}$ (Beulke and Brown, 2001). The half-lives for the different treatments were 9.6 days for PK, 10.7 days for control, 10.8 days for OM, 11.8 days for NPK, and 15.1 days for NK (**Table 2**). Thus the half-life for cypermethrin within the NK treatment was significantly longer than those for other treatments. Cypermethrin dissipated faster in the PK and control treatments and no significant difference was found between these two treatments. There was no significant difference in the dissipation of cypermethrin between long-term fertilization with composted organic manure versus inorganic NPK fertilization.

Table 2. Degradation kinetics of cypermethrin in treatments and half-life.

Treatments	First-order kinetics[1]	R^2	Half-life (d)
OM	C=11.25exp(-0.064t)	0.92	10.8 bc[2]
NPK	C=10.91exp(-0.059t)	0.95	11.8 b
PK	C=10.67exp(-0.072t)	0.96	9.6 c
NK	C=10.50exp(-0.046t)	0.96	15.1 a
Control	C=10.75exp(-0.065t)	0.96	10.7 c

[1]In the equation $C = C_0e^{-kt}$, C = concentration at time t, C_0 = initial concentration at time = 0, and k = elimination rate constant. [2]Values followed by different letters within a column are significantly different at p<0.05

A correlation test was conducted between the cypermethrin half-lives and soil properties. There was a strong positive relationship between the cypermethrin half-life and the N/P ratio (soil available N to soil available P ratio; r=0.926, p=0.012) and a similar positive correlation was found with soil available N (r=0.846, p=0.035). This relationship suggests that long-term fertilization without P, or with high levels of N, can increase soil N/P ratios and available N content, and thus inhibit the dissipation of cypermethrin. This result is consistent with reports by Graham et al. (1999), Caracciolo et al. (2005) and Entry (1999). Total and available P content were negatively correlated with cypermethrin half-life, but not to a significant degree, and could enhance degradation to some extent. Soil organic carbon was weakly correlated with cypermethrin half-life in soil.

Conclusion

In the long-term, different fertilization strategies have a significant effect on soil physicochemical properties. Soil organic carbon content was higher in soils with balanced fertilization, especially fertilization with composted organic manure, than in soils with unbalanced fertilization. Soil N and P contents also varied greatly in soils with different fertilization treatments.

Cypermethrin persistence also differed significantly among soils with different modes of fertilization in this long-term study. Cypermethrin dissipated faster in soils fertilized with PK and in the control. The slowest dissipation was observed in the NK treatment. No significant difference in dissipation was observed between long-term fertilization with inorganic NPK and fertilization with organic manure. Soil N/P ratio and available N content showed significant positive correlation with cypermethrin half-life (p<0.05), and could inhibit cypermethrin dissipation. Total soil P and available P content showed a non-significant negative correlation with the pesticide half-life and may enhance dissipation to some extent. These results can help us to establish scientific modes of fertilization and to predict the fate of cypermethrin in soils and minimize environmental risks. BC

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IPNI Project Nanjing-10

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Manganese Nutrition of Glyphosate-Resistant and Conventional Soybeans

By Barney Gordon

This study was conducted to determine if glyphosate-resistant (GR) soybeans respond differently to Mn fertilizer than conventional soybean varieties in an irrigated high-yield environment, and if so to develop fertilization strategies that will prevent or correct deficiencies. Yield of the GR variety was less than the conventional variety without Mn fertilizer. However, Mn application (banded at planting) to the GR variety closed the yield gap. The conventional soybean variety was not responsive to Mn fertilization. Conversely, yield was reduced at the highest rate of Mn. A second phase of the study showed that a combination of Mn applied as starter and foliar application provided maximum yield response.

Glyphosate-resistant soybean variety planting dwarfs that of conventional varieties in the U.S. by a factor of about 9 to 1. Nevertheless, GR soybean yield may still lag behind that of conventional soybeans, as many farmers have noticed that yields are not as high as expected, even under optimal conditions. In Kansas, average yield seldom exceeds 60 to 65 bu/A even when soybeans are grown with adequate rainfall and/or supplemental irrigation water.

There is evidence to suggest that glyphosate may interfere with Mn metabolism and also adversely affect populations of soil micro-organisms responsible for reduction of Mn to a plant-available form. Manganese availablity is also strongly influenced by soil pH. As soil pH increases, plant-available Mn decreases. It is unlikely that Mn deficiencies will occur on acid soils. It stands to reason that the addition of supplemental Mn at the proper time may correct deficiencies and result in greater GR soybean yields.

In higher plants, photosynthesis in general and photosynthetic O_2 evolution in Photosystem II (Hill Reaction), in particular, are the processes most sensitive to Mn deficiency. Manganese deficiency-induced changes in O_2 evolution are correlated with changes in the ultrastructure of thylakoid membranes (internal chlorophyll containing membranes of the chloroplast where light absorption and the chemical reactions of photosynthesis take place). When Mn deficiency becomes severe, the chlorophyll content decreases and the ultrastructure of the thylakoids is drastically changed.

Manganese acts as a cofactor, activating about 35 different enzymes. Manganese activates several enzymes leading to the biosynthesis of aromatic amino acids such as tyrosine and secondary products such as lignin and flavonoids. Flavonoids in root extracts of legumes stimulate *nod* (nodulation) gene expression. Lower concentrations of lignin and flavonoids in Mn-deficient tissue is also responsible for a decrease in disease resistance of Mn-deficient plants. In nodulated legumes such as soybean which transport N in the form of allantoin and allantoate to the shoot, the degradation of these ureides in the leaves and in the seed coat is catalyzed by an enzyme that has an absolute requirement of Mn. Ureides account for the majority of N transported in the xylem sap to the aerial portions of soybean. Tissue Mn deficiency and drought stress can increase shoot ureide concentration. In research done in Arkansas, it was found that foliar Mn applications reduced soybean shoot ureide concentrations and prolonged N_2 fixation. Information is needed to determine if field-grown GR soybean responds to applied Mn in a different manner than conventional soybean and, if so, what fertilization practices are best to correct the problem. Currently there is little information on Mn fertilization of soybean in Kansas.

Research in Kansas found that a GR soybean variety did not accumulate Mn in the same manner as a conventional variety in the high-yield environment of the study.

The objective of this research was to determine if GR soybeans respond differently to applied Mn than conventional soybeans and, if so, to develop fertilization strategies that will prevent or correct deficiencies leading to improved yield for soybean producers.

Methods

Two separate sprinkler irrigated experiments were conducted on a Crete silt loam soil (fine, smectitic, mesic Pachic Argiustolls) with a pH of 7.0 at the North Central Kansas Experiment Field, located near Scandia, Kansas. Experiment I compared response of the GR soybean variety KS 4202 RR and its conventional near-isoline to granular Mn sulfate applied at planting in a band beside the row to give rates of 2.5, 5, and 7.5 lb Mn/A. A zero Mn check plot also was included. Soybeans were planted without tillage in early May in 2005 and 2006. The experimental design was a randomized complete block with a split-plot arrangement. Whole plots were herbicide resistant and conventional soybean varieties and split plots were Mn rates and sources.

Experiment II evaluated liquid chelated Mn applied to soybean as a starter at planting and as a foliar treatment at three growth stages (V4, V8, and R2). Manganese was applied to the GR soybean variety, KS 4202RR, to give a rate of 0.33

Abbreviations and notes for this article: Mn = manganese; N = nitrogen; O_2 = oxygen; ppm = parts per million.

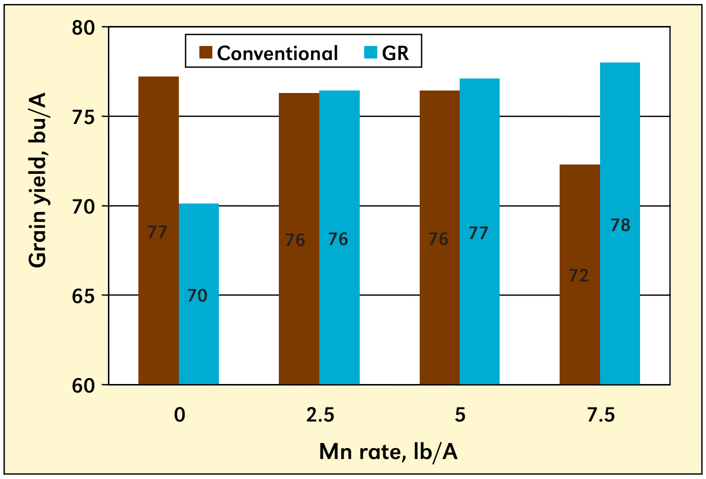

Figure 1. Soybean yield response to applied Mn, 2005-2006.

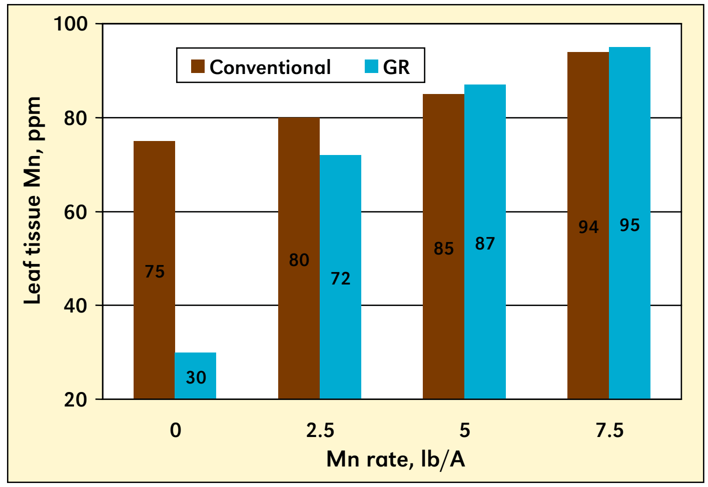

Figure 2. Soybean leaf tissue Mn concentration (uppermost expanded trifoliate at full bloom) 2005-2006.

Table 1. Foliar applied Mn effects on soybean yield, 2006.

Stage of growth	Yield, bu/A
Starter (0.33 lb)	66
Starter (0.66 lb)	70
Starter (0.33 lb) + V4 (0.33 lb)	74
V4 (0.33 lb)	66
V4 + V8 (0.33 +0.33 lb)	72
V4+V8 +R2 (0.33+0.33+0.33 lb)	74
Untreated check	66
LSD (0.05)	3

lb/A Mn at each application.

Results

In Experiment I, yield of the GR variety (KS 4202 RR) was 7 bu/A lower than its conventional near-isoline when no Mn was applied (**Figure 1**). The application of 2.5 lb Mn/A improved yield of the GR variety equal to that of the conventional near-isoline. Yield of the conventional near-isoline was depressed at the high rate of Mn. Tissue Mn concentration (upper most expanded trifoliate at full bloom) in the herbicide resistant near-isoline was less than half of the conventional variety when no Mn was applied (**Figure 2**). However, Mn fertilizer application closed the gap in tissue Mn concentration between the GR and conventional varieties.

In Experiment II, yield of the glyphosate–resistant soybean variety KS 4202 RR was maximized by a combination of Mn applied as a starter 2 in. to the side and 2 in. below the seed at planting, plus a foliar application at the same rate applied at the 4 leaf stage (**Table 1**). A starter alone application at either 0.33 or 0.66 lb Mn/A did not give results equaling the combination of starter and foliar treatment. Application of foliar-applied Mn at 0.33 lb Mn/A at the V4, V8, and R2 stages of growth gave yields equal to the starter plus one foliar application at the V4 stage. One or two foliar applications were not as effective as the starter plus foliar or the three foliar applications. Higher rates of starter-applied Mn and single foliar applications will be investigated next year in order to determine if timing is critical or if higher rates applied earlier in the growing season may be as effective as lower rates applied more frequently.

This research provides evidence that the GR soybean variety used in this study did not accumulate Mn in the same manner as the conventional variety, and did respond to application of Mn in this high-yield environment. BC

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InfoAg 2009 Set for July 14-16

InfoAg 2007 was a resounding success, with over 570 participants sharing their ideas, questions, and experiences in application of precision technology, data management, electronic communication, and remote sensing. Over 100 presentations, a 60-booth exhibit hall, a pre-conference tour, and ample networking opportunities made this one of the best conferences yet for promoting the adoption of modern technology in crop and soil management. More details about the conference, including PDF files of most of the presentations, are available at the website: **www.infoag.org**.

