

BETTER CROPS

WITH PLANT FOOD

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2011 Number 2

In This Issue...

Nitrogen Utilization by Cotton in the Western U.S.



Nutrient Management in Rainfed Inner Mongolia



Nitrogen Management for Winter Wheat in Russia



Also:

SSNM in Rice-Based Cropping Systems — India
...and much more

**How the Aims of Optimal Crop Production
And Low Greenhouse Gas Emissions
Are Remarkably Similar....see page 16**



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BETTER CROPS WITH PLANT FOOD

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Our cover: Best management practices, optimizing nitrogen use efficiency, offer many benefits. See article on pages 16-17.

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Dr. Robert E. Wagner, Retired President of PPI, Passes Away at Age 90

Dr. Robert E. “Bob” Wagner, who served as President of the Potash & Phosphate Institute (PPI) from 1975 to 1988, passed away March 31, 2011. PPI was the forerunner organization of the International Plant Nutrition Institute (IPNI).

“Dr. Wagner will be remembered as an energetic and forward-looking leader, one who understood the importance of agronomic research, the fertilizer industry, and production agriculture,” said Dr. Terry L. Roberts, IPNI President. “He practiced and believed in the power of positive thinking and he leaves a



Well known for his success in building agronomic understanding around the world, Dr. Wagner (right) is shown at an international conference in 1986 with Prof. Xie Jianchang of the Nanjing Institute of Soil Science.

great legacy in the many people whose lives he improved.” After retiring as President of the Institute at the end of 1988, Dr. Wagner and his wife, Bernice, lived at Stone Mountain, Georgia. He is also survived by their three

sons (Bob, Jr., Jim, and Doug) and their wives, and five grandchildren. Dr. Wagner remained active with many interests after retiring from PPI, including fulfillment of a lifelong dream in developing a top quality herd of purebred cattle on his farm south of Atlanta. A native of Garden City, Kansas, Dr. Wagner was born March 6, 1921. He received his B.S. degree in Agronomy at Kansas State University in 1942. He earned his M.S. at the University of Wisconsin in 1943 and worked as a Forage Crops Specialist in Kansas and as an Associate Agronomist with USDA before completing his Ph.D. at the University of Wisconsin in 1950. After becoming leader of a USDA pasture and range research project, Dr. Wagner was named chairman of the Department of Agronomy at the University of Maryland in 1956.



Dr. Wagner and wife Bernice were married for 63 years. They are shown here at Christmas in 2007.

In 1959, he joined the staff of the American Potash Institute (forerunner of PPI and IPNI) and became a vice president of the organization. From 1967 to 1975, he served as Director of the University of Maryland Cooperative Extension Service.

During his tenure as president of the Institute, there were many important

advances. When membership was extended to phosphate producers in 1977, the name of the organization became the Potash & Phosphate Institute. Dr. Wagner also served as president of the Foundation for Agronomic Research (FAR).

Among his many honors, Dr. Wagner was elected Fellow of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, and the American Association for the Advancement of Science. He was the author of numerous technical papers and popular publications and was a popular speaker and panel member at a tremendous number of events. He travelled extensively in various responsibilities during his career and is well-remembered around the world.

In 1985, Dr. Wagner was honored with the Distinguished Service in Agriculture Award, presented by Kansas State University. The award recognizes individuals who have made outstanding contributions in a professional field or public service related to agriculture.

Always working toward greater profitability for farmers, Dr. Wagner was a long-time proponent of the concepts of Maximum Yield Research (MYR) and Maximum Economic Yield (MEY). He also championed the ideas of more balanced nutrient



During an early visit to China, Dr. Wagner communicated with this group of young people.

application rates and the power of nutrient interactions. He encouraged researchers to try innovative approaches.

Dr. Wagner served as a member of the Board of Directors and as President of the American Forage and Grassland Council. He was a member of the steering committee for the Fertilizer Industry Advisory Committee of the Food and Agriculture Organization (FAO) of the United Nations.

From 1976 to 1997, Dr. Wagner served on the Board of Directors of IFDC (An International Center for Soil Fertility and Agricultural Development). He was a member of the Executive Committee and Program Committee. IFDC President and Chief Executive Officer Dr. Amit Roy spoke for many in expressing his sympathy to the family, noting that in addition to his long and illustrative career in agriculture, Dr. Wagner was active in his community, his church, and the interests of his children and grandchildren. **DC**



Dr. Robert E. Wagner

Nutrient Deficiencies and Toxicities – as Relevant as Ever for Crops

By W.M. (Mike) Stewart and William F. Bennett

This article briefly highlights some tips and resources that can help in recognizing and understanding nutrition problems in plants.

Crop nutrition issues are as old as farming itself. The application of plant and animal based residue to improve production appears to have started in the river basins of the Euphrates and Tigris in ancient Mesopotamia (now Iraq). Other independent developments may have occurred in the Orient and elsewhere. There have been many discoveries and contributions to the understanding of plant nutrition in the intervening centuries, and perhaps the most noteworthy of the contributors was the German scientist Justus von Liebig. He made remarkable strides in advancing the understanding of chemistry, plant nutrition and soil science and has been referred to as the father of the fertilizer industry. Liebig correctly believed that plants obtain mineral nutrition from the soil.

Today we take for granted what was once a significant discovery. Modern agronomists and other agriculturalists learn early on about the fundamentals of crop nutrition and fertilization. We learn, for example, that soils have limited reserves of nutrients held in the mineral and/or organic fraction. When these reserves are exhausted, nutrient deficiency will result and crop yield and quality will suffer. Furthermore, nutrient deficiency can be temporarily induced by environmental conditions where uptake is retarded. A classic example of this



Symptoms of P deficiency are shown on these corn plants.

is P deficiency in early season corn planted in cool moist soil conditions. Whatever the cause, nutrient deficiencies have specific visual symptoms, and recognition of the various symptoms is fundamental to effective crop scouting and agronomic practice. Knowledge of the function of plant nutrients is always helpful in determining fertilizer needs. It also will help to pinpoint the nutrient causing a deficiency symptom.

Nutrient deficiency symptoms were first noted and reported in the early 1900s. They became more widely used as a tool in diagnosing nutrient need in the 1940s and 1950s. The first standard and classic work describing and visualizing these symptoms was prepared by Howard Sprague in the book *Hunger Signs in Crops*, first published in 1941.

Nutrient deficiency symptoms can be a useful tool in de-

termining nutrient need. Other time-tested methods are soil tests, plant tissue tests (in both the field and the laboratory), and fertilizer strips for comparison. The main drawback to nutrient deficiency symptoms as a diagnostic tool is that once the symptom appears, yield levels may have already been reduced. But reacting to a symptom and applying needed nutrients may minimize yield reduction. Soil and tissue tests should be used before deficiency symptoms appear.

There are 16 nutrients that are essential for proper plant growth and function. Visual symptoms of nutrient deficiencies are distinguishable by specific features involving location, markings, color, and morphological and growth effects. The more mobile a nutrient is within the plant, the more likely it is that deficiency symptoms will occur on the lower leaves first, and vice versa. For example, K is highly mobile in plant tissue and is easily transported from one part of a plant to another. Therefore, symptoms will generally show first on older leaves as K is transported to younger tissue with the onset of deficiency.

There are exceptions to almost every rule though, and in some circumstances K deficiency can appear on younger leaves before older, as is the case with midseason K deficiency in cotton in some regions where very high K demand by developing bolls strips young leaves of K and disrupts the normal deficiency symptomology.

Nutrients such as Zn that are immobile in plant tissue will most always exhibit visual symptoms in younger tissue. **Figure 1** shows a general depiction of

termining nutrient need. Other time-tested methods are soil tests, plant tissue tests (in both the field and the laboratory), and fertilizer strips for comparison. The main drawback to nutrient deficiency symptoms as a diagnostic tool is that once the symptom appears, yield levels may have already been reduced. But reacting to a symptom and applying needed nutrients may minimize yield reduction. Soil and tissue tests should be used before deficiency symptoms appear.

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Late-season K deficiency in cotton can sometimes appear on younger leaves, as in this Arkansas plot.



Potassium deficiency typically shows first on older leaves, as on these corn plants.



Late-season K deficiency in cotton can sometimes appear on younger leaves, as in this Arkansas plot.



Zinc deficient rice, with symptoms on younger tissue.

the portion of the plant where specific symptoms are likely to first occur.

Visual deficiency symptoms are usually indicative of severe conditions and less acute shortages may not be so readily identified. The effects of other stresses such as drought

and pests can complicate diagnoses. It is worth noting too that some crops are more susceptible to specific deficiencies than others, and toxicities of some nutrients can occur as well. Therefore, it behooves those involved in crop production – from the field consultant to the university professor – to have access to an accurate and dependable reference on nutrient deficiency and toxicity symptoms. One such resource is published by the American Phytopathological Society. The book, entitled *Nutrient Deficiencies & Toxicities In Crop Plants*, is one of the timeless, dependable standards on the subject, and is recommended for the library of any agriculturist. Details on availability and purchase are shown below.