Dates for the next Information Agriculture Conference have been set for **July 14-16, 2009**, again in Springfield, Illinois. BC

Right Product, Right Rate, Right Time, and Right Place...the Foundation of BMPs for Fertilizer

By Terry L. Roberts

This article was originally presented as a paper at the International Fertilizer Industry Association (IFA) Workshop on Fertilizer Best Management Practices, March 7-9, 2007, in Brussels, Belgium. It is reprinted here with permission...see reference below[1].

The concept of agricultural best management practices (BMPs) is not a new one. First introduced almost 20 years ago, scientists at the Potash & Phosphate Institute (PPI) defined BMPs as those practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency, and environmental protection (PPI, 1989; Griffith and Murphy, 1991). Today, the emphasis appears to be more on environmental protection than optimal production potential as current definitions suggest BMPs are practical management practices or systems designed to reduce soil loss and mitigate adverse environmental effects on water quality caused by nutrients, animal wastes, and sediments. Common BMPs directed towards mitigation include strip cropping, terracing, contour stripping, grass waterways, special manure handling, animal waste structures, ponds, minimal tillage, grass filter strips, and nutrient application. Agronomic BMPs leading towards optimizing production potential include: variety, planting date, hybrid maturity, row-spacing, seeding rates, plant population, integrated pest management, weed control, disease control, and nutrient management.

Both soil conservation and agronomic-based BMPs can work together to meet objectives of optimal production potential and mitigation of adverse nutrient-caused environmental effects on water quality. While BMPs may differ depending on objective, to be used by farmers they must also be economic…the practices and management they employ must be profitable and sustainable. Nutrient management deserves special attention because it is critical to both optimizing production potential and to environmental stewardship.

One of the challenges we face in the fertilizer industry is that much of society does not trust us. Many believe that fertilizers are applied indiscriminately, that the industry is only interested in increased profits…through unwarranted fertilizer sales…and that farmers are willing recipients who unnecessarily over-apply nutrients to ensure high yield crops resulting in excessive levels of plant nutrients to the detriment of the environment. This, of course, is not true, but the perception is there and that drives policymakers towards regulating nutrient management, water quality guidelines, total daily load limits, and other policies or practices aimed at restricting or eliminating the use of fertilizer.

Part of the solution in gaining the public's confidence in our ability to manage nutrients responsibly is through encouraging the widespread adoption of fertilizer BMPs. As an industry we need to be unified in the promotion of BMPs designed to improve nutrient use efficiency and therefore environmental protection, without sacrificing farmer profitability. The North American industry has been advocating management practices that foster the effective and responsible use of fertilizer nutrients with a goal to match nutrient supply with crop requirements and minimize nutrient losses from fields (Canadian Fertilizer Institute, The Fertilizer Institute). The approach is simple: apply the correct nutrient in the amount needed, timed and placed to meet crop demand—right product, right rate, right time, and right place. These are the underpinning principles of fertilizer BMPs.

The following summarizes these guiding principles for fertilizer management. A more in-depth discussion is available in Roberts (2006).

- **Right product**: Match the fertilizer source and product to crop need and soil properties. Be aware of nutrient interactions and balance nitrogen, phosphorus, potassium, and other nutrients according to soil analysis and crop needs. Balanced fertilization is one of the keys to increasing nutrient use efficiency.
- **Right rate**: Match the amount of fertilizer applied to the crop needs. Too much fertilizer leads to leaching and other losses to the environment and too little results in lower yields and crop quality and less residue to protect and build the soil. Realistic yield goals, soil testing, omission plots, crop nutrient budgets, tissue testing, plant analysis, applicator calibration, variable rate technology, crop scouting, record keeping, and nutrient management planning are BMPs that will help determine the right rate of fertilizer to apply.
- **Right time**: Make nutrients available when the crop needs them. Nutrients are used most efficiently, when their availability is synchronized with crop demand. Application timing (pre-plant or split applications), controlled release technologies, stabilizers and inhibitors, and product choice are examples of BMPs that influence the timing of nutrient availability.
- **Right place**: Place and keep nutrients where crops can use them. Application method is critical for efficient fertilizer use. Crop, cropping system, and soil properties dictate the most appropriate method of application, but incorporation is usually the best option to keep nutrients in place and increase their efficiency. Conservation tillage, buffer strips, cover crops, and irrigation management are other BMPs that will help keep fertilizer nutrients where they were placed and accessible to growing crops.

[1]Fertilizer Best Management Practices. General Principles, Strategy for their Adoption and Voluntary Initiatives vs Regulations. Proceedings of the IFA International Workshop on Fertilizer Best Management Practices, 7-9 March 2007, Brussels, Belgium. Published by International Fertilizer Industry Association, Paris, France, 2007.

There is not one set of universal fertilizer BMPs. By definition BMPs are site-specific and crop-specific; they vary from one region to the next and one farm to the next depending on soils, climatic conditions, crop and cropping history, and management expertise. BMPs can be implemented in large, extensive farming operations and on small family farms. Right rate, right time, and right place offer sufficient flexibility that these guiding principles can be applied to fertilizer management for rice production in Indonesia, banana production in Latin America, maize production in the U.S. Corn Belt, or any farming system used throughout the world.

Fertilizer BMPs should help ensure that fertilizer uptake and removal by target crops is optimized and fertilizer loss to the environment is minimized. Fertilizer BMPs should increase nutrient use efficiency, but maximum use efficiency is not the primary objective. The goal is to use fertilizers efficiently and effectively in providing adequate nutrition for crops.

If maximizing fertilizer efficiency was the goal, we just need to work lower on the yield response curve. For a typical yield response curve, the lower part of the curve is characterized by low yields since few nutrients are available or applied (**Figure 1**). Nutrient use efficiency is high at the bottom of the yield curve because any addition of a limiting nutrient gives a relatively large yield response as much of the applied nutrient is taken up by the nutrient-limited crop. If highest nutrient use efficiency were the only goal, it would be achieved here in the lower part of the yield curve and by applying the first increments of fertilizer. Lower rates of fertilizer appear better for the environment, because more nutrients are removed by the crop, leaving less in the soil for potential loss. But lower yielding crops produce less biomass and leave fewer residues to protect the land from wind and water erosion and less root growth to build soil organic matter. As you move up the response curve, yields continue to increase, albeit at a slower rate, and nutrient use efficiency typically declines. However, the extent of the decline in nutrient use efficiency will be dictated by the BMPs employed as well as soil and climatic conditions.

Fertilizer nutrients are essential for modern agriculture to meet its crop yield and quality goals, but fertilizers must be used responsibly. Development and adoption of BMPs for fertilizer are necessary for the fertilizer industry to demonstrate its commitment to product and environmental stewardship, and to help the farmer produce sustained, profitable yields. Every farm and field is different. Fertilizer BMPs must be adaptable to all farming systems…one size does not fit all. Right nutrient, right rate, right time, and right place provide a framework for a farmer to select those BMPs best suited to the farm's soils, crops, and climate and to the farmer's management capabilities. BC

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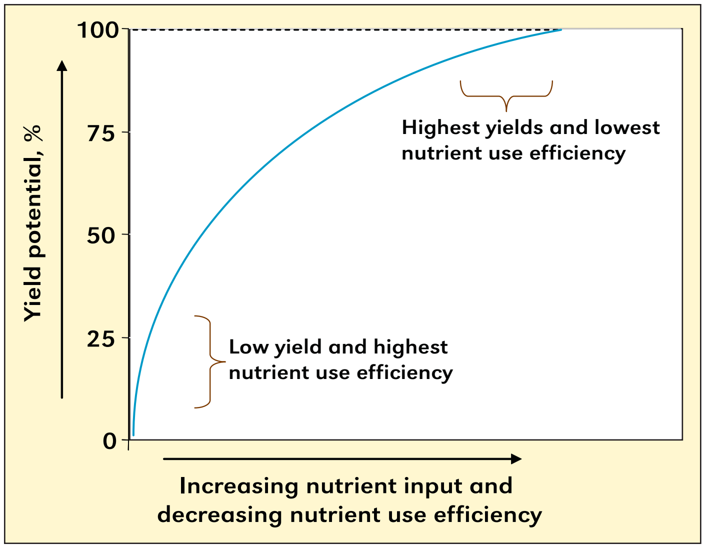

Figure 1. Relationship between yield response and nutrient use efficiency (adapted from Dibb, 2000).

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Editor's Note: The article which begins on the next page, titled "Best Management Practices to Minimize Greenhouse Gas Emissions Associated with Fertilizer Use", takes a closer look at the current science on this timely question. It is an executive summary of a more comprehensive literature review to be available soon.

Best Management Practices to Minimize Greenhouse Gas Emissions Associated with Fertilizer Use

This article is an Executive Summary of a literature review in preparation by the International Plant Nutrition Institute (IPNI).

By C.S. Snyder, T.W. Bruulsema, and T.L. Jensen

Climate change and global warming continue to be topics of considerable scientific debate and public concern. Increasingly, agriculture is viewed as a large contributor to GHG emissions which drive GWP, and fertilizer N use has been identified as a major factor. This paper presents a review of the scientific literature on the impacts of fertilizer use and management on GHG emissions, and represents a brief overview of the current science.

Agriculture plays a substantial role in the balance of the three most significant GHGs whose emissions are influenced by humankind. The three gases are – CO_2, N_2O, and CH_4. The GWP of each of these gases can be expressed in CO_2 equivalents. The GWPs of N_2O and of CH_4 are 296 and 23 times greater, respectively, than a unit of CO_2. Among the three gases, N_2O may be the most important to fertilizer use because of its large CO_2 equivalent influence on GWP.

Agriculture represents less than 8% of the total GHG emissions in Canada and less than 10% in the United States, and it is not increasing (**Figure 1**). For the total economy, CO_2 emissions are the most important, but for agriculture the most important is N_2O (**Figure 2**). Emissions of CH_4, mainly from livestock, are also substantial contributors to the GWP. Even though N_2O constitutes only a small part of U.S. GHG emissions (**Figure 2**), it becomes the major focus of this review because agriculture is its major source, and it is linked to soil management and fertilizer N use.

Atmospheric concentrations of N_2O have risen from about 270 parts per billion (ppb) during the pre-industrial era to 319 ppb in 2005. Emission of N_2O from the Earth's surface has increased by about 40 to 50% over pre-industrial levels as a result of human activity. The proportion of cropland N_2O emissions directly induced by fertilizer are estimated at about 23% world-wide, and range from about 24% to 35% in North America.

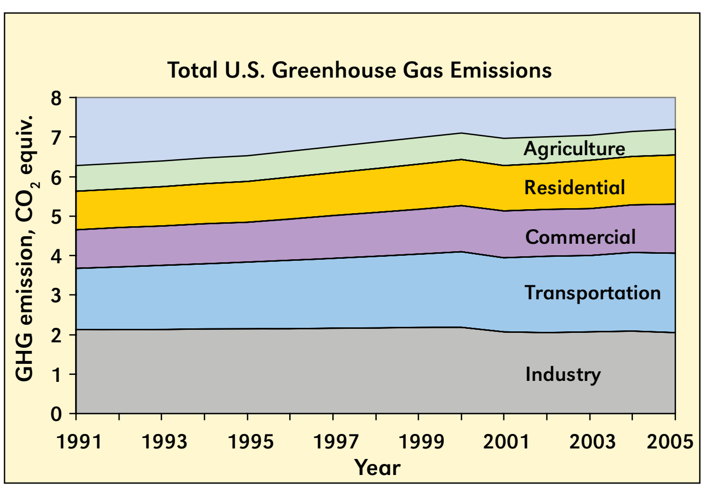

Figure 1. Greenhouse gas emissions from the U.S. economy, by sector, in billion (10^9) tonnes of CO_2 equivalents.

Fertilizer N – Source, Rate, Timing, Placement

The foundation of good fertilizer stewardship rests on the principles of using the right source, at the right rate, at the right time, and with the right placement (Roberts, 2007). Most studies have shown that soil conditions such as water filled pore space, temperature, and soluble C availability have a dominant influence on N_2O emissions. Fertilizer source and crop management factors may affect N_2O emissions, but due to interactions with soil conditions it is difficult to make general conclusions. Mismanagement of the appropriate rate, source, timing, or placement of fertilizer N, and lack of proper balance with other essential nutrients can increase overall N loss and N_2O emissions. When N is applied above the economic optimum N rate, or when available soil N (especially in NO_3^- form) exceeds crop uptake, the risk of increased N_2O emissions rises. When legumes or other N-fixing crops are included in cropping system rotations, they may also contribute post-season N_2O emissions as their plant residues decompose. Research around the world has shown contrasting results in emissions of N_2O from various fertilizer N sources. At the present time, based on the available literature, no conclusions can be made that differentiate one source of N as having a greater risk of loss as N_2O than another.

Urease and Nitrification Inhibitors, and Enhanced Efficiency Products

Enhanced efficiency fertilizers (slow and controlled-release fertilizers and stabilized N fertilizers) have been defined as

Abbreviations and notes for this article: GHG=greenhouse gas; GWP=global warming potential; N=nitrogen; CO_2=carbon dioxide; N_2O= nitrous oxide; NO_3^- = nitrate; CH_4=methane; SOM=soil organic matter; C=carbon; SOC=soil organic C.

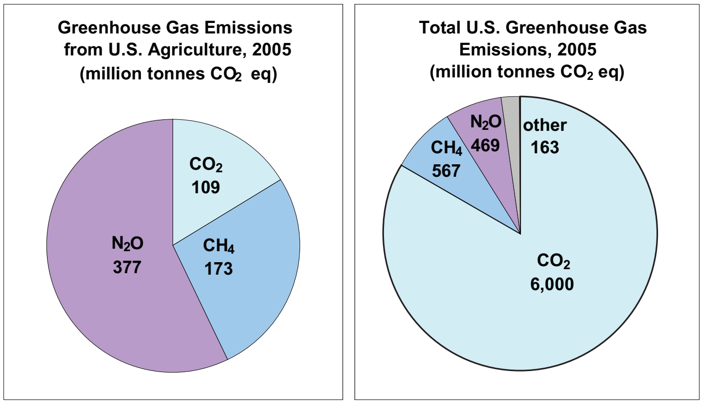

Figure 2. Distribution of greenhouse gas emissions from U.S. agriculture and total.

products that minimize the potential of nutrient losses to the environment, as compared to "reference soluble" fertilizers. Urease and nitrification inhibitors have shown good potential in increasing soil retention and plant recovery of applied fertilizer N, but less is known about their impacts on reductions in total N_2O emissions. Slow release, controlled release, and stabilized fertilizers have been shown to enhance crop recovery and reduce losses of N via drainage or atmospheric emissions. Their benefits in reducing N_2O emissions have been explored to a lesser degree. Recent evidence suggests they can be effective in reducing short-term emissions, but the effect on long-term losses is less clear. Studies are underway to better quantify these emissions and potential benefits.

Global Warming Potential of Intensive Cropping Systems

Although often considered a GHG source, in some conditions agriculture can also be a net sink for CO_2 and actually cause a net reduction in GWP. Adequate fertilization can contribute to the increase of SOM or slow its decline. Inadequate fertilization limits crop biomass production, and can result in less C returned to the soil, lower SOM, and potentially impaired long-term soil productivity.

Optimum N inputs are essential for supporting primary plant productivity and stabilization of SOM, upon which SOC storage depends. Combinations of fertilizer source, rate, timing and placement that optimize crop yields minimize the GWP of emissions per unit of production and reduce the need for conversion of natural lands to agriculture.

Intensive crop management practices to enhance nutrient uptake while achieving high yields can be a principal way to achieve reductions in GHG emissions from crop production. High-yielding crops can increase soil C storage. The following crop, soil, and fertilizer management factors help minimize net GWP: (1) choice of the right combination of adapted varieties or hybrids, planting date, and plant population to maximize crop biomass production; (2) use of tactical water and N management, including frequent N applications to achieve high N use efficiency with minimal opportunity for N_2O emissions; and (3) use of crop residue management approaches that favor a build-up of SOC, as a result of large amounts of crop residues returned to the soil.

Recent measurements show that the largest factors contributing to differences among cropping systems in net GWP are linked to soil C change and N_2O emissions (**Table 1**). The same data show that increases in N fertilizer use do not always increase net GWP, and that intensive production systems using higher rates of N may have lower net GWP per unit of food production than low-input and organic production systems.

Sparing Natural Areas through Intensive Crop Production

An intensive production approach can result in more food produced per unit of land area. For example, the less intensive systems in MI required almost three times the land area as in the NE systems to achieve the same amount of corn production (**Table 1**). The importance of assessing cropping systems for their GWP per unit of productivity is underscored by the fact that for net GWP mitigation, land spared from production presents a greater opportunity (an example of cropland conversion to poplar forest is included in **Table 1**). Fertilizer best management practices (BMPs), and related practices which tend to enhance crop recovery of applied N, increase yield, and reduce the risk of GHG emissions include: appropriate N source, rate, timing and placement; application equipment calibration; crop-tillage-nutrient management system planning and evaluation; appropriate use of N conversion inhibitors (urease, nitrification) and enhanced efficiency sources; and consideration of site-specific soil and water conservation practices, since they may interact with other management practices and also serve as a secondary line of defense in limiting environmental nutrient losses.

Fertilizer Management Actions – Environmental Challenges and Opportunities

This review exposed many challenges in proper measurement of the combined effects of different cropping-tillage-nutrient management systems on GHG emissions. One critical challenge is the lack of simultaneous measurement of all three GHGs (CO_2, N_2O, and CH_4) over extended time periods in agronomic and environmental studies. It became apparent during this review that many studies report emissions of only one GHG, based on measurements only over a relatively short time span, often less than 30 days. This "snapshot" evaluation of GHG emissions limits the ability to accurately determine system-level crop and nutrient management effects on net GWP. Another short-coming exposed in this review is the inadequate sampling of SOC among tillage systems. Many studies soil sampled no deeper than the surface 15 cm, which results in imprecise and inaccurate measurement of the mass of C stored, due to differences in soil bulk density, rooting patterns, and rhizosphere biology.

There are many opportunities to expand our knowledge about the full environmental effects of proper nutrient management on reduced GHG emissions and GWP. Greater collaboration between agronomic and environmental scientists will be required in the future to achieve global food, fiber, and fuel production and environmental goals. Some of these collaborative research opportunities are identified in the conclusions of the paper and include: proper nutrient management for cellulosic (annual and perennial) biofuel crops; long-term evaluation of nutrient losses via leaching/drainage/runoff and simultaneous measurements of atmospheric emissions of CO_2, N_2O, and CH_4 for major world cropping-tillage systems; and

Table 1. Comparison of selected agricultural cropping systems for net GWP.

Cropping system			GWP in CO_2 equivalents, kg/ha/yr					Mean crop yields, t/ha			Food yield[1]
Location	Rotation[4]	Tillage	Soil C[5]	N fert. production[6]	Fuel	N_2O	Net GWP	Corn	Wheat	Soybean	Gcal/ha/yr
MI[2]	C-S-W	CT	0	270	160	520	1,140	5.3	3.2	2.1	12
MI[2]	C-S-W	NT	-1,100	270	120	560	140	5.6	3.1	2.4	13
MI[2]	C-S-W low input with legume	CT	-400	90	200	600	630	4.5	2.6	2.7	12
MI[2]	C-S-W organic with legume	CT	-290	0	190	560	410	3.3	1.6	2.7	9
NE[3]	CC BMP	CT	-1,613	807	1,503	1173	1,980	14.0			48
NE[3]	CC intensive	CT	-2,273	1,210	1,833	2090	3,080	15.0			51
NE[3]	C-S BMP	CT	1,100	293	1,283	917	3,740	14.7		4.9	35
NE[3]	C-S intensive	CT	-73	660	1,613	1247	3,740	15.6		5.0	37
MI[2]	Cropland conversion to poplar forest	NT	-1,170	50	20	100	-1,050				

[1] Food energy calculated from crop yields and USDA national nutrient database http://riley.nal.usda.gov/NDL/index.html
[2] Rainfed cropping system (Robertson et al., 2000)
[3] Irrigated cropping system (Adviento-Borbe et al., 2007)
[4] C-S-W = corn – soybean – wheat; CC = continuous corn
[5] Estimates of net soil C storage are based on changes in soil C measured to a depth of 7.5 cm in the MI study and 30 cm in the NE study. Shallower sampling depths tend to upwardly bias the C sequestration estimates in no-till systems.
[6] GWP for manufacture and transport of fertilizer N was assumed to be 4.51 and 4.05 kg CO_2/kg N in the MI and NE studies, respectively.

large plot or field-scale studies of crop N sensing and variable rate and/or variable N source application evaluations to include environmental loss and emissions measurements.

Significant conclusions from this review include:

1) appropriate fertilizer N use helps increase biomass production necessary to help restore and maintain SOC levels;
2) BMPs for fertilizer N play a large role in minimizing residual soil NO_3^-, which helps lower the risk of increased N_2O emissions;
3) tillage practices that maintain crop residue on the soil surface can increase SOC levels, but usually only if crop productivity is maintained or increased;
4) differences among fertilizer N sources in N_2O emissions depend on site- and weather-specific conditions; and
5) intensive crop management systems do not necessarily increase GHG emissions per unit of crop or food production; they can help spare natural areas from conversion to cropland and allow conversion of selected lands to forests for GHG mitigation, while supplying the world's need for food, fiber, and biofuel.

Short-term, a greater emphasis is needed in educating agricultural practitioners about: 1) the basic principles of productive, sustainable cropping system management; 2) pathways of nutrient loss to air and water resources; 3) opportunities to mitigate GHG emissions through existing and promising fertilizer BMPs which address loss pathways; and 4) greater dialogue between agronomic scientists and environmental scientists, which encourages mutual understanding and collaboration, to avoid polarization and adversarial relationships on GHG emissions and other environmental issues. The GHG emissions issue increases the need for a high level of management applied to the use of fertilizers in cropping systems. As with all fertilizer BMPs, those selected need to be evaluated in the context of mitigation of all GHG emissions from the full cropping system. BC

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Withholding Phosphorus after Long-Term Additions – Soil and Crop Responses

By F. Selles, C.A. Campbell, R.P. Zentner, D. James, and P. Basnyat

Soil P change was directly related to the balance between input as fertilizer and output as grain removal in semiarid southwestern Saskatchewan. A change of 6 lb P/A in P balance produced a change of 1 lb P/A in Olsen P. In the absence of P fertilizer additions, Olsen P remained at approximately 15 lb P/A in the surface 6 in. of soil. While fallow-grown wheat responded positively to P applied annually, withholding fertilizer P after soil P buildup did not affect yields. Both N and P were required to optimize the yield of stubble-grown wheat.

In the semiarid prairies of western Canada, N and P are the two main nutrients limiting crop yield and quality. In this region, where summerfallow and spring wheat predominate the cropping mix (Campbell et al., 2002), rates of N applied to crops grown on summerfallow are low because much N mineralization occurs during the 21 month summerfallow period. However, P is usually applied. For crops grown on stubble, N is generally required for optimum yield, and P may also be applied. When difficult economic situations arise, producers often consider ways to reduce input costs and usually choose between reducing pesticide or fertilizer inputs, mainly P.

Most prairie soils are high in total P, but low in available P (Doyle and Cowell, 1993). Low soil water and low temperatures in early spring further act to reduce P availability (Stewart and Karamanos, 1986). In these soils, 75 to 90% of P fertilizer is left unused by the first crop after application. However, the residual P remains in forms available to subsequent crops (Spratt and Read, 1980; Roberts, 1992). Thus, there can be a build up of large amounts of residual P from the addition of regular small amounts of P fertilizer over extended periods (Spratt and McCurdy, 1966; McKenzie and Roberts, 1990; Campbell et al., 2005).