The International Plant Nutrition Institute (IPNI) also has a database of nutrient deficiency images that is under continual development. Visit the website at: <http://media.ipni.net>

The topic of nutrient deficiencies, toxicities, and balance is particularly appropriate in today's environment. As population increases and the world rumbles with the food crises, the role of agricultural producers and their advisers grow ever more important. Sound crop nutrition, and the skills and information

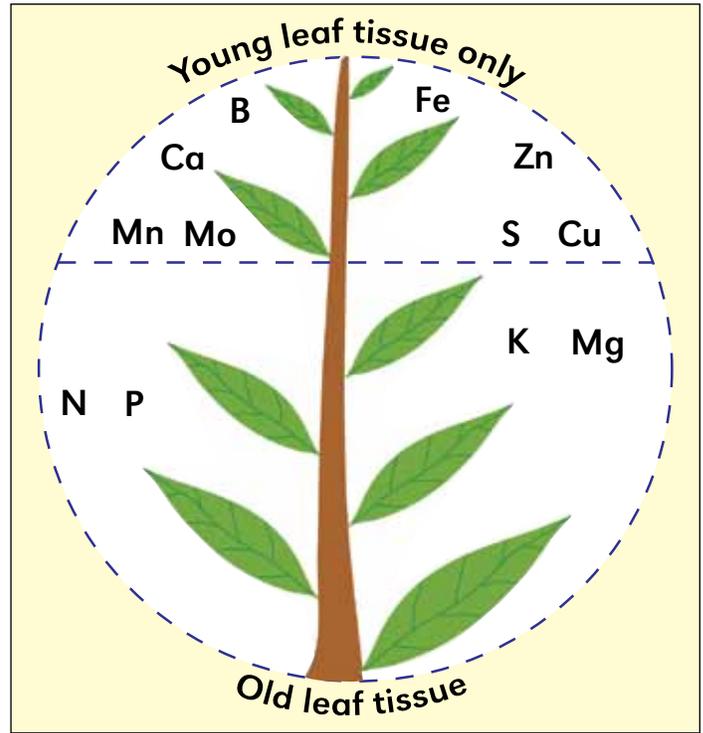


Figure 1. This generalized diagram indicates the portion of the plant where various nutrient deficiency symptoms are typically first observed. The more mobile a nutrient is within the plant, the more likely symptoms will appear on older leaves first.

necessary to implement it, is central to meeting the growing demands for agricultural goods. 

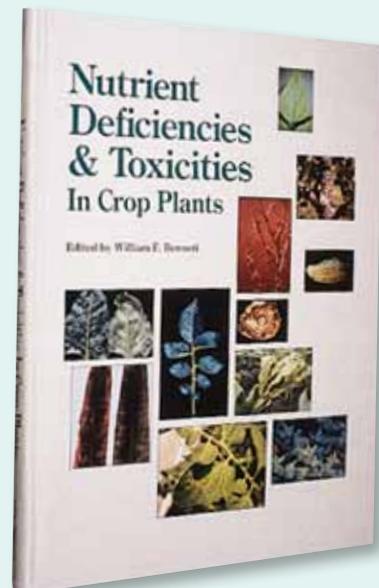
Dr. Stewart is Director, IPNI Southern and Central Great Plains Region, located at San Antonio, Texas; e-mail: mstewart@ipni.net. Dr. Bennett is a soil scientist, former Associate Dean of the College of Agriculture, and now Professor Emeritus at Texas Tech University, Lubbock.

Nutrient Deficiencies and Toxicities in Crop Plants **Book Now Available at Reduced Price**

A co-author of the accompanying article, Dr. William F. Bennett, Ph.D., is also the creator and editor of the publication titled *Nutrient Deficiencies & Toxicities In Crop Plants*. This book is one of the best-selling reference titles ever published by The American Phytopathological Society (APS).

For a limited time, readers of *Better Crops with Plant Food* are entitled to a discount of USD 30.00 (thirty dollars) off the normal price of the book, which covers more than 20 fruit and field crops with expert discussion and advice, and also includes over 300 diagnostic photos of nutrient problems.

Reduced price of USD 39.00 (thirty-nine dollars) is available until June 29, 2011. For the discounted price, visit the website: <http://www.apsnet/apsstore/shopapspress/Pages/41515.aspx>. Or call APS at 1.800.328.7560.



Sulfur Emerges as a Nutritional Issue in Iowa Alfalfa Production

By John Sawyer, Brian Lang, and Daniel Barker

Sulfur is often classified as a “secondary” essential element, mainly due to a smaller plant requirement, but also because it is less frequently applied as a fertilizer compared to N, P, and K. This has certainly been the case in Iowa, where research had not documented S deficiency or fertilization need for optimal crop production. However, if deficient, S can have a dramatic effect on plant growth and crop productivity – more than the classification “secondary” would imply.

In Iowa, over 40 years of field research (before 2005) conducted at many locations across the state had measured a yield response to S application only three times out of approximately 200 trials with corn and soybean – an indication of adequate available S supply and quite limited S deficiency. This began to change in the early 2000s as producers in northeast Iowa began to notice yellow plant foliage and reduced growth in areas of alfalfa fields. After investigating several potential reasons, such as plant disease, demonstration of S fertilizer application documented improved coloration and growth of alfalfa in affected areas (example in **Figure 1**).

Alfalfa Response to Sulfur Fertilization

The observations of poor alfalfa growth and production led to research trials at several northeast Iowa fields in 2005 where 40 lb S/A was applied as ammonium sulfate (AmS) and calcium sulfate (gypsum) in replicated plots and compared to a non-S treated control. The S fertilizers were applied after the first alfalfa cutting and before re-growth, and in paired locations in established alfalfa that had exhibited poor growth/coloration and alfalfa that appeared normal in growth and coloration. The alfalfa yields from those trials (**Table 1**) documented large increases from the S application in the poor growth areas and no increases in the good growth areas. This yield response was also measured in the first cutting of the second year.

Subsequent research was conducted with established alfalfa at multiple locations in northeast Iowa to study response to S rate (**Tables 2 and 3**). Four of six sites had a yield increase to S application, with the maximum dry matter increase occurring at 12 to 29 lb S/A. Most importantly, the S concentration in the plant tissue (6-in. plant top collected before cutting) indicated a critical concentration similar to that found in other research, 0.25% S. Combining data from all alfalfa research trials indicated a low to no increase in alfalfa dry matter when the tissue concentration (top 6-in. of growth) was greater than approximately 0.22 to 0.25% S (**Figure 2**). At the current price of alfalfa and S fertilizers, the economic breakeven point would be near 0.23% S. The same success (indicating S deficiency) was not found with the soil sulfate-S ($\text{SO}_4\text{-S}$) test of samples from the top 6-in. of soil (calcium phosphate extractant). Examples of this can be seen in **Tables 1, 2, and 3** where the responsiveness of a site was not related to soil $\text{SO}_4\text{-S}$ concentration.

This research documented S deficiency problems in northeast Iowa alfalfa production fields. The majority of S deficiencies tended to occur in areas within fields, not entire

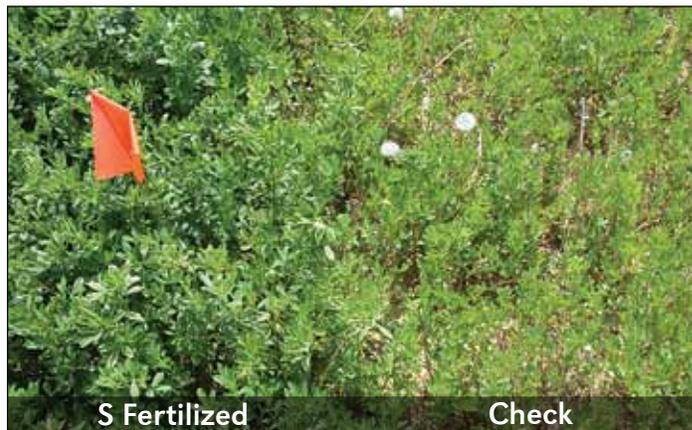


Figure 1. Alfalfa plant growth with and without S application, showing S deficiency symptoms of plant yellowing and poor growth in the non-S treated check.

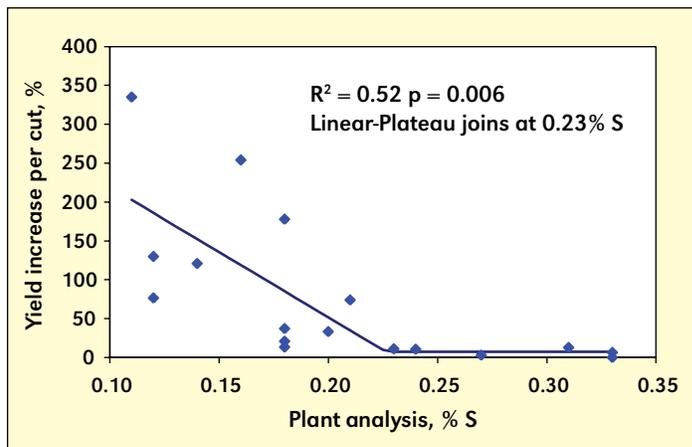


Figure 2. Yield increase per cut from S fertilization relative to the alfalfa plant tissue S concentration, 6-in. plant top with no S applied.

fields. However, that non-uniformity can account for large economic losses on a field scale. Most of the soils involved are lower organic matter, side-slope position, silt loam soils. However, alfalfa grown on other soils has also responded to S fertilization. Need for S application was not present in all fields. For example, fields receiving livestock manure have no symptoms of S deficiency. If S deficiency is confirmed in alfalfa (through plant tissue analysis or field response trial), the amount of S fertilizer recommended is 20 to 30 lb S/A. Where deficiencies occurred in the 2006 rate trials, the first 15 lb S/A gave the largest incremental increase in yield, but the next 10 to 15 lb S/A was profitable at most sites. Also, S fertilizers do not need to be applied each year as alfalfa will respond to S applied in a prior year.