On the Canadian prairies, low P soils are those with less than 9 to 13 lb Olsen-P/A in the top 6 in. With these soils, economic yield response to P fertilization can be obtained each year (Stewart and Karamanos, 1986). But even soils high in Olsen-P (e.g., 40 lb/A) can respond to applied P about 25% of the time, especially if applied in the seed-row when soil is cool in early spring (Stewart and Karamanos, 1986; Roberts, 1992). Under cool conditions, root growth and P movement are restricted. This limits P availability to plants unless some P, preferably NH_4-P, is placed near the seed (Rennie and Mitchell, 1954). In Saskatchewan and Manitoba, the recommended rates of P fertilizer when Olsen-P in the top 6 in. are 0 to 9, 10 to13, 14 to 17, 18 to 53, and >53 lb/A are 30, 25, 20, 15, and 0 lb P_2O_5/A, respectively (Saskatchewan Agriculture, 1985).

In 1967, a field study was initiated at Swift Current, Saskatchewan, on an Orthic Brown Chernozem (Aridic Boroll) to determine the extent to which grain yield, P uptake, and soil-available P would be influenced in various crop rotations by stopping P fertilization after 27 years, and also by the continued addition or withdrawal of N fertilizer for a further 12 years. The loam soil has a pH of 6.5.

In this study, five of the initial treatments were: fallow-spring wheat-spring wheat (F-W-W) receiving (i) N and P fertilizer (N+P), (ii) P only (+P), and (iii) N only (+N), and continuous wheat (Cont W) receiving (i) N and P (N+P), and (ii) P only (+P). In 1993, we split these five treatments to provide subplots in which P was withheld from treatments that were receiving P, and N withheld

Table 1. Comparison of average grain yields, P concentration, P uptake in grain, P balances, and changes in soil Olsen P during the 1967-1993 period vs. the 1994-2005 period[1]. (Values pertain to rotation phases in parentheses, except for gain or loss, which is for the rotation).

Period and period difference	Wheat on fallow			Wheat on stubble				
	F-(W)-W			F-W-(W)			Cont W	
	Rot 1 (+P)	Rot 2 (N+P)	Rot 5 (+N)	Rot 1 (+P)	Rot 2 (N+P)	Rot 5 (+N)	Rot 8 (N+P)	Rot 12 (+P)
	Grain yield, bu/A							
1967-1993	29.3	30.5	27.0	19.4	21.7	19.4	21.1	17.3
1994-2005	45.5	46.1	36.6	21.9	33.0	31.0	36.5	24.9
Difference, %	55	51	35	13	52	59	73	44
	P concentration in grain, %							
1967-1993	0.34	0.34	0.34	0.40	0.39	0.35	0.38	0.40
1994-2005	0.40	0.39	0.32	0.46	0.43	0.36	0.43	0.47
Difference, %	18	15	-6	15	10	3	13	18
	P uptake in grain, lb/A							
1967-1993	6.0	6.2	5.4	4.5	4.9	4.1	4.9	4.2
1994-2005	10.8	10.6	6.9	5.8	8.1	6.1	9.0	6.9
Difference, %	81	70	28	27	65	50	84	64
P balance, gain (+) or loss (-), lb/A								
1967-1993	+67	+60	-86				+108	+127
1994-2005	+7	-4	-53				0	+27
Change in soil Olsen-P, lb/A								
1967-1993	26.6	18.2	-1.3				19.9	30.1
1994–2005	16.6	5.0	-4.6				-4.5	32.6

[1] Average growing season precipitation in 1967-1993 = 7.4 in. and in 1994-2005 = 9.3 in.; the 104-yr mean = 8.3 in.

Abbreviations and notes for this article: P = phosphorus; N = nitrogen; NO_3 = nitrate; MAP = monoammonium phosphate; NH_4^+ = ammonium.

from the F-W-W (+N) treatment.

Ammonium nitrate was broadcast in the spring and incorporated with a pre-seeding tillage, based on levels of soil NO_3 (0 to 24 in.) measured in individual plots in the previous fall. From 1967 to 1989, we used N rates (soil test + fertilizer N) of 58 lb/A, which increased to 80 lb/A on fallow and 65 lb/A on stubble in 1990 in accordance with changes in soil test recommendations. Phosphorus fertilizer (MAP) was applied with the seed at an average rate of 20 lb P_2O_5/A using a hoe drill. Soil samples from the surface 6 in. were collected annually and bicarbonate-extractable (Olsen) P determined (Hamm et al., 1970). We monitored grain yield, P concentrations, and P uptake in grain annually. During the 1967 to 1993 period, growing season precipitation (GSP) averaged 7.4 in. (i.e., 10% below the 8.3 in. long-term average), but during the period 1994 to 2005, GSP averaged 9.25 in. (12% above average).

Under the original fertilization protocol, grain yield of wheat grown on fallow was increased by P fertilization in 1967 to 1993 and even more so in the wetter 1994-2005 period (Rot 2 vs Rot 5, **Table 1**). However, there was no response to N (Rot 1 vs Rot 2) because N was being adequately supplied by mineralization. Yield of wheat grown on stubble was increased by N (Rot 1 vs Rot 2 and Rot 8 vs Rot 12) especially in the wetter 1994-2005 period, but response to P was minimal (**Table 1**).

A P balance (fertilizer P minus P removed in the grain) calculation (**Table 1**) indicated that systems receiving P had accumulated Olsen-P (**Figures 1 and 2**) to levels two to three times the initial quantities by 1993. However, in the F-W-W (+N) system Olsen-P levels had remained constant until about 1990, likely because P uptake (**Table 1**) was restricted by the below average precipitation conditions prevalent in the 1967 to 1993 period. During the 1994 to 2005 period, growing season precipitation was above average and yield and P uptake were much greater (**Table 1**), thus resulting in a reduction in Olsen-P in the F-W-W (+N) system (**Figure 1**). During this latter period, Olsen-P in systems receiving P tended to remain constant when N was also being applied, but tended to increase when only P was applied (**Figures 1 and 2**) and P uptake

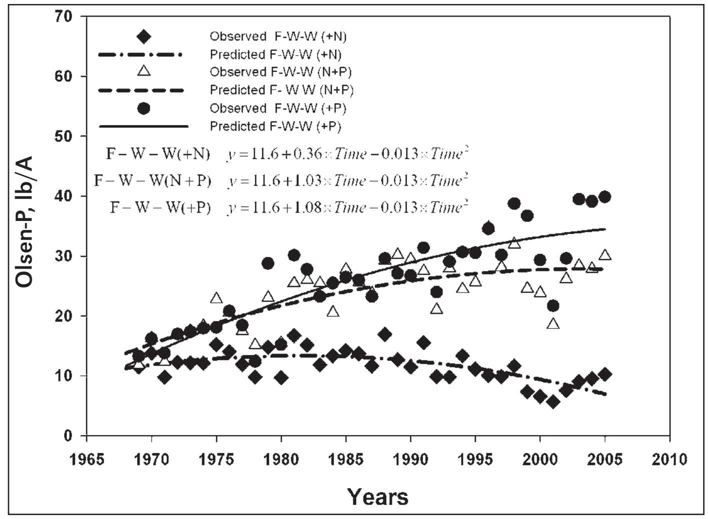

Figure 1. Long-term effect (1968 to 2005) of fertility regimes on Olsen-P content of the soil (0 to 6 in.) under F-W-W rotation. Equations shown were obtained from a quadratic model fitted to all rotations, with rotations as an indicator variable.

was lower for wheat grown on stubble than when both N and P were applied (**Table 1**).

Since the change in the P fertilization protocol in 1994, wheat grown on fallow did not respond to P fertilizer (Rot 1 vs Rot 2, **Table 2**), but wheat grown on stubble did in most cases (Rot 1, Rot 8 and Rot 12, **Table 2**). This suggests that after P was built up in the soils, mineralization and/or solubilization during the fallow period released adequate available P amounts to satisfy the crop needs. Further, because in stubble cropping N is more limiting than P after 27 years of buildup of available P in soil, withholding P in F-W-(W)(N+P) did not influence yield. However, withholding P in F-W-(W)(+P) reduced yield, suggesting that extended cropping without N fertilization in this last system has reduced the ability of the crop to use the built up P stores, possibly due to reduced root growth. Phosphorus uptake by the plant is proportional to the concentration of P in the soil and the volume of soil explored by roots.

Table 2. Effect[1] of N and P and withholding of N or P after 27 years on grain yield, P concentration, and P uptake of wheat grown on fallow or stubble from 1994-2005. (Values are for rotation phases in parentheses).

	Fallow crop [F-(W)-W]										
Grain	Rot 1		Rot 2		Rot 5						LSD[3](p<0.05)
characteristic[1]	(+P)	(no N or P)	(N+P)	(+N)	(+N)	(no N or P)					treat**
Yield, bu/A	45.5	44.0	46.1	45.9	36.6	37.5					2.4
P conc., %	0.40	0.38	0.39	0.37	0.32	0.34					0.01
P uptake, lb/A	10.8	10.0	10.6	10.0	6.9	7.6					0.7
	Stubble Crop										
	F-W-(W)						Cont W				
	Rot 1		Rot 2		Rot 5		Rot 8		Rot 12		
	(+P)	(no N or P)	(N+P)	(+N)	(+N)	(no N or P)	(N+P)	(+N)	(+P)	(no N or P)	
Yield, bu/A	21.9	19.2	33.0	34.1	30.9	23.4	36.5	32.9	24.9	22.4	2.6
P conc., %	0.46	0.47	0.43	0.41	0.36	0.42	0.43	0.41	0.47	0.47	0.01
P uptake, lb/A	5.8	5.2	8.1	8.1	6.1	5.7	9.0	7.8	6.9	6.8	0.7

[1] Values are averaged over years. The year × treatment interactions were significant (p<0.01) but are not shown to simplify interpretation.

[2] Grain yields and P uptake were converted from g/m^2 to kg/ha by multiplying by 10, and to lb/A by multiplying by 0.89.

[3] The treatment and year LSDs were all significant (p<0.01) in the full split plot analysis, but we show only the treatment means here for simplicity of interpretation.

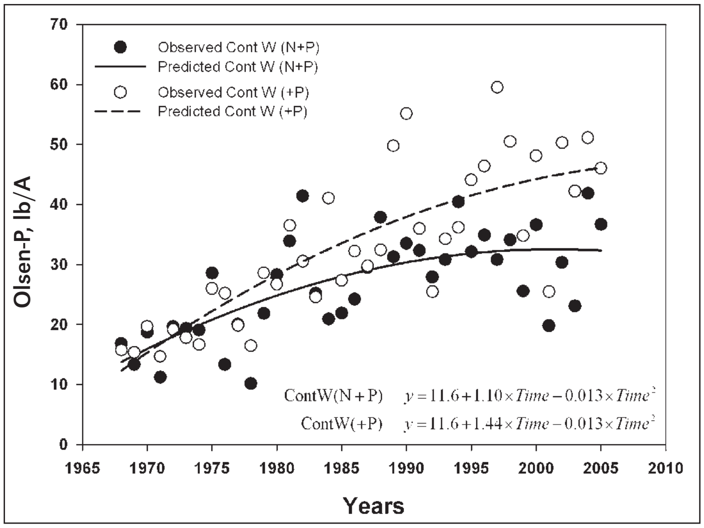

Figure 2. Long-term effect (1968 to 2005) of fertility regimes on Olsen-P content of the soil (0 to 6 in.) under Cont W rotation. Equations shown were obtained from a quadratic model fitted to all rotations, with rotations as an indicator variable.

The 27 years of withholding P from the F-W-W(+N) system did not influence Olsen-P (**Figure 1**), and reduced yields only slightly (**Table 1**). However, withholding N thereafter (**Table 2**), though reducing substantially the yields of wheat grown on stubble, did not influence yield of wheat grown on fallow mainly because sufficient N was mineralized during the fallow period.

Olsen-P in F-W-W(N+P) remained generally constant between 1994 and 2005. The relationship between Olsen-P in the 0 to 6 in. depth (y), in lb/A, and *Time* (years) for this system was : $y = 27.3 - 2.41 \times Time + 0.20 \times Time^2$. Withholding P from this system during this period decreased Olsen-P before leveling at about 15 lb/A 8 years after suspending fertilization. The relationship between y and *Time* in this case was: $y = 27.3 - 3.23 \times Time + 0.20 \times Time^2$. There was a concomitant negative P balance (-67 lb P/A) and Olsen-P decreased at an average annual rate of 0.61 lb/A. The P balance during 1994 to 2005 for Cont W (N+P) was zero (**Table 1**) and the calculated rate of change in Olsen-P was also zero (data not shown). Withholding P from this treatment resulted in a sharp initial decrease in Olsen-P that leveled off at 15 lb/A (data not shown).

The rates of change in Olsen-P in the surface 6 in. of soil over the study period was greater for Cont W (N+P) than for F-W-W (N+P) (0.57 vs 0.41 lb/A/yr), and greater for Cont W (+P) than for F-W-W (+P) (0.92 vs 0.55 lb/A/yr), because of the greater amount of P applied to Cont W. Further, the rates of increase in Olsen-P over the study period were higher when only P was applied compared to when N+P were applied because with the better nutrient supply (N + P) increased P uptake, thereby reducing residual P in soil. The rates of Olsen-P increase were greater in the 1967-1993 period when conditions were drier, because of lower P uptake than in the wetter 1994-2005 period (e.g., F-W-W(N+P) = 0.57 vs 0.06 and Cont W(N+P) = 0.73 vs 0.22 lb/A per year). The results obtained with the P balance calculation agreed with those calculated from the rates of Olsen-P change over time (**Table 1**). Changes in Olsen-P in the soil in this long-term study were directly proportional to the P balances of the different treatments; thus Olsen-P change = 9.6 + 0.17 x P balance, R^2=0.7 indicating that a change in P balance of 6 lb P/A produces a change of 1 lb P/A in Olsen-P.

In conclusion, fallow-grown wheat yield was increased by P fertilization under the original fertilization protocol, especially in the wetter than average 1994-2005 period, while there was no response to N on fallow. For stubble-grown wheat, the converse was true – it responded to N but not to P. After a build-up in available soil P, and the change in fertilization protocol in 1994, fallow grown wheat did not respond to the withholding of P. However, both N and P were required to optimize yields of stubble grown wheat. Soil P change was related to the balance between fertilizer input and P removal in grain. BC

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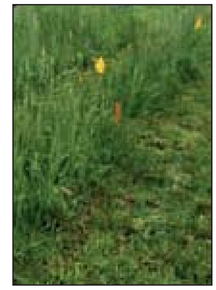
Building Soil Phosphorus and Potassium in a Low-Testing Fescue Field



By Gene Stevens, David Dunn, and Steve Hefner

The objective of this long-term study is to evaluate the effects of P and K build-up periods on tall fescue hay yield and to validate the build-up equations used in the University of Missouri (MU) fertilizer recommendation program.

The MU soil test laboratory recommendations for P and K fertilizer are based on three components: target level, crop removal, and build-up. Target level is the amount of extractable nutrient found in a soil at which point applying more fertilizer containing the nutrient will probably not increase crop yields. Crop removal is how much the nutrient is reduced in the soil annually from harvested forage, grain, or fiber. Build-up is the additional fertilizer needed above crop removal to increase low- and medium-testing soil P and K to the target fertility levels for crop production.

Soil P and K build-up can be slow or fast depending on the economic situation of the farmer. Total fertilizer applied in slow and fast build-up programs is about the same amount, but the cost may be spread out over more years in slow build-up periods. The current soil test recommendation system used by MU allows growers to select the number of years over which to build-up soils. This decision has a large effect on the amount of fertilizer that a farmer will purchase and apply in a given year. If a grower does not select a build-up period, the soil test lab uses an 8-year default build-up time to calculate fertilizer recommendations.

Research has not been conducted to determine which build-up strategy is the most profitable to manage crop nutrients in fescue forage production. Long build-up programs help farmers manage their financial resources by spreading fertilizer costs over several years. However, growers need information concerning the magnitude of yield loss that may occur early in an 8-year build-up as compared to a shorter build-up (1 to 4 years).

A field experiment in a non-renovated fescue hay field was begun in 2004 and is currently mid-way through an 8-year evaluation. The study location is on a Tonti-Hogcreek complex (Typic Fragiudult) soil in the Ozark Highlands near Mountain View, Missouri. The experimental design is a randomized complete block with four replications. Initial soil test levels in the test area averaged 8 lb Bray-1 P/A and 162 lb ammonium acetate-extractable K/A. Cation exchange capacity was 6.5 meq/100g soil and organic matter content was 1.5%.

Table 1. Annual fertilizer application rates based on soil tests for soil P and K build-up programs beginning in 2004 (Year 1) in an Ozark Highland hay field.

	Year 1		Years 2, 3, 4		Years 5, 6, 7, 8	
Build-up program	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
	lb/A					
Untreated check	0	0	0	0	0	0
N only	0	0	0	0	0	0
1-year build	404	156	18[1]	68[1]	18[1]	68[1]
4-year build	115	90	115	90	18[1]	68[1]
8-year build	66	79	66	79	66	79

[1] Only crop removal P and K applied.

Each spring before fertilizer applications are made, 0 to 6-in. composite soil samples are collected from each plot and analyzed for Bray-1 P and ammonium acetate-extractable K at the MU- Delta Center Soil Laboratory at Portageville, Missouri. Hay yield from each plot is determined by harvesting forage (typically two or three cuttings per year) using a lawnmower with a bagging attachment. Forage subsamples are collected from each plot and oven dried to calculate moisture content and analyzed for N, P, and K content, crude protein, and acid and neutral detergent fiber (ADF and NDF, respectiviely).

Fertilizer treatments used in the experiment were an untreated check, a N only check, and 1-year, 4-year, and 8-year P and K build-up programs (**Table 1**). The treatments were designed so that at the end of 8 years, the total amount of fertilizer applied to each plot would be close to equal. Triple superphosphate (0-46-0) and muriate of potash (0-0-60) were used as P and K sources. Each plot except the untreated check was fertilized with 80 lb N/A as ammonium nitrate and ammonium sulfate each year (50 lb N and 9 lb S/A in late March, 30 lb N/A in early September).

Shown below are the equations used at MU to calculate the P and K build-up component of soil test recommendations.

$$\text{Build-up } P_2O_5 = \frac{110\,(X_d^{1/2} - X_o^{1/2})}{\text{Years}} \qquad \text{Build-up } K_2O = \frac{75.5\,(X_d^{1/2} - X_o^{1/2})}{\text{Years}}$$

X_d = target soil test level in lb P or K per acre
X_o = observed soil test level in lb P or K per acre
Years = desired time period for build-up

The MU Bray-1 P target for fescue is 40 lb P per acre. Target ammonium acetate-extractable lb K/A is 160 + (5 x CEC). The soil CEC of the test field was 6.5 so the calculated K target was 193 lb K/A. When farmers submit soil samples to Missouri labs for testing, they are asked to provide a crop yield goal to be used to calculate additional fertilizer needed to compensate for crop removal. For the test field at Mountain View, the farmer selected a 2 t/A yield goal. Current MU recommendations estimate fescue hay nutrient removal at 9 lb P_2O_5 /ton and 34 lb K_2O /ton. Thus, the 2 t/A yield goal used for this study resulted in the crop removal fertilizer component in the build-up treatments being 18 lb P_2O_5/year and 68 lb K_2O /year (**Table 1**).

After 3 years, fertilizer treatments increased soil test P levels in plots compared to the untreated and N only checks, with soil test levels for plots with 1-year build-up being above the target 40 lb Bray-1 P/A (**Table 2**). The 4 and 8-year build-up

Abbreviations and notes for this article: P = phosphorus; K = potassium; N = nitrogen; S = sulfur; t = tons (2,000 lb); CEC = cation exchange capacity.

P treatments were below the target levels; however, they are on track to be above the target level by the end of their respective build-up periods. Soil K levels for all treatments, including the one year build-up program, were below the original 162 lb K/A levels measured in 2004 (**Table 2**).

Tissue P and K contents in first cutting hay from 2004 through 2006 are shown in **Table 3**. Converting % K into pounds K_2O per ton, the average observed K removal across treatments and years was 54 lb K_2O/t compared to the MU removal estimate of 34 lb K_2O/t. This difference was a contributing factor to the failure of the one year build-up program to raise soil test K values above the target level. The highest K removal occurred in the first year (2004) with the 1-year build-up program (75 lb K_2O/t).

Table 2. Soil test P and K levels after 3 years of P and K build-up treatments. Samples were collected in March 2007 before spring fertilizer treatments were applied.

Build-up program[1]	Soil test levels after 3 years P	K
	- - - - - - - - lb/A - - - - - - - -	
Check	13	108
N only	14	97
1 yr build-up	50	149
4 yr build-up	35	110
8 yr build-up	26	108

[1] Targets are 40 lb Bray-1 P/A and 193 lb ammonium acetate-extractable K/A.

Table 3. Annual dry matter hay yields and P and K content in first cutting hay in 2004, 2005, and 2006.

Build-up program	2004 Hay	P	K	2005 Hay	P	K	2006 Hay	P	K
	t/A	—%—		t/A	—%—		t/A	—%—	
Check	1.5	0.08	2.0	0.9	0.08	2.2	0.7	0.05	1.8
N only	2.1	0.13	2.4	1.3	0.07	1.6	1.0	0.09	1.9
1-year	3.0	0.31	3.1	2.0	0.18	2.2	1.6	0.18	2.2
4-year	2.8	0.25	2.7	2.0	0.16	2.2	1.6	0.18	2.0
8-year	2.6	0.19	2.7	1.9	0.15	2.3	1.5	0.15	2.3
$LSD_{.05}$	0.4	0.07	0.8	0.3	0.05	0.5	0.2	0.05	n.s.

N.S.= not significant at the 0.05 probability level.

Table 4. Cumulative effect of build-up programs (2004+2005+2006) on total fertilizer cost and fescue hay yield.

Build-up program	Cumulative for 3 years N	P_2O_5	K_2O	Cost[1]	Hay yield	Mean across years[2] CP	ADF	NDF
		- - - - lb/A - - - -		$/A	t/A			
Check	0	0	0	0	3.1	9.0	34.5	63.6
N only	240	0	0	89	4.4	11.6	33.2	62.5
1-year build	240	441	291	282	6.6	10.8	35.3	64.2
4-year build	240	351	270	251	6.4	10.8	34.9	64.0
8-year build	240	195	237	197	6.1	12.8	35.2	63.9
$LSD_{.05}$					0.4	2.3	1.1	1.2

[1] Costs are based on $0.37/lb N, $0.30/lb P_2O_5, $0.21/lb K_2O.
[2] Mean hay analyses values from subsamples collected at first cutting each year.
CP=crude protein, ADF= acid detergent fiber, NDF= neutral detergent fiber.

Converting % P in hay to pounds P_2O_5/t shows that the MU removal value for P (9 lb P_2O_5/t) is close to the observed average across three years in this study (7 lb P_2O_5/t). The highest P removal also occurred in the first year (2004) with the 1-year build-up program (14 lb P_2O_5/t). These results suggest that luxury plant consumption of P and K may occur when large amounts of fertilizer are applied at one time to correct low soil test levels.

Crude protein in the harvested forage was significantly lower in untreated check plots compared with the average crude protein in fertilized treatments (**Table 4**). Crude protein in hay from N only plots was not different from plots receiving P and K; however, hay from N only plots contained lower ADF and NDF than hay from plots receiving P and K fertilizer. This result suggests that farmers with high fertility fescue fields should cut hay earlier and more often to maximize quality.

Rainfall at the test site was unusually low in July and August of 2005 and 2006. In 2006, N fertilizer alone increased fescue dry matter yields 33% compared to the untreated check (**Table 3**). Applying P and K fertilizer with N increased hay yields an additional 35%, suggesting that P and K fertilizer helped produce fescue plants with healthy root systems that withstood drought better than plants in low fertility plots. In good rainfall years, local hay prices are usually around $30/t. However during drought years, hay has to be shipped in from other regions of the country and hay price can reach more than $100/t. Thus, even in dry years, P and K fertilization for fescue hay production on low-testing soils may be economically favorable.