Abbreviations: S = sulfur; N = nitrogen; P = phosphorus; K = potassium; ppm = parts per million; OM = organic matter; $\text{CaSO}_4\cdot\text{H}_2\text{O}$ = calcium sulfate (gypsum); $(\text{NH}_4)_2\text{SO}_4$ = ammonium sulfate (AmS).

Summary

This research indicates a change in need for S fertilization of alfalfa, especially in northeast Iowa and the associated soils. However, research also shows that alfalfa does not respond to S application in all fields or field areas. **BG**

Acknowledgements

Appreciation is extended to Honeywell International Inc. and the Foundation for Agronomic Research for partial financial support of this research. Appreciation is also extended to the producer cooperators who allowed us to use their fields.

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Table 1. Alfalfa forage yield, plant S analysis, and harvest S removal with S fertilizer application in field areas with observed poor and good plant coloration/growth.

Sulfur application [†]	2005 [†]						2006 [‡]	
	Cuts 2+3		Cut 2		Cuts 2+3		Cut 1	
	Dry matter yield		Plant top S [§]		S removal		Dry matter yield	
	Observed coloration/growth area							
	Poor	Good	Poor	Good	Poor	Good	Poor	Good
	---- ton/A ----		----- % S -----		---- lb S/A ----		---- ton/A ----	
None	1.18d [#]	2.99ab	0.14d	0.22c	2.8e	10.6d	1.10b	2.04a
AmS	2.76bc	3.26a	0.40a	0.35b	16.5bc	18.2ab	2.18a	2.22a
Gypsum	2.49c	3.21a	0.41a	0.37b	15.3c	18.1ab	2.14a	2.19a

[†] Across three field sites in 2005: Elgin (Fayette silt loam), Gunder (Fayette silt loam), and West Union (Downs silt loam), Iowa. Extractable SO₄-S soil test and soil OM for the poor and good areas, respectively: soil SO₄-S – Elgin, 6 and 7 ppm; Gunder, 7 and 8 ppm; West Union, 6 and 7 ppm; and OM – Elgin, 2.3 and 2.3%; Gunder, 2.7 and 2.9%; and West Union, 2.3 and 2.6%.
[‡] Across two field sites in 2006 (S application in 2005): Elgin and Gunder, Iowa.
[§] Sulfur concentration for 6-in. plant tops collected before second cut.
[†] Sulfur (AmS and gypsum) applied at 40 lb S/A after the first cut in 2005.
[#] Means followed by the same letter are not significantly different, p ≤ 0.10.

Table 2. Alfalfa plant tissue S concentration and site characteristics, 2006.

Sulfur rate [†] , lb S/A	Site					
	Wadena	Waucoma [‡]	Nashua	Waukon	West Union	Lawler
	----- % S [§] -----					
0	0.14	0.21	0.33	0.18	0.18	0.27
15	0.20	0.30	0.35	0.29	0.24	0.36
30	0.30	0.43	0.34	0.40	0.29	0.39
45	0.39	0.36	0.37	0.41	0.28	0.37
Soil SO ₄ -S, ppm [¶]	7	3	7	1	6	3
Soil OM, % [¶]	3.1	2.1	4.2	3.8	3.3	2.6
Soil type	Fayette silt loam	Wapsie loam	Clyde-Floyd loam	Fayette silt loam	Fayette silt loam	Ostrander loam

[†] Sulfur applied as gypsum in April at Nashua and in May at other sites.
[‡] Waucoma site had 10 lb of elemental S applied in the spring across the entire field.
[§] Sulfur concentration for 6-in. plant tops collected before second cut.
[¶] Soil samples collected after first cut, 0 to 6-in. depth.

Table 3. Alfalfa total dry matter for harvests collected in 2006.

Sulfur rate [†] , lb S/A	Site					
	Wadena	Waucoma [‡]	Nashua	Waukon	West Union	Lawler
	----- ton/A -----					
0	1.32	1.85	6.73	1.39	0.78	2.14
15	2.59	3.06	6.98	2.97	1.05	2.11
30	2.76	3.14	6.85	3.33	1.07	2.11
45	2.92	3.24	7.14	3.58	1.07	2.07
Statistics [§]	*	*	NS	*	*	NS
Max rate, lb S/A [¶]	25	22	0	29	12	0
Cut harvested	2+3	2+3	1+2+3+4	2+3	3	2+4

[†] Sulfur applied as gypsum in April at Nashua and in May at other sites.
[‡] Waucoma site had 10 lb of elemental S applied in spring across the entire field.
[§] Indicates statistically significant (*) or non-significant (NS) yield response to S rate, p ≤ 0.10.
[¶] Applied S rate at the maximum dry matter yield response.

Suggestions for Managing S Applications in Alfalfa

- The S concentration in tissue samples from the top 6 in. of plants at the early bud stage is a good indicator of S deficiency and need for S application. Concentrations less than 0.23% S should be considered deficient and S applied, with concentrations of 0.23 to 0.25% S considered marginal.
- The extractable SO₄-S concentration in the 0 to 6-in. soil depth is not reliable for indicating potential S deficiency or need for S application.
- For confirmed S-deficient alfalfa fields, apply 20 to 30 lb S/A. Sulfur fertilizers do not need to be applied each year as alfalfa will respond to S applied in a prior year. Therefore, it is possible to apply the crop needs for multiple years in one application. That rate will be more than is needed for just one year, and some luxury uptake is possible. Since SO₄²⁻ forms of S fertilizers are immediately available for plant uptake, they can be applied after any cutting. Good yield response has been measured with applications in-season, even in dry periods. This flexibility allows for rapid correction of S deficiencies found through plant analysis. Elemental S, since it must be oxidized to the SO₄²⁻ form, should be applied some time ahead of crop need or at seeding.
- Manure is a good source of S, and eliminates the need for S fertilizer application.
- Common soil conditions where S deficiency has been found include low organic matter soils, side-slope landscape position, eroded soils, and coarse-textured soils.
- Work with alfalfa clearly showed differential response in poor and good coloration/growth areas within fields, indicating that whole fields would not respond to S application. However, it is likely most prudent to simply fertilize entire fields when deficiency exists rather than attempt site-specific applications because 1) S fertilization is relatively low cost, 2) many fields indicate considerable areas with S deficiency, 3) large yield increases have been observed with S application, and 4) there is a need to take plant tissue samples to determine S deficiency.

Sulfur Fertilization Response in Iowa Corn Production

By John Sawyer, Brian Lang, and Daniel Barker

With the positive results from S fertilization in alfalfa (see related article, page 6), trials were started in 2006 corn fields where early plant growth was exhibiting S deficiency symptoms or where there was expectation of S deficiency. Calcium sulfate ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$, gypsum) was surface broadcast applied after early corn growth at 40 lb S/A, with a control treatment for comparison. The 40 lb S/A rate was chosen as a non-limiting S rate to maximize any potential yield increase.

Corn yield was increased with the S application at five of six sites (**Table 1**). The yield increases were quite large, especially considering the surface sidedress application. However, the sites were chosen based on expected S deficiency, with many sites showing severe plant yellowing. With rainfall after application, plant response (increase in greenness) was observed in a short time period. Across all sites, the yield increase from S application was 38 bu/A. These results indicate that a substantial corn yield increase to S application is possible when soil conditions are conducive to low S supply and severe S deficiency exists. In this study, those conditions were coarse textured soils and a soil/landscape position similar to that with documented S deficiency in alfalfa.

Response to Sulfur Fertilization Rate

An expanded set of trials was conducted in 2007 and 2008 at 45 sites in north-central to northeast Iowa to determine corn response to S rate. The sites were selected to represent major soils, cropping systems, and a range in potential S response. Sites had no recent or known manure application history. Gypsum was surface broadcast applied with no incorporation shortly after planting at 0, 10, 20, and 40 lb S/A. Individual site S response was determined by grain yield comparison of the no S control vs. applied S. Corn yields were averaged across responsive sites by fine and coarse soil textural grouping, with response models fit to the yield response. Economic optimum S rate was determined with S fertilizer at USD 0.50/lb S and corn grain at USD 4.00/bu.

Corn grain yield was increased with S fertilizer application at 17 of 20 sites in 2007 and 11 of 25 sites in 2008, and ear leaf S concentration was increased at 16 sites each year. Across all sites, the average yield increase was 13 bu/A. When grouped by soil texture just for responsive sites (**Figure 1**), the yield increase was 15 bu/A for the fine-textured soils (loam, silt loam, silty clay loam, and clay loam) and 28 bu/A for the coarse-textured soils (fine sandy loam, loamy fine sand, and sandy loam). Grain yields increased with S application at 21 of 34 (62%) fine-textured soil sites and 7 of 11 (64%) coarse-textured soil sites. These are frequent and large yield increases to S fertilization. However, sites located more toward the north-central and central geographic areas of Iowa had a lower frequency of yield response to S application, indicating soil or other factors affecting potential need for S fertilization that are different from the northeast area of Iowa.

When analyzed by the responsive sites, the maximum S response rate for the 21 fine-textured soil sites was 17 lb S/A, with an economic optimum rate at 16 lb S/A (**Figure 1**). For the seven coarse-textured soil sites, the maximum response rate was 25 lb S/A, with an economic optimum rate at 23 lb S/A.

Abbreviations: S = sulfur; P = phosphorus; ppm = parts per million; SO_4^{2-} = sulfate; USD = U.S. dollar.