We concluded that a 4-year soil P and K build-up program can be used by farmers without sacrificing hay yields in the first 3 years. No significant fescue hay yield increase was observed when using a 1-year build-up program compared to the 4-year build-up program (**Table 3**). However, in 2004, hay yield was significantly higher with 1-year build-up P and K applications than the 8-year build-up program. Cumulative costs of fertilizer build-up programs for the first 3 years are shown in **Table 4**.

The most expensive program for the first 3 years was the 1-year build-up program. However, most of this cost occurred in 2004 and for the rest of the study, the only fertilizer that will be applied according to the 1-year build-up program will be to off-set crop removal. By the end of the study, the total P and K fertilizer costs, not including interest, should be about the same for 1, 4, and 8-year programs. However, a farmer could have part of the large up-front money used to purchase fertilizer in the 1-year program earning interest in the bank or invested in some other enterprise on the farm. BC

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Post-Seeding Nitrogen on Spring Wheat and Canola — A Balancing Act

By Guy Lafond, Stewart Brandt, William May, and Chris Holzapfel

The positive results obtained from this study would support the recommendation that N fertilizer can be managed more precisely with post-emergent N applications provided that 50% is applied as starter N.

Nitrogen is the most limiting nutrient in crop production on the northern Great Plains. Nitrogen recovery efficiency has been estimated at 47% in the year of application, and 65.5% over the period of five growing seasons (Krupnik et al., 2004). The changes in fertilizer N prices with natural gas price fluctuations have made it a major component for a farmer's crop budget. These economic conditions are stimulating many agronomic questions related to the management practices necessary to achieve higher N use efficiency.

It is well recognized that the highest efficiencies for N fertilizer are obtained when N fertilizers are applied as close as possible to the start of maximum N uptake by the crop, thus reducing the opportunity for losses through leaching, denitrification and immobilization (Mahli et al., 2001). A number of studies were conducted in the last few years to examine more closely the merits of post-emergent N applications using UAN solutions and surface dribble applications as a way to apply N closer to the time of crop needs (Lafond et al., 2004; Holzapfel et al., 2007). The studies showed that this approach was feasible, but was not without risk and was never better than putting all the N fertilizer on at the time of seeding. The studies found that the unpredictability of rainfall increases the risks of surface dribble bands because some rainfall is required to move the fertilizer into the soil. The conclusion was that some N would need to be applied at seeding and the proportion would more than likely be greater than 33% of the recommended N needs.

The objective of this study was to quantify more accurately the risks associated with post-emergent N and to determine how these risks can be reduced. The study examined what proportion of the desired N rate should be applied at seeding, with the balance applied in-crop as liquid UAN in a surface dribble band for three early growth stages in both spring wheat and canola.

Studies were conducted at Indian Head and Scott, Saskatchewan, using no-till management systems. At the Indian Head site, the urea N applied at seeding was mid-row banded between every second row while at Scott the urea N was side-banded to the side and below the seed. Spring wheat and canola were grown over 3 years (2004-06), with the 2006 crop lost due to an August frost at Scott. The treatments involved a no N check, 100% of N as urea in-soil banded at seeding, 67% as urea at seeding, and the remaining 33% as UAN dribble banded at the sixth leaf, start of stem extension, and 5% flowering growth stages for canola, and 1 to 1.5 leaf, 3 to 3.5 leaf and 5 to 5.5 leaf stages for spring wheat. The urea N applied at seeding was lowered to 50% and 33% of the total, with the remaining N, 50% and 67%, respectively, applied as UAN at the above three growth stages. The rates of fertilizer N applied varied each year of this study, depending on the soil residual nitrate-N and the target yield of the wheat and canola crops (**Table 1**). Grain yield for canola and spring wheat are reported here using the mean for the 5 site-years of data.

Studies with canola and spring wheat indicate that N fertilizer can be managed more precisely when some N is applied as starter and some as post-emergent in semiarid regions.

The effects of wheel tracks on canola grain yield were important when the post-emergent N applications were applied at the start of bolting and start of flowering. In **Table 2**, the values in the row for 100% of fertilizer N at seeding indicate a treatment that received all N as an in-soil band at seeding, but was then driven through at the crop leaf stage shown as a means of quantifying the impact of the tractor on the crop. The effect was not significant at the 5 to 6 leaf stage, although there was a tendency for the grain yields to be lower than the at seeding treatment with no wheel tracks. The analysis of variance conducted has taken the effects of wheel tracks into consideration (data not shown).

Table 1. Soil residual nitrate-N and fertilizer N applied to wheat and canola.

		2004		2005		2006	
Location		Soil N[1]	Fert N	Soil N	Fert N	Soil N	Fert N
		lb/A					
Indian Head	Wheat	57	45	23	83	19	76
	Canola	56	67	39	111	20	95
Scott	Wheat	60	72	49	67	–	–
	Canola	73	67	36	67	–	–

[1] Soil N was nitrate-N determined by modified Kelowna extraction method on a 0 to 24 in. sample.

Abbreviations and notes for this article: N = nitrogen; UAN = urea-ammonium nitrate.

Table 2. Canola response to different proportions of fertilizer N (%) applied at seeding on grain yield (kg/ha).

Fertilizer N at seeding, %	Check, no N	Crop leaf stage			
		At seeding	5-6 leaf	Start of bolting	5% flowering
–	1,747	–	–	–	–
100	–	2,552	2,393a[1]	2,344a[1]	2,210a[1]
67	–	–	2,338a	2,181a	2,013b
50	–	–	2,242a	2,182a	2,009b
33	–	–	2,156b	2,147a	1,981b
0	–	–	2,196b	1,925a	1,789b

[1] Means within a column followed by the same letter are not significantly different ($LSD_{0.05}$) from the mean where all the fertilizer was applied at seeding for each crop stage in that same column This is to take into consideration the negative effects of wheel tracks on grain yield.

Table 3. Spring wheat response to different proportions of fertilizer N (%) applied at seeding on grain yield (kg/ha).

Fertilizer N at seeding, %	Check, no N	Crop leaf stage			
		At seeding	1 to 1.5 leaf	3 to 3.5 leaf	5 to 5.5 leaf
–	2,194c	–	–	–	–
100	–	2,775a[1]	–	–	–
67	–	–	2,726a	2,749a	2,717a
50	–	–	2,666a	2,692a	2,687a
33	–	–	2,661a	2,687a	2,692a
0	–	–	2,530b	2,646a	2,538b

[1]Means followed by the same letter are not significantly different at 5% level from the mean where all fertilizer N was applied at time of seeding. The overall $LSD_{0.05}$ value for the experiment is 167. Note that the check yield was lower than all the other treatments.

There was a positive response to the N fertilizer applied on the canola crop (**Table 2**). At the 5 to 6 leaf stage, putting 50 or 67% of the target N rate at the time of seeding and the balance as a surface dribble did not result in lower grain yields compared with applying all of the fertilizer N at the time of seeding. There was also no difference recorded when the N was applied at the start of bolting although the trend was for lower yields as the proportion of N applied at seeding was reduced. At the start of flowering, a reduction in yield was observed when less than 100% of the targeted N rate was applied at seeding, indicating that delaying any application until flowering reduced yields.

Based on the results, it would appear that as long as at least 50% of the targeted N rate is applied at time of seeding, and the balance post-emergent by the bolting stage, grain yields of canola can be maintained. This not only provides important information for when to apply N in crop, but can be combined with recent developments for using in-crop optical sensors to assess the N status of crops and apply additional N fertilizer where required in the same field operation (i.e. Greenseeker Technology, NTech Industries Inc.).

Spring wheat showed a positive response to N application in this study, with little negative impact recorded when some of the total N was applied at seeding (**Table 3**). Only at the 1 to 1.5 leaf and 5 to 5.5 leaf stages of post-emergence application was a difference recorded, and that was when the entire quantity of N was applied after seeding. It is important to note that none of the treatment yields exceeded that of the treatment where the entire quantity of N was applied at seeding. However, it is an important finding that these wheat crops could have some portion of their N post-emergence applied, as long as some was applied at seeding. This provides the farmer in a semi-arid region the option of delaying N application for a period of time in the spring to assess soil water status and potential for crop yield formation. Varying the timings and application method did not affect wheat grain protein in this study (data not shown).

Based on the results of this study, some starter N needs to be applied at the time of seeding in order to protect yield potential and minimize the risks associated with post-emergent N applications for spring wheat and canola. The best proportion of starter N applied at the time of seeding may be dictated by the agro-ecological zone in question. In the drier zones, more starter N fertilizer may be required in comparison with the wetter zones, less may be required. In our studies, at least 50% should be applied at time of seeding to reduce the risks of post-emergent N applications. For individuals with low tolerance to risk, they may want to consider 66% of their target N at seeding. The positive results obtained from this study indicate that using optical sensors to predict yield potential and supplementing the crop with N to achieve this potential is feasible for Canadian prairie conditions because the risk of post-emergent N applications can greatly be reduced if at least 50% of the N is applied during the seeding operation. BC

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Partial Factor Productivity of Nitrogen in Potato

By V.K. Dua, P.M. Govindakrishnan, S.S. Lal, and S.M. Paul Khurana

Partial factor productivity (PFP) and agronomic efficiency (AE) of N in potato were estimated from published literature in India over the years 1968 to 2000. Results revealed that PFP had an increasing trend during this time, which can be attributed to balanced and efficient use of fertilizers in potato in contrast to other crops and the N-efficient cultivars developed over the years.

Potato has emerged as one of the most important food crops in India. There has been almost a five-fold increase in area and a nearly 16-fold increase in potato production since the independence of India. The increase in production is not only due to an increase in area, but also due to productivity, which has improved from 66 quintals/ha (1 quintal = 100 kg) during 1949-50 to 198 q/ha during 2001-02. This increase has been brought about by both higher levels of inputs and more efficient, high yielding cultivars. However, as input use to grow potato increases, there is generally a decline in its use efficiency. Unless this is countered through better genotypes and best nutrient management, there are likely to be problems of pollution as well as reduced returns for the investment. Thus, there is a need to periodically review the efficiencies of input use in different crops.

Nitrogen is the key nutrient in potato production. A low utilization efficiency with N means the nutrient is prone to leaching, volatilization, etc. To determine the efficiency of applied nutrients, Cassman et al. (1996) introduced the term PFP. The advantage of this index is that it quantifies total economic output from any particular factor/nutrient, relative to its utilization from all resources in the system, including indigenous soil nutrients and nutrients from applied inputs. Thus, the changes in PFP for N over the years can be used to indicate the sustainability of the potato production system.

The data on potato yield under different N levels were obtained from 107 published papers with experiments conducted between 1968 and 2000. Since different research workers have used different N doses, these were classified into six ranges: 20 to 60 kg, 61 to 100 kg, 101 to 140 kg, 141 to 180 kg, 181 to 220 kg, and >220 kg N/ha, besides the zero N (control). Partial factor productivity and agronomic efficiency were calculated as below:

PFP = Yf/Na - expressed in kg yield per kg of N applied

AE = (Yf-Yc)/Na - expressed in kg yield per kg N applied.

Where 'Yf' stands for yield from a N-fertilized plot, 'Yc' stands for yield in control plot, and 'Na' stands for amount of N applied in kg/ha. The PFP was also calculated separately for the last three decades (1971-80, 1981-90, and 1991-2000) and for different cultivars as well.

The overall mean tuber yield showed an increase with an increasing N level up to 220 kg N/ha during 1968-2000 (**Table 1**). Beyond 220 kg N/ha, no increase in the potato tuber yield was observed up to 1980. As for the temporal yield response, during the 1970s the response of potato to applied N was restricted up to 180 kg N/ha (**Table 1**), while during the 1980s the response was up to 220 kg N/ha, and in the 1990s the response to N exceeded 220 kg/ha.