Table 1. Effect of S fertilizer application on corn grain yield, 2006.

County	Previous crop	Soil type [†]	Soil $\text{SO}_4\text{-S}^\ddagger$ ppm	Grain yield	
				- S	+ S [§]
				--- bu/A ---	
Buchanan	soybean	Sparta lfs	6	123	151*
Buchanan	soybean	Sparta lfs	7	154	198*
Delaware	soybean	Chelsa lfs	9	88	108*
Delaware	soybean	Kenyon l	13	196	204 ^{NS}
Allamakee	alfalfa	Fayette sil	3	96	172*
Allamakee	alfalfa	Fayette sil	-	118	171*
Across sites				129	167*

[†] lfs, loamy fine sand; l, loam; sil, silt loam.

[‡] Extractable sulfate-S in the 0 to 6 in. soil depth.

[§] Sulfur applied at 40 lb S/A. Symbol indicates statistically significant (*) or non-significant (NS) yield increase with S application, $p \leq 0.10$.

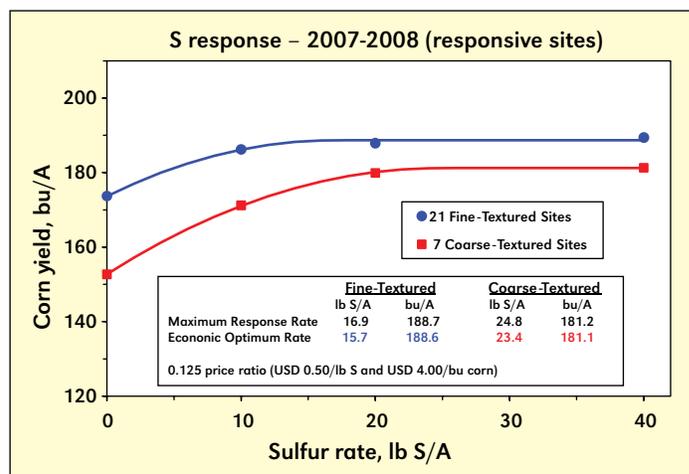


Figure 1. Corn grain yield response to S application rate at responsive sites.

One test for evaluating potential S deficiency is plant analysis for ear leaf S concentration. There is a wide range in published minimum sufficiency concentrations for corn ear leaves at the silking stage, from 0.10 to 0.21% S. The current study does not confirm or refute these minimum levels. Across measured leaf S concentrations there was no clear relationship between ear leaf S and yield response (**Figure 2**). Therefore, it is not possible to define a critical level from this study. Sulfur application increased leaf S concentration, but it was not a large increase. Across sites, an increase of 0.02% S occurred with the 40 lb S/A rate and the leaf S concentration was below 0.21% S at all except one site.

Another test for evaluating potential S deficiency is soil testing for extractable $\text{SO}_4\text{-S}$. This study used calcium phosphate extraction. Concentrations (0 to 6 in. depth) were not related to yield response (**Figure 3**). Also, several sites had

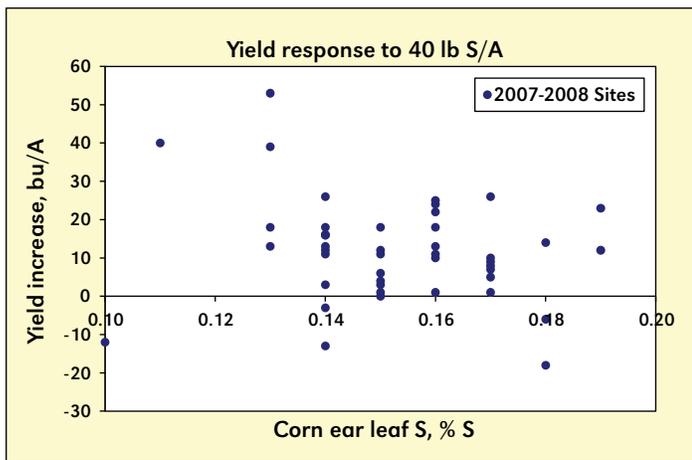


Figure 2. Corn grain yield response to S application as related to ear leaf S concentration in the no-S control.

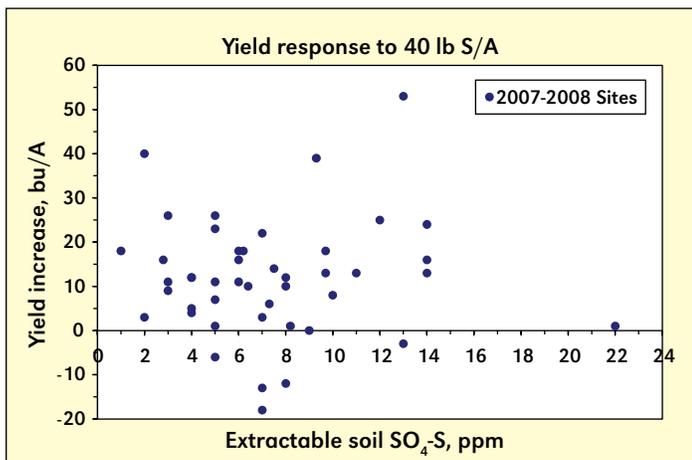


Figure 3. Corn grain yield response to S application as related to extractable soil $\text{SO}_4\text{-S}$ concentration, 0 to 6-in. soil depth in the no-S control.

concentrations above the 10 ppm S level considered sufficient, but responded to S application. This has been found in other studies where the $\text{SO}_4\text{-S}$ soil test has not been reliable for predicting crop response to S application on soils in the Midwest USA. Supply of crop-available S is related to more than the $\text{SO}_4\text{-S}$ concentration in the top 6-in. of soil, thus the poor relationship between yield response and soil test. Soil organic matter has a somewhat better relationship to yield response, but for similar reasons does not clearly differentiate between responsive and non-responsive sites (**Figure 4**). These results highlight the complex combination of environment, soil, and crop factors that result in deficient or adequate season-long supply of available S. Visual observation of deficiency symptoms can lead to correct determination of S response (**Figure 5**). However, hidden hunger can exist where the corn plant does not exhibit deficiency symptoms, but yield increase may or may not occur (**Figure 5**).

Sulfur Fertilizer Product Evaluation

Field trials were conducted in 2006 (northeast Iowa, two sites), 2008 (northern Iowa, one site), and 2009 (central to northern Iowa, two sites) on producer fields to evaluate P-S fertilizer co-products: Simplot and Mosaic 13-33-0-15S (Simplot SEF in 2006 and Mosaic MES15 in 2008) and Mosaic

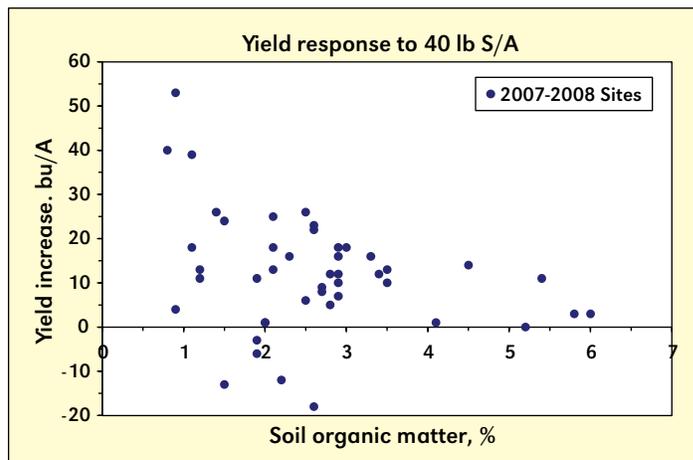


Figure 4. Corn grain yield response to S application as related to soil organic matter, 0 to 6-in. soil depth in the no-S control.

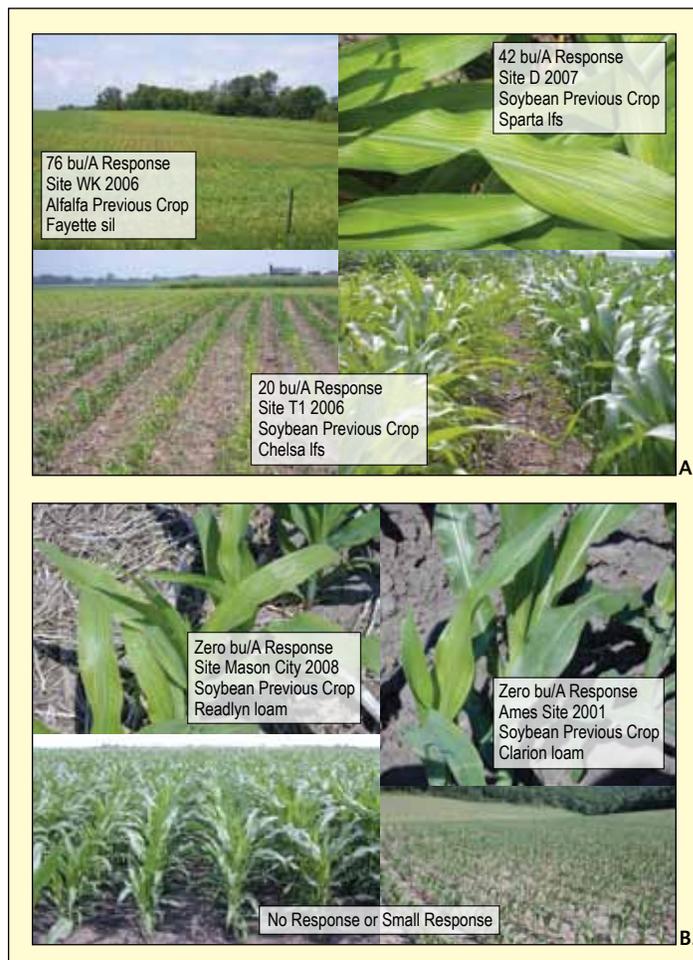


Figure 5. Corn expressing dramatic S deficiency symptoms and having large yield increase from S application (photo grouping A, top), and corn not showing deficiency symptoms and either having a yield increase or no increase from S application (photo grouping B).

12-40-0-10S (MES10 in 2009). The SEF and MES products contained half of the S as SO_4^{2-} and half as elemental. These products were compared to ammonium sulfate (AmS). The fertilizers were broadcast by hand prior to spring tillage or corn planting. For this article, only treatments related to S response are discussed: S control, AmS at 10 and 30 lb S/A, and SEF and MES at 10 and 30 lb S/A. Rates of N and P were

Table 2. Sulfur strip trials conducted in central and northeast Iowa, 2009.

Site	County	Previous crop	Special remarks [†]	S rate, lb/A	Corn yield, bu/A	
					- S	+ S
3	Greene	corn	a	40	225	229
4	Greene	corn	a	40	210	215*
5	Greene	corn	b	40	217	228*
6	Dallas	soybean	-	40	201	200
9	Dallas	corn	c	40	147	152*
10	Dallas	corn	a, d	40	135	134
1	Fayette	soybean	-	15	224	236*
2	Howard	soybean	-	20	186	192*
7	Dubuque	soybean	-	30	216	229*
8	Floyd	-	e	20	199	203
11	Winneshek	soybean	-	30	215	212

[†] Special remarks:

a) Planter split with two hybrids.

b) 16 of 24 rows cultivated.

c) Visual S deficiency symptoms on June 17, corn at V6-V7 growth stage.

d) Field has manure history.

e) Only two replications and considerable yield data missing from two strips.

* Significantly different yield than with no S applied, $p < 0.10$.

If no symbol, then yields are not statistically different.

equalized. The extractable soil $\text{SO}_4\text{-S}$ concentrations were 4 to 8 ppm in the top 6 in. across sites.

In 2006, the corn grain yield response across sites between the control and 10 lb S/A as AmS or SEF was 15 bu/A (196 vs. 211 bu/A). There was no yield increase to additional S application with the 30 lb S/A rate for either S fertilizer. The ear leaf S concentration was increased from 0.15% S in the control to 0.18% and 0.21%, respectively, for the 10 and 30 lb S/A rates. The leaf S concentration and corn grain yield were the same for both AmS and SEF, indicating similar plant-available S supply from both fertilizer products. In 2008, despite early season plant S deficiency symptoms where no S was applied (a no-till site), there was a visual plant response, but no yield response to S application with either S fertilizer (MES or AmS). Yields were 172 bu/A for the control and 168 bu/A for the S application average. In 2009, despite an increase in ear leaf S concentration (same for both MES and AmS), there was no corn yield response to applied S. These results indicate that the P-S co-products supplied crop available S to corn and were similar to an all- SO_4^{2-} form.

Strip-Trials for Field-Scale Evaluation

In 2009 replicated field-length strip trials were conducted in 11 fields in central and northeast Iowa with spring preplant broadcast gypsum compared to no S application. One rate of S was used in each field, but the rate varied among sites (**Table 2**). These strip trials are considered a survey of potential field-scale S response in corn.

Six of the eleven fields had a corn yield increase from S application, with the other five fields having no S response (**Table 2**). This is a 55% response rate to S application, which is similar to the recent small plot research conducted in north central to northeast Iowa. For the six responding sites, the average yield increase was 9 bu/A, with a range of 5 to 13 bu/A.

Suggestions for Managing S Applications in Corn

- The extractable $\text{SO}_4\text{-S}$ concentration in the 0 to 6-in. soil depth is not reliable for indicating potential S deficiency or need for S application.
- The S concentration in ear leaves collected at silking can indicate low S supply, but a specific critical concentration with modern hybrids could not be established in this research.
- For confirmed S deficiencies, on fine-textured soils apply approximately 15 lb S/A and on coarse-textured soils 25 lb S/A.
- Sulfur deficiencies have been documented and large crop yield response measured in some fields. However, at this time we are uncertain about the geographic extent of S deficient soils across Iowa. Some common soil conditions where S deficiency has been found include low organic matter soils, side-slope landscape position, eroded soils, and coarse-textured soils. With reduced- and no-till systems, lack of soil mixing and cooler soils reduce mineralization which slows release of S from organic materials — a main source of available S.
- Research to date has not fully documented the variability of deficiency within corn fields. Site-specific response is possible, but inexpensive and reliable methods are needed to “map” S deficiency. This is especially problematic in corn as symptoms are not always present or obvious, especially with minor S deficiency and small but economic yield response (**Figure 5**). Research and development is needed to provide tools for reliable S deficiency detection.

These yield increases are large enough to more than pay for a field-wide S application. This strip trial work confirms that field-scale S deficiency is occurring across a wide geographic area from central to northeast Iowa.

Summary

Corn grain yield increase to S fertilization has occurred with high frequency. Also, the magnitude of yield increase has been large. Across the small plot rate studies, 62% of the sites had a statistically significant yield increase to applied S fertilizer: 72% of sites with loam, silt loam, fine sandy loam, loamy fine sand, and sandy loam textural classes; and 14% of sites with silty clay loam or clay loam textural classes. The across-site yield increase averaged 19 bu/A for the responsive sites. Analyzed across S rate, the economic optimum S rate was 16 lb S/A for fine-textured soils and 23 lb S/A for coarse-textured soils.

This research indicates a change in need for S fertilization, especially in northeast Iowa and the associated soils, and that S application is an economically viable fertilization practice on soils in areas neighboring northeast Iowa. However, the research also shows that corn does not respond to S application in all fields. 

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Crop Nutrient Deficiency Image Collection Now Available from IPNI

While music and clothing and other styles are subject to drastic change as the years go by, classic symptoms of nutrient deficiencies in crop plants don't change much. Yet, there is an ongoing need for resources that can serve as a guide or ready reference to aid in education and recognition of deficiency symptoms.

The International Plant Nutrition Institute (IPNI) has released an updated collection containing more than 400 images showing nutrient deficiency symptoms in plants. The photos were collected from research plots, farm fields, plantations, diagnostic labs, and other sources. Some came from an annual contest which IPNI conducts each year, where photos of documented deficiencies are submitted by crop advisers, researchers, extension workers, crop scouts, farmers, students, and others.

The images are organized in groups including primary nutrients, secondary nutrients, and micronutrients. The image galleries and search results can be narrowed by available crop-type.

Text and diagrammatic descriptions of nutrient deficiency are also available as supporting information.

The IPNI Crop Nutrient Deficiency Image Collection is available either on a CD for USD 30.00 (thirty dollars) or on a USB Flash Drive for USD 40.00 (forty dollars). Both prices include shipping for a single item. They can be ordered directly from the IPNI store, available at the website: www.ipni.net.

If you have questions or are interested in multiple copies of either the CD or USB Flash Drive, contact us for details on possible discounts for quantities.:

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New Initiative and Website Increase Awareness of 4R Nutrient Stewardship

There is a new online resource aimed at helping farmers boost yields, manage input costs, and maintain soil health. The website, www.nutrientstewardship.com, is a collaborative effort of the fertilizer industry aimed at increasing awareness of 4R nutrient stewardship, a site-specific, scientific framework that addresses use of the right fertilizer source at the right rate, the right time, and the right place.

The new effort streamlines efforts to promote awareness and adoption of science-based fertilizer best management practices (BMPs), while also creating a "brand" for the 4Rs that will allow the agriculture community to speak with one voice regarding its commitment to environmental stewardship and sustainability.

The 4R nutrient stewardship concept and website are a cooperative effort of The Fertilizer Institute (TFI), the International Plant Nutrition Institute (IPNI), the Canadian Fertilizer Institute (CFI), and the International Fertilizer Industry Association (IFA). The new site is designed to serve as an online clearinghouse for information on 4R-related tools and resources and will serve as the cornerstone for a multi-faceted nutrient stewardship initiative.

In addition to introducing site visitors to the 4R concept, the website offers information regarding a wide range of agronomic topics related to nutrient management, and provides a how-to guide for implementing the 4Rs on the farm.

"We're in a time in agriculture where the risk of making the wrong decision when it comes to nutrient management is greater than ever before," noted IPNI President Dr. Terry Roberts. "In addition to meeting the challenge of feeding a growing population, agriculture is facing increasing regulatory pressure to limit the use of crop nutrients and those factors make right now the right time for promoting increased awareness and adoption of 4R nutrient stewardship."

Learn more about 4R nutrient stewardship by visiting www.nutrientstewardship.com or the IPNI website at www.ipni.net. DC



Upcoming Events...

American Society of Agronomy-Crop Society of America-Soil Science Society of America (ASA-CSSA-SSSA) 2011 International Annual Meetings. Oct. 16-19, San Antonio, Texas. www.acsmeetings.org



Information Agriculture Conference 2011. July 12-14, 2011. Springfield, Illinois. www.infoag.org



Optimization Principles of Nitrogen Management for Winter Wheat at the Farm Level

By V. A. Romanenkov

Despite the long history of studies and the diversity of calculation methods, the problem of optimization of the rates of mineral fertilizers and the ratios of nutrients in them is still the focus of attention. The rise in prices of material resources of agriculture and, hence, the rise in cost of agricultural produce make this problem even more acute.