The analysis revealed that as the applied dose of N increased, there was a decrease in PFP (**Table 1**). The overall PFP for the entire period (i.e.1968-2000) was 421 kg tubers/kg N when applied in the range of 20 to 60 kg N/ha, which declined to 130 kg tubers/kg N when applied at doses exceeding 220 kg N/ha. A similar trend was observed during the different decades. This trend reflects the law of diminishing returns – as applied N increases, the response to N decreases. This is also confirmed by AE calculations, which is the response per unit N applied (**Table 2**). The AE shows that the conversion of applied N to yield was higher at lower level of N application (20 to 60 kg/ha).

Perusal of the absolute values for PFP showed it to be higher during the 1990s compared to the 1970s and 1980s at all the levels of N application except at the lowest category (20 to 60 kg N/ha) (**Table 1**). The yield levels also showed an increase with time at any given N level implying that the crop required lesser N during the 1980s and still lesser during the 1990s to maintain the same level of yield as that in the 1970s. This is due to the introduction of high yielding and more N use efficient cultivars like Kufri Badshah and Kufri Bahar during the 1980s and Kufri Anand, Kufri Ashoka and Kufri Sutlej during

Table 1. Potato tuber yield (q/ha) and partial factor productivity (PFP) of N (kg tubers/kg N applied) in potato in India.

		Range of N levels, kg/ha					
Period	Mean	20-60	61-100	101-140	141-180	181-220	>220
1971-1980	PFP	428	277	211	158	134	111
	Tuber yield	221	226	254	265	268	270
	No. of studies	21	19	25	22	1	4
1981-1990	PFP	399	253	206	177	154	114
	Tuber yield	220	237	248	286	308	283
	No. of studies	61	43	38	62	16	20
1991-2000	PFP	409	329	235	188	155	148
	Tuber yield	220	280	294	307	318	350
	No. of studies	19	23	18	31	3	19
1968-2000	PFP	421	282	220	178	156	130
	Tuber yield	229	250	268	291	313	314
	No. of studies	109	88	86	120	21	44

Abbreviations and notes for this article:
N = nitrogen

Table 2. Agronomic efficiency (kg tubers/kg N applied) of N in potato under different N levels.

Range of N levels, kg/ha		Agronomic efficiency
20-60	Mean	135
	No. of studies	78
61-100	Mean	102
	No. of studies	58
101-140	Mean	93
	No. of studies	52
141-180	Mean	75
	No. of studies	78
181-220	Mean	71
	No. of studies	15
>220	Mean	48
	No. of studies	29

the 1990s (Anonymous, 2001).

The varietal composition in the experiments conducted during the different decades showed that during the 1970s early maturing Kufri Chandramukhi and medium maturing Kufri Jyoti cultivars were tested in 67% of the experiments, while during the 1980s and 1990s, these two cultivars were tested in 62% and 42% of the experiments, respectively. These two cultivars had lower yield potential and PFP (**Table 3**) than the other major potato cultivars tested in the experiments which were of medium (Kufri Jawahar and Kufri Bahar) and late (Kufri Badshah and Kufri Sindhuri) maturity, and comparatively higher yield levels and PFP than Kufri Chandramukhi and Kufri Jyoti. The proportion of these high yielding and medium to late maturing potato cultivars in the experiments increased from 23% during the 1980s to 42% during the 1990s. Therefore, PFP has shown an increasing trend with time at similar N levels and is a reflection of the varietal behaviour.

Comparison of the PFP of different cultivars (**Table 3**) showed large differences. However, all the cultivars showed a decreasing trend with increasing N levels. As regards to differences among cultivars, Kufri Ashoka had the highest PFP (486.5) at 20 to 60 kg N/ha while Kufri Jyoti had the lowest PFP (392) at this level. Though the PFP decreased with increase in N level applied, the rate of decrease varied with cultivar.

Under Indian conditions, the economic optimum dose of N is usually in the range of 180 to 220 kg N/ha and at this dose Kufri Badshah had the highest PFP (202). Kufri Sindhuri, Kufri Jawahar, and Kufri Ashoka were also not far behind at this level, while Kufri Chandramukhi and Kufri Jyoti were far behind (142 and 140, respectively). Even at N levels >220 kg/ha, Kufri Badshah, Kufri Sindhuri, Kufri Jawahar, and Kufri Ashoka had higher PFP than Kufri Chandramukhi and Kufri Jyoti at 180 to 220 kg N/ha. Difference in response to N among cultivars has also been reported by Govindakrishnan et al. (1999). They found that Kufri Ashoka required only one-third of the N dose applied to Kufri Chandramukhi to attain the same yield level. Trehan (2004) has also reported that Kufri Jawahar, Kufri Pukhraj, Kufri Sindhuri, Kufri Bahar, and Kufri Sutlej are more N efficient than Kufri Jyoti. Thus, potato breeders have developed higher yielding cultivars over time so as to fully exploit the natural climatic resources, and in turn increasing the cultivar's N use efficiency. Hence, the widespread adoption of these cultivars by farmers would lead to greater N use efficiency.

This study revealed that high yielding potato cultivars released in India from time to time were more N use efficient than earlier varieties. Thus, the goal of realizing more and more of the potential yield would not adversely affect the efficiency of N use. The study also brings out the usefulness of the PFP concept in evaluating the implications of technological developments in any crop. BC

Table 3. Partial factor productivity of N (kg tubers/kg N applied) and yield (q/ha) of some popular potato cultivars.

		Range of N levels, kg/ha					
Cultivar	Mean	20-60	61-100	101-140	141-180	181-220	>220
K. Chandramukhi	PFP	414	261	207	165	142	112
	Tuber yield	217	233	252	268	284	276
	No. of studies	39	32	27	42	9	15
K. Jyoti	PFP	392	257	220	173	140	107
	Tuber yield	215	231	264	291	279	261
	No. of studies	26	15	22	24	4	5
K. Sindhuri	PFP	451	254	230	185	195	135
	Tuber yield	269	233	277	308	390	316
	No. of studies	10	11	12	11	2	4
K. Bahar	PFP	417	374	296	281	197	157
	Tuber yield	231	310	281	301	393	357
	No. of studies	8	7	5	12	1	4
K. Ashoka	PFP	487	303	248	202	199	166
	Tuber yield	212	275	319	329	398	393
	No. of studies	2	3	2	3	1	2
K. Badshah	PFP	444	387	229	207	202	152
	Tuber yield	267	314	275	336	404	356
	No. of studies	5	5	4	9	1	6
K. Jawahar	PFP	428	372	233	176	-	140
	Tuber yield	223	335	294	317	-	350
	No. of studies	3	1	3	3	-	3

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Nutrient Needs of Coconut-Based Fodder Production Systems in Homesteads of Kerala

By S. Lakshmi, Anju George, G. Raghavan Pillai, and T. Nagendra Rao

An experiment was conducted in Kerala to assess the nutrient requirements of a unique coconut-based fodder production system using soil testing and crop uptake as criteria. Fodder fertilization also produced a synergistic, yield improving effect within the main coconut crop indicating that appropriate fertilization of the forage intercrop benefited the entire cropping system.

Kerala State is located at the southernmost tip of the Indian sub-continent. The area enjoys a humid, tropical climate, and all arable lands are cultivated with either food or cash crops. As such, homestead farming remains popular because of the region's limited land resources. This system is unique to Kerala and is highly intensive and diverse with a variety of crops and animals immediately surrounding the home. The different enterprises are interdependent and complementary to each other. Rearing of dairy cattle is an important subsidiary occupation within every household. However, commonly small holding sizes do not easily permit farmers to adopt large scale fodder cultivation.

Fodder crops are cultivated on 7,000 ha which produces green fodder to meet only about 2% of the total dry fodder requirement of the state. At present, Kerala has 3.5 million head of cattle which require 6.0 M t of dry fodder per year, and only 4.0 M t is available. The important sources of dry matter available are crop wastes such as paddy straw, banana pseudostems and leaves, coconut leaves, pineapple waste, jack leaves, coca waste, road side grazing, weeds, and other materials which are very poor in nutrients. There is huge scarcity of green fodder in the summer season. Besides these sources, dairy farmers depend on highly priced concentrates for feeding cattle which offset their profit to a considerable extent. Hence, fodder cultivation will commonly find place in the existing homestead farming system. Coconut occupies a major area (0.75 M ha) in the state and the suitability of fodder crops as intercrops under coconut gardens is well established (Lakshmi et al., 1998; Pillai G.R. 1987). Thus fodder cultivation as an intercrop under coconut in homesteads is a viable alternative for the state to help fill its fodder deficit gap. This present investigation was designed to understand the nutrient requirement of a high yielding coconut-fodder cropping system and optimize its nutrient application.

Soil samples collected from the experimental area were analysed for their macro- and micronutrient status by studying nutrient sorption characteristics (Portch and Hunter, 2002). The site was a 25-year-old coconut plantation located at the Instructional Farm, College of Agriculture, Vellayani, Kerala. The coconut variety was West Coast Tall and the canopy of coconut filtered 50% of the incident solar energy to lower layers. The coconut stand was planted at a spacing of 7.5 m between palms. Excluding the 2 m area immediately around the base of palm, the remaining space was planted to guinea grass (*Panicum maximum*), a popular and nutritious, high yielding, palatable fodder crop which is tolerant to shade. The experiment was arranged in a randomised block design (RBD) with 16 treatments and three replications.

Abbreviations and notes for this article: M t = million metric tons; N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; B = boron; Zn = zinc; Mn = manganese.

Guinea fodder performance with variable nutrient doses.

Treatment levels for applied nutrients and their combinations were selected considering the most limiting nutrients, annual nutrient removal by crops, actual soil requirement, nutrient use efficiency, nutrient losses from the soil, and yield goals. Nutrients included N, P, K, Mg, and B (plus common doses of Zn and Mn) applied to both crops within the same plot. Variable nutrient doses were imposed to guinea grass while comparing official fertilizer doses to both crops and a zero fertilization control.

The coconut-guinea grass cropping system was studied for 3 years to assess the nutrient needs of the entire system. Since coconut is a perennial crop, actual responses to coconut fertilization are generally observed from the third year onwards. Hence the results from the third year are presented here for

Table 1. Effect of K and P on the yield of guinea grass and coconut.

Nutrient levels	Green fodder yield, t/ha	Nut yield of coconut, nuts/palm
K_2O levels, kg/ha		
100	78.2	86.5
150	76.0	80.8
200	88.4	107.2
Critical Difference (0.05)	3.4	2.4
P_2O_5 levels, kg/ha		
100	78.6	87.8
150	85.8	97.5
200	78.6	89.2
Critical Difference (0.05)	3.4	2.4

Table 2. Effect of selected treatments on the yield of fodder guinea and coconut.

	Treatments	Green fodder yield, t/ha	Nut yield of coconut, nuts/palm	Net returns, Rs./ha
1	200:150:200+Mg+B (C_1)	94.5	107.4	150,232
2	200:100:200+Mg+B (C_1)	85.7	103.1	111,180
3	200:150:150+Mg+B (C_1)	81.7	92.8	95,198
4	200:150:150+B (C_1)$_{(-Mg)}$	67.7	66.9	73,331
5	200:150:150+Mg (C_1)$_{(-B)}$	69.7	67.5	61,000
6	200:150:150+Mg+B (C_0)	65.9	50.5	26,634
7	State recommendation	62.1	47.0	64,323
8	No fertilization	20.1	18.5	20,581
	Critical Difference (0.05)	8.6	4.1	

C_1 = Application of nutrients as per state recommendation to coconut.
C_0 = No nutrient application to coconut.
State recommendations = Guinea: 200-50-50 kg N-P_2O_5-K_2O ha/year;
Coconut: 0.5-0.32-1.2 kg NPK palm/year (88-57-112 kg N-P_2O_5-K_2O/ha).
Mg and B were applied at 100 and 1 kg/ha.
Zn and Mn were applied uniformly to treatments 1 thru 6 at 7 and 10 kg/ha, respectively.

both crops. Cumulative yields of 18 harvests of each crop were analyzed during the study period.