The geographic network of experiments with fertilizers created in Russia on the initiative of D.N. Pryanishnikov represents an adequate tool to solve such problems as optimization of N rates for winter wheat. Officially, these experiments began in 1941. The results obtained up to 1970 made it possible to find the major regularities concerning zonal effects of different kinds and rates of fertilizers. The efficiency of average rates of fertilization was also determined. On this basis, the efficiency of fertilizer use on the main types of soils was calculated, and recommendations on the optimum average rates of fertilizers in the main soil-climatic zones and economic regions of the country were suggested (Regulations

the rates of major nutrients and ratios between them.

The mean yield of winter wheat in the Moscow region in 2005–2009 reached 2.78 t/ha. This is sufficient for the profitable production of wheat grains, particularly with the predicted favorable changes in the climate of the nonchernozemic zone in the 21st century (Gordeev et al., 2006).

Calculation of the Rates of Nitrogen Fertilizers Ensuring Their Payback

The experiments performed during 32 years at the Central Experimental Station of the Pryanishnikov All-Russia Research Institute of Agricultural Chemistry (VNIIA) in Domodedovo district of Moscow oblast provided 380 results of regular observations of the efficiency of fertilizers with variations in the rates of N (0 to 240 kg/ha), P_2O_5 (0 to 180 kg/ha), and K_2O (0 to 260 kg/ha). The agrochemical indices of the soil fertility varied within the following limits: organic matter content, 1.1 to 1.9%; soil pH, 4.1 to 6.6; available P_2O_5 , 11 to 166 mg/kg; and available K_2O , 79 to 318 mg/kg. According to the norms of fertilizer payback, the recommended rates of application of N, P_2O_5 , and K_2O were 100, 90, and 90 kg/ha, respectively. The efficiency of fertilizers depended on the water supply conditions and varied within 40 to 70% of the value obtained at the control plot.

These data showed that in the case of the low supply of available P, the efficiency of average rates of N fertilizers (60 to 90 kg/ha) is subjected to considerable fluctuations depending on weather conditions. In the case of the medium supply of available P, the highest gains in the yield of winter wheat were obtained with application of N at the rate of 60 to 90 kg/ha. Under favorable weather conditions, the gain in grain yield reaches 2.4 t/ha. With higher rates of N fertilizers, it decreases. This decrease was especially pronounced for N fertilization rates of 120 to 150 kg/ha. In the case of the low nutrient status of the soil, the maximum gain in the yield was achieved with N fertilization rates of 120 to 150 kg/ha, though the absolute increase was less than 1.2 t/ha (Romanenkov et al., 2008).

Regression models have been used to calculate the yields, fertilizer payback, and net revenue (Sirotenko et al., 2009). To calculate the revenue, a standard index – bulk profit from grain sales minus the cost of N fertilizers – was used. Real net revenue, of course, is lower (Buresh and Witt, 2008), resulting in lower net revenue. However, this index proved to be helpful for comparing the economic efficiency of the suggested fertilizer management practices. Two extreme scenarios reflecting the maximum and minimum ratios of grain prices and N fertilizer costs were examined on the basis of real values in 2006–2009. As suggested by Buresh and Witt (2008), the cost of fertilization and harvest operations have not been taken into account.



Field station of Tymiryazev Agricultural Academy next to VNIIA.

for Determining the Demands of Agriculture in Mineral Fertilizers, 1985).

However, these rates had to be specified for the particular farms and fields. The corrections were made for the degree of soil cultivation, for the planned crop yields, and for the particular cultivation technologies (Litvak, 1990). The calculation methods used to find optimum fertilizer rates had their own drawbacks related to difficulties in the transformation of the growing amount of factual data into relatively simple calculation schemes and in the refinement of the latter. The dynamics of prices for agricultural produce and fertilizers and the variation in weather conditions represented major difficulties for the researchers. The study of such multifactor systems remains a quite complicated problem despite the long-term experience in this field and the diversity of the methods used to calculate

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; GRF = gross returns over fertilizer cost; AEN = N agronomic efficiency (kg grain yield increase per kg N applied).

Table 1. Yield, fertilizer N, N agronomic efficiency, and gross return over fertilizer costs for different scenarios of agricultural production.

Parameter	Unit	Low soil fertility	High soil fertility	High soil fertility and new varieties	----- High soil fertility -----			
					Max favorable climatic year	Highly unfavorable climatic year	Highly unfavorable climatic year	
----- Average climatic year -----								
Grain yield, without N	Y_0	t/ha	1.28	2.01	1.67	2.76	1.63	0.90
Grain yield, max	Y_{max}	t/ha	2.40	3.16	5.61	4.98	2.33	1.6
----- Wheat price = 100 USD/t; cost of fertilizer N = 678 USD/t -----								
Grain yield, at max GRF	Y	t/ha	2.15	2.81	3.17	4.63	1.97	1.25
Fertilizer N, at max GRF	F_N	kg/ha	90	80	100	150	40	40
AEN, at max GRF	AE_N	kg/kg	10	10	15	13	9	9
Change in net benefit at max GRF relative to low soil fertility	Δ GRF	USD/ha	-*	+81	+110	+162	-67	-67
----- Wheat price = 167 USD/t; cost of fertilizer N = 400 USD/t -----								
Grain yield, at max GRF	Y	t/ha	2.38	3.11	3.22	4.92	2.27	1.55
Fertilizer N, at max GRF	F_N	kg/ha	140	140	110	210	100	100
AEN, at max GRF	AE_N	kg/kg	8	13	14	10	6	6
Change in net benefit at max GRF relative to low soil fertility	Δ GRF	USD/ha	-**	+113	+149	+258	-115	-115

* Price of food grain 3rd class and ammonium nitrate.

** +175 compared to low ratio grain price/fertilizer cost.

Calculations for Average Weather Conditions with Changing Grain Price/Fertilizer N Cost Ratios

The results of calculations are shown in **Table 1** and **Figure 1**. As seen from **Table 1**, the optimum rates of N fertilizers in the case of the minimum grain price/fertilizer N cost ratio and maximum profit range from 80 to 100 kg/ha. In this case, the grain yield reaches 2.8 t/ha on the highly fertile soils and 2.1 t/ha on the low fertility soils. The return does not exceed 10 kg grain/kg N fertilizer. The rate of N fertilizer application can be reduced by 10 kg/ha in the case of highly fertile soils. The use of new wheat strains against the background of well-managed fertile soils makes it possible to raise the return to 15 kg/kg with the increased rate of N fertilizer application (100 kg/ha). In this case, the yield reaches 3.2 t/ha (or 57% of the maximum yield). The gross return increases by USD 80/ha due to improvement of soil fertility and by an additional USD 30/ha with the use of new wheat varieties. In the latter case, it is possible to increase the return by 1.5 times (up to 15 kg/ha).

With the maximum grain price/fertilizer N cost ratio, which is much more favorable for farmers, the optimum rate of N fertilizer increases to 140 kg/ha. In this case, the return gained from the highly fertile soils increases from 8 to 13 kg/ha, and the grain yield increased up to 3.1 t/ha, approaching the maximum value.

The use of new varieties makes it possible to reduce the optimum rate of fertilizer N and to raise the return to 14 kg/kg. In this case, the gain in yield is relatively low (from 3.1 to 3.2 t/ha). The economic efficiency of measures on the improvement of soil fertility reaches about USD 110/ha; the use of new



Optimum N rate for wheat increases in years with favorable weather.

varieties increases it by about USD 40/ha.

As follows from this analysis, with the high cost of fertilizer N and low grain price, the average (for the entire Moscow oblast) grain yield can only be achieved upon winter wheat cultivation on the highly fertile soils. The improvement of soil fertility does not lead to the corresponding rise in the gross return over fertilizer cost, and the additional gain in the yield and return rates (by 15 and 50%, respectively) can be achieved with the use of new wheat varieties. Thus, the recommended rate of fertilizer N is 100 kg/ha, which corresponds to the average rate of N fertilization in Moscow oblast. In other cases, the maximum return can be gained with the lower (by 10 to 20 kg/ha) rates of fertilizer N application.

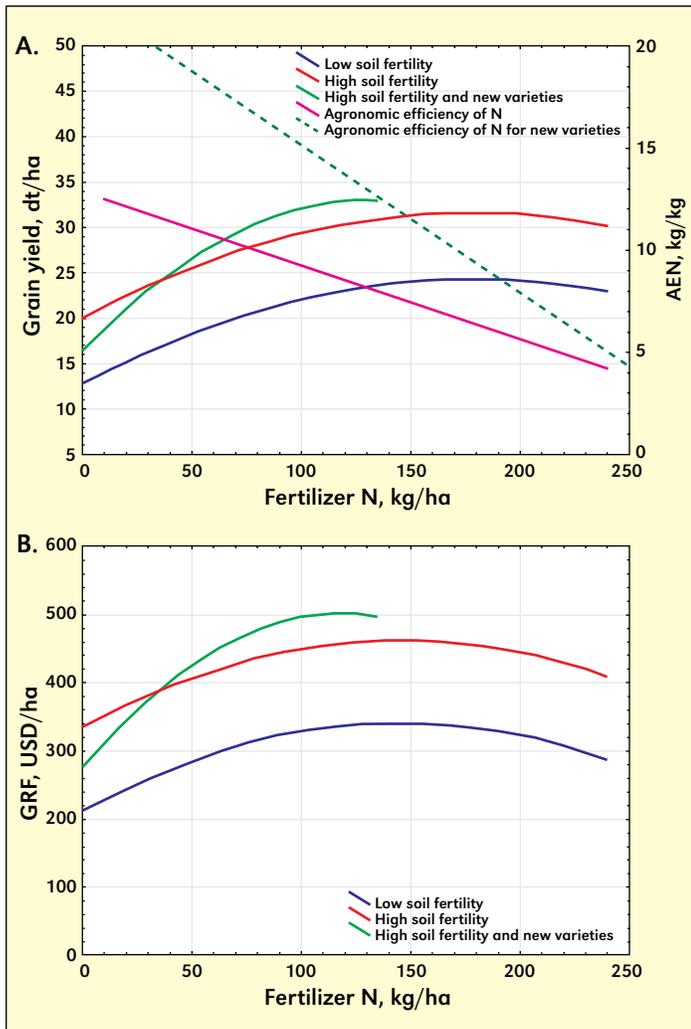


Figure 1. Response of winter wheat to N application at VNIIA Central Experimental Station, Moscow Region: (a) relationship between grain yield, N rate, and AEN; (b) relationship between GRF and N rate. Red and blue lines were calculated based on average of 32-years climate conditions of the site.

With the more profitable grain price/fertilizer cost ratio, the optimum rate of fertilizer N can be increased up to 140 kg/ha. The improvement of soil fertility ensures the gain in the gross return by USD 30/ha in comparison with the previous scenario, and the use of new wheat varieties makes it possible to reduce the rate of fertilizer N to 110 kg/ha for the same economic efficiency of farming as in the case of the unfavorable grain price/fertilizer cost ratio.

Calculations Considering Weather Conditions and Changing Grain Price/Fertilizer N Cost Ratios

Proper accounting for real weather conditions makes it possible to introduce certain corrections to the optimum rates of fertilizers. With the favorable grain price/fertilizer cost ratio and favorable weather conditions, the optimum rate of fertilizer N can be increased by 70 kg/ha (up to 210 kg/ha). This assures a grain yield of 4.9 t/ha and a return of 10 kg grain/kg fertilizer N and the gross revenue increases by 56%, or by USD 145/ha in comparison with the average revenue for the soils with the high fertility level (Table 1, Figure 2).

With an unfavorable grain price/fertilizer N cost ratio, the

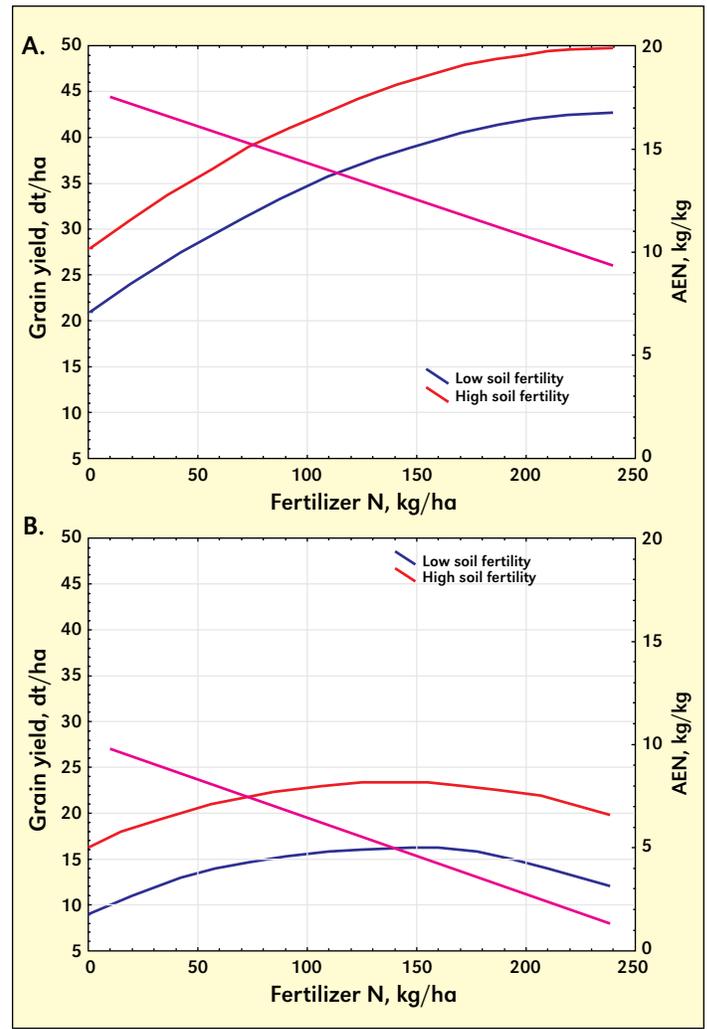


Figure 2. Relationship between grain yield of winter wheat and N rate and AEN at VNIIA Central Experimental Station, Moscow Region: (a) highly favorable climatic year; (b) unfavorable climatic year.

optimum rate of fertilizer N can also be increased by 70 kg/ha, or up to 150 kg/ha, which should provide a return of 13 kg/kg and a yield of 4.6 t/ha (or 90% of the maximum yield). The additional gross revenue increases by two times (double) in comparison with the average revenue for the soils with the high fertility level and reaches USD 81/ha.

Under unfavorable weather conditions and favorable grain price/fertilizer cost ratio, the optimum rate of fertilizer N decreases from 140 to 100 kg/ha, providing a grain yield of 2.27 t/ha on the highly fertile soil and 1.55 t/ha on the low-fertility soil with the return of 6 kg/kg. The loss in the gross revenue in comparison with that in the year with average weather conditions is estimated at USD 115/ha, which is comparable with the effect of soil improvement procedures (Table 1).

Under the same weather conditions and unfavorable grain price/fertilizer cost ratio, the optimum rate of fertilizer N should be decreased to 40 kg/ha with grain yields on the highly fertile and low-fertile soils of 1.97 and 1.25 t/ha, respectively. The return from fertilizer N application reaches 9 kg grain/kg fertilizer, and the loss in the gross revenue (in comparison with the year with average climatic conditions) is estimated

at USD 67/ha. It should be noted that a decrease in the grain yield corresponding to the maximum return on the low-fertility soils in comparison with that on the highly fertile soils with the unfavorable grain price/fertilizer cost ratio reaches 58%. When the grain price/fertilizer cost ratio is favorable, it decreases by 46%. In comparison with the minimum average yield in Moscow oblast for 1995–2009 (1.42 t/ha for the low-fertile soils), the yield gained on the experimental field during the year with unfavorable weather conditions even in the case of the optimum rate of fertilizer N is somewhat lower. The surplus yield (in comparison with the average yield in Moscow oblast) in the year with unfavorable weather conditions with both favorable and unfavorable grain price/fertilizer cost ratios can only be gained on the highly fertile soils.

As seen from this example, the grain price/fertilizer cost ratio on the market affects the optimum rate of fertilizer N, which should also be corrected for the particular weather conditions. Only in this case, we can avoid application of excessive and economically inefficient fertilizers. With the rise in the grain price/fertilizer cost ratio, increased rates of fertilizer N should be applied in the case of favorable weather conditions. Lowering of the grain price/fertilizer cost ratio necessitates a considerable reduction (by two times) in the rate of fertilizer N application ensuring the maximum gross revenue. This means the relative changes in the yield of winter wheat are highly sensitive to changes in the weather conditions, though the absolute changes in the gross revenue are lowered by \$30 to 50/ha.

What are the particular mechanisms for the correction of the optimum rates of fertilizer N application?

The optimum rate of fertilizer N can be calculated with due account for several factors specifying the efficiency of applied fertilizers, depending on precipitation in the spring season, when vegetative growth of winter wheat resumes. Calculations on the basis of the obtained regression equations show that the maximum gain in the yield per unit fertilizer N is proportional to precipitation in April, which specifies soil moisture conditions after the beginning of wheat vegetative growth. For the studied experimental farm, each 10 mm increase in precipitation in April leads to a rise in the fertilizer return rate of 0.6 to 1.5 kg grain/kg N due to the increased grain yield (Figure 3). Thus, if we know moisture conditions for the spring period, we can introduce necessary corrections to the optimum rates of N fertilization during the early stages of the winter wheat vegetation.

Conclusions

The suggested approach specifies the development of grain crop yields at the farm level and makes it possible to predict the efficiency of mineral fertilizers with due account for the particular weather conditions and the level of soil fertility. The optimum rate of fertilizer N increases up to 150 to 210 kg/ha in years with favorable weather conditions. Annual corrections for the level of soil fertility should be determined.