Results revealed a positive yield response to the application of P and K in guinea grass while comparing the treatment averages at individual nutrient levels (**Table 1**). Application of 150 kg P_2O_5/ha and 200 kg K_2O/ha significantly increased fodder yield to 85.8 and 88.4 t/ha, respectively. The corresponding coconut yields of 98 and 107 nuts/palm/year corresponded to guinea grass yields indicative of a synergistic effect of fodder fertilization to the main coconut crop. Moreover application of Mg and B to guinea grass positively influenced both fodder and coconut yield (**Table 2**). In the absence of Mg there was 17 and 28% yield decline in forage and coconut yields respectively. Similarly, the forage and coconut yield decline in the absence of B was 15 and 27%, respectively.

Application of 200-150-200 kg N-P_2O_5-K_2O/ha plus 100 kg Mg/ha and 1 kg B/ha to guinea grass, along with a state recommended dose of 88-57-112 kg N-P_2O_5-K_2O/ha to coconut recorded the highest yields of 94.5 t/ha of green fodder and 107 nuts/palm/year. Profitability was also highest at Rs.150,232 (US$3,700) per annum under this treatment.

Guinea fodder as intercrop in coconut gardens.

Proper fertilization of guinea fodder contributes to coconut yields.

Guinea fodder as intercrop and coconut as main crop.

Conclusion

This study has also quantified the effect of improper fertilization in homestead farming. Results indicate that skipping fertilization altogether or opting to fertilize either the main crop or intercrop alone will drastically reduce yields in both crops as well as overall farmer profitability.

The feasibility of intercropping in coconut depends upon the judicious management of the intercrop to avoid excessive intercrop competition. Addressing the nutrient requirements of these intercropping systems is another key to creating compatibility intercropped systems. Application of required quantities of macro- and micronutrients at the appropriate time will enhance coconut-based fodder production systems. Results indicate a large benefit to dairy farmers who adopt such guinea grass production as an intercrop under coconut gardens. BC

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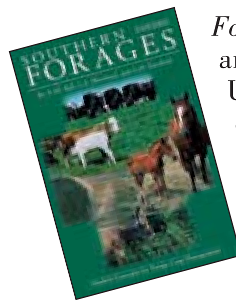
Posters Feature Forage Legumes and Grasses/ *Southern Forages* Book Now in Fourth Edition

Two educational 24 x 30-in. posters, *Forages Legumes* and *Forage Grasses*, are now available from IPNI. Each poster features color photographs of 30 species of important forage plants, along with descriptive text on seeding/establishment, fertility needs, pest considerations, and other practical tips.

The posters were prepared by the authors of the popular book, *Southern Forages*. They are Dr. Don Ball, Auburn University; Dr. Carl Hoveland, University of Georgia; and Dr. Garry Lacefield, University of Kentucky. The book was first published in 1991 and has become a standard among farmers, educators, horse owners, individuals managing wildlife plots, and many others.

"The new posters provide one more level of information accessibility for the many people interested in forage grasses and legumes. We have seen the popularity and usefulness of the *Southern Forages* book for many types of audiences and believe the posters will effectively enhance understanding of forage production and management," noted IPNI President Dr. Terry Roberts. Many of the species included on the posters are grown across large areas of North America and some in other countries.

The posters would be appropriate for display in classrooms, seed outlets and farm stores, Extension and soil/water conservation meeting rooms, farm offices, and various other settings. A single poster is available for purchase at US$3.00 plus shipping. The cost for a set including one of each poster is US$8.00 sent folded or US$9.00 rolled in a mailing tube.



The Fourth Edition of the book *Southern Forages* was published by IPNI in early 2007 and is now available for US$30.00 plus US$4.00 shipping and handling for a single copy. Discounts are available on larger quantities.

For more information and cost details, contact: Circulation Department, IPNI, 655 Engineering Drive, Suite 110, Norcross GA 30092-2837; phone 770-825-8082; fax 770-448-0439; e-mail: circulation@ipni.net; website: **www.ipni.net/sf**. BC

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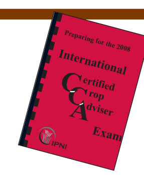


Individuals preparing for the 2008 International Certified Adviser (ICCA) exam will be interested to know that an updated edition of the popular study guide offered by the International Plant Nutrition Institute (IPNI) is now available. The 173-page training guide is organized and updated each year by Dr. John Gilmour, Professor Emeritus, University of Arkansas, and published by IPNI.

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

The 2008 edition of the ICCA exam study guide (Item # 50-1000) is available for purchase directly from IPNI. The price of US$45.00 includes shipping and handling. Contact: Circulation Department, IPNI, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone 770-825-8080, fax 770-448-0439, or e-mail: circulation@ipni.net.

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

Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* (and previous issues) can be found as PDF files at the IPNI website: >**www.ipni.net**<

Conversion Factors for U.S. System and Metric Units

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

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

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

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

Other Useful Conversion Factors

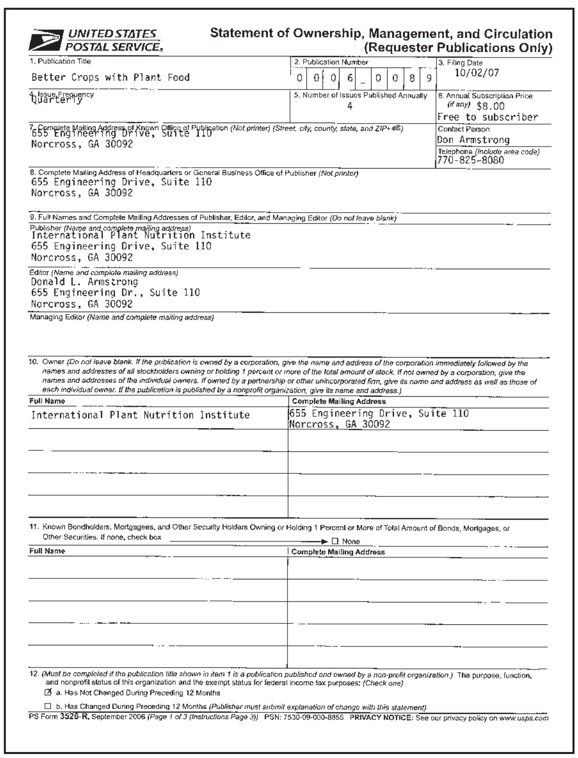
Phosphorus (P) x 2.29 = P_2O_5 — P_2O_5 x 0.437 = P

Potassium (K) x 1.2 = K_2O — K_2O x 0.830 = K

parts per million (ppm) x 2 = pounds per acre (lb/A)

Corn (maize) grain — bu/A x 0.062 = t/ha

Wheat or Soybeans — bu/A x 0.0674 = t/ha



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1. Publication Title: Better Crops with Plant Food
2. Publication Number: 0 0 0 6 _ 0 0 8 9
3. Filing Date: 10/02/07
4. Issue Frequency: Quarterly
5. Number of Issues Published Annually: 4
6. Annual Subscription Price (if any): $8.00 Free to subscriber
7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4®): 655 Engineering Drive, Suite 110, Norcross, GA 30092
Contact Person: Don Armstrong
Telephone (Include area code): 770-825-8080
8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not printer): 655 Engineering Drive, Suite 110, Norcross, GA 30092
9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor (Do not leave blank)
Publisher (Name and complete mailing address): International Plant Nutrition Institute, 655 Engineering Drive, Suite 110, Norcross, GA 30092
Editor (Name and complete mailing address): Donald L. Armstrong, 655 Engineering Dr., Suite 110, Norcross, GA 30092
Managing Editor (Name and complete mailing address)
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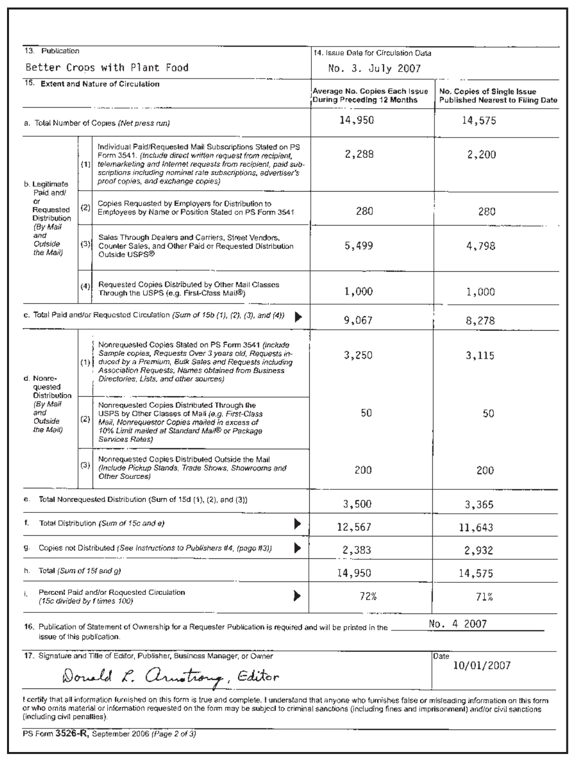

13. Publication: Better Crops with Plant Food
14. Issue Date for Circulation Data: No. 3. July 2007

15. Extent and Nature of Circulation	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies (Net press run)	14,950	14,575
b. Legitimate Paid and/or Requested Distribution (By Mail and Outside the Mail) (1) Individual Paid/Requested Mail Subscriptions Stated on PS Form 3541. (Include direct written request from recipient, telemarketing and Internet requests from recipient, paid subscriptions including nominal rate subscriptions, advertiser's proof copies, and exchange copies)	2,288	2,200
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g. Copies not Distributed (See Instructions to Publishers #4, (page #3))	2,383	2,932
h. Total (Sum of 15f and g)	14,950	14,575
i. Percent Paid and/or Requested Circulation (15c divided by f times 100)	72%	71%

16. Publication of Statement of Ownership for a Requester Publication is required and will be printed in the No. 4 2007 issue of this publication.
17. Signature and Title of Editor, Publisher, Business Manager, or Owner: Donald L. Armstrong, Editor — Date: 10/01/2007

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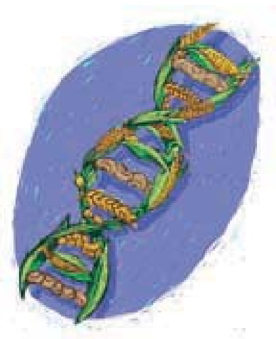

The science of human nutrition changes rapidly. Its complexity is growing, branching into emerging disciplines including nutritional genetics and nutrigenomics. These new fields of study link people's genetic make-up to their nutritional requirements. They could change your life!

Nutritionists have already begun providing different advice for different ages and stages. Young children need frequent small servings to get enough energy. Women of child-bearing age have particular needs for iron and folate. Men and women over 50 need more vitamin D. Much more remains to be learned about genetically-specific nutritional requirements. The science of nutrigenomics strives to identify those requirements by studying the genome.

There are two reasons why scientists in plant nutrition need to pay attention to nutrigenomics.

The first is its similarity in principle to plant nutrition. The "right food for the right person" is analogous to crop management practices supplying the "right nutrient at the right rate, time, and place." Best management practices ensure that each plant genotype gets the amount of nutrients to which it has potential to respond.

Second, the nutrition of plants influences the nutrients they contain and provide. Science has uncovered effects of potassium on soybean isoflavones, effects of phosphorus and potassium on tomato lycopene, and effects of nitrogen on carotenes and Vitamin A. Much more remains to be discovered, and continued research on plant genetics and genomics will have an influence as well.

As a generalization, good plant nutrition produces food with good nourishment. But producers in the future may be called on to do more, producing fruits, vegetables, grains, pulses, and oilseeds with very specific levels of particular health-functional compounds, or nutraceuticals.

Dr. Peter Jones, Director of the University of Manitoba's new Richardson Centre for Functional Foods and Nutraceuticals, states: "Nutrigenomics is the way of the future. It will define a person's genetic susceptibility to respond positively, or not, to a given nutraceutical."

Nutrigenomics is not going to eliminate the need to eat. Likewise, plant genomics is not going to eliminate the need to fertilize. Both are aiming to enhance the effectiveness and efficiency with which nutrients are used. Both are promising fields for future research. The needs for and rewards from these kinds of science will be tremendous.

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