With the high cost of fertilizers and low grain price, the soils of the investigated farm can provide the grain yield equal to the average in Moscow oblast only in the case of the winter wheat growing on the highly fertile soils. With the favorable

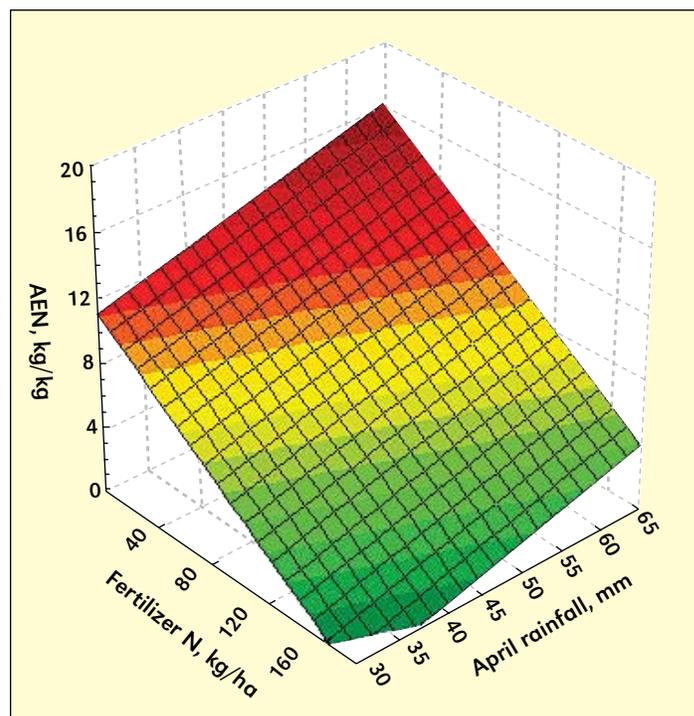


Figure 3. Relationship between the agronomic N efficiency, fertilizer N rates, and April rainfall for winter wheat.

grain price/fertilizer cost ratio and unfavorable weather conditions, yields higher than the average yield in the Moscow oblast can also be obtained only on the highly fertile soils. The use of new wheat strains makes it possible to reduce the rates of fertilizer N upon the favorable grain price/fertilizer cost ratio and to gain maximum gross revenue. 

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Best Nitrogen Management Practices to Decrease Greenhouse Gas Emissions

by Jan Willem van Groenigen, Oene Oenema, Kees Jan van Groenigen, Gerard Velthof, and Chris van Kessel

Agricultural soils are the main source of human-caused emissions of the greenhouse gas (GHG) nitrous oxide (N_2O) to the atmosphere. Those emissions are often expressed per area of land use or as a percentage of the fertilizer application rates. In a recent scientific journal article, we argued that N_2O emissions should instead be related to agricultural production. In a meta-analysis of 19 independent studies that report both N_2O emissions and crop yield, we show that N_2O emissions per unit of harvested product are stable as long as the aboveground N surplus remains low. We conclude that the aims of optimal agricultural production and low GHG emissions are remarkably similar and might best be achieved through implementing best management practices (BMPs). Management should be focused on optimizing fertilizer N use efficiency (NUE) rather than on simply reducing fertilizer N application rates.



Nitrous oxide is a potent greenhouse gas. Per gram, its atmospheric warming effect is approximately 296 times as strong as carbon dioxide. The rise in atmospheric N_2O concentration since the start of the industrial era has been largely due to increased agricultural activity; agricultural soils and their management are by far the largest source of man-made N_2O emissions. This is mainly due to increased use of commercial fertilizer-N, either applied directly to the soil or indirectly through recycling as manure (Crutzen et al., 2008). As worldwide fertilizer N demand is expected to rise from 100 million metric tons (M t) in 2006 to >135 M t in 2030, N_2O emissions are widely expected to rise in the future. It is estimated that every kg of newly fixed fertilizer N will eventually lead to an emission of 30 to 50 g N_2O -N, either directly from the soil or indirectly after other N deliveries to water resources or the atmosphere.

Despite these potential effects on N_2O emissions, as well as other N losses to the environment, fertilizer N remains essential to global crop production. Highly productive agricultural systems are often associated with relatively large N losses to the environment, including N_2O emissions. This is because the relationship between crop productivity and fertilizer N input is not linear, but follows the well-known diminishing return function. Therefore, simultaneous achievement of large yields and high NUE is inherently difficult (Cassman et al., 2003).

Although both GHG emissions and NUE are linked to N application rates and soil management, studies on both issues have been largely disconnected in the past. However, there have been some efforts to link the two in order to find some sort of combined optimum. For example, BMPs such as balanced N management and crop rotation have been shown to decrease N_2O emissions (Snyder et al., 2009; Adviento-Borbe et al., 2007). In our article, we expand on the concept of linking agronomic productivity to environmental sustainability (Mosier et al., 2006). We postulate that, instead of assessing N_2O emissions in terms of fluxes per ha or per unit of applied fertilizer N, we should focus on N_2O emissions per unit of harvested product. Such “yield-scaled N_2O emissions” should be minimized in order to achieve cropping systems that are both

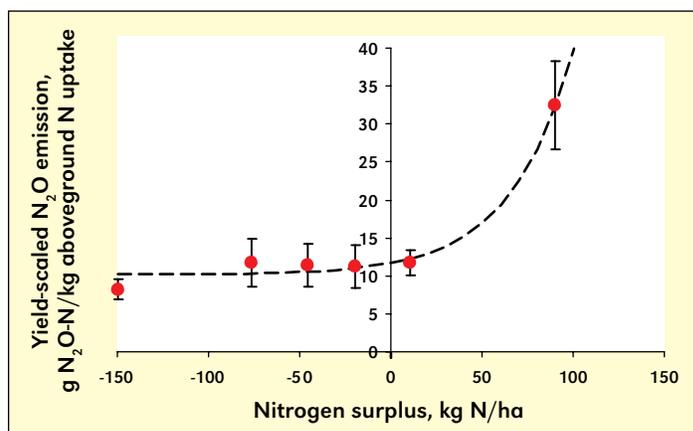


Figure 1. Meta-analysis results of the relationship between N surplus and yield-scaled (i.e. expressed per unit of aboveground N uptake) N_2O emissions. Nitrogen surplus was defined as above-ground N uptake minus N application rate.

highly productive and environmentally sustainable.

We tested this concept in a meta-analysis of studies published on both N_2O fluxes and yield data (Van Groenigen et al., 2010). In our analysis, we explored relations between NUE, N surplus, and yield-scaled N_2O emissions in order to find the optimal combination of agronomic productivity and GHG emissions.

Data Analysis

A literature survey of peer-reviewed publications that reported both N_2O emissions and total N accumulation in crops in agricultural systems was carried out. A total of 19 studies encompassing 147 observations were included, with more than half of the studies located in North America and the remainder located in Europe, Asia, and Oceania. Crops included maize (corn), wheat, potato, onion, and flooded rice. Total inorganic and organic N (manure or sludge) input ranged between 0 and 802 kg N/ha with both an average (and median) value of 134 kg N/ha. The N surplus was calculated as the amount of applied inorganic and/or organic N minus aboveground N uptake (grain plus residue).

Yield-scaled N_2O emissions showed no increase up to a small N surplus of approximately 10 kg N/ha (**Figure 1**). At a

Abbreviations: GHG = greenhouse gas; N_2O = nitrous oxide; BMPs = Best Management Practices; N = nitrogen, GWP = global warming potential.

surplus of 90 kg N/ha, (yield-scaled) N₂O emissions increased more than three-fold. An increase in N₂O emissions when more N is applied than is taken up by the crop has been observed and is predicted to be a common response. With a larger N surplus, more mineral N is available in the soil for N₂O emissions. It is of interest that within the range of a N ‘deficit’ of approximately 150 kg N/ha to a small N surplus of approximately 10 kg N/ha, total N₂O emissions/ha did not change significantly. This probably reflects the capacity for crops to take up moderate rates of applied N during the growing season, before N₂O emissions might be stimulated by wetter conditions.

Yield-scaled N₂O emissions showed a significant and negative relationship with NUE (**Figure 2**). This is a clear indication that agronomic aims of increasing fertilizer NUE are directly linked to GHG efficiency by minimizing N₂O fluxes. Yield-scaled N₂O emissions decreased from 12.7 to 7.1 g N₂O-N/kg N uptake when NUE increased from 19 to 75%.

Because of the wide variety of agroecosystems included in this study, N₂O emission variability remains large, even after accounting for N application rates. Specific factors such as weather, crop type, crop residue quality, soil type and fertilizer type, will all significantly affect N₂O emissions (Mosier et al., 1998). For our findings to result in actual fertilizer recommendations, agroecosystem-specific relationships between N₂O emissions and yield will have to be established. Routine reporting of yield and above-ground N uptake in N₂O emission studies would therefore be of great benefit. Such data are relatively inexpensive and easy to collect, compared with N₂O flux measurements, and the data would provide much insight in the crop-, climate-, and management-related variations in yield-scaled N₂O emissions.

For a full assessment of the GHG efficiency of agricultural production systems, including carbon dioxide and methane effects, an integral lifecycle analysis (LCA) would be needed. However, N₂O emissions are often a decisive factor in the GHG budget of agricultural production systems (Robertson et al., 2000), making our observed relationships significant when developing policy on reducing GHG emissions.

Conclusion

Our results suggest that the best management options for ‘N₂O-efficient’ agronomic production are similar to those promoting agronomic efficiency in general. Rather than focusing on small N application rates [as the Intergovernmental Panel on Climate Change (IPCC) Tier 1 default N₂O emission standard might suggest implicitly] management practices should be aimed at maximizing uptake of applied N in the crop, while achieving high yields. Our analyses show no significant differences in the amount of N₂O emitted per unit of crop N uptake up to a N surplus of 11 kg N/ha. The adoption of BMPs, which can be implemented without a reduction in total yield or total-N accumulation in the crop (Adviento-Borbe et al., 2007), should be considered as a strategy for N₂O reduction. Agroecosystem-specific relationships will be needed to translate our findings into fertilizer recommendations. We recommend routine reporting of yield and crop N uptake rates in N₂O emission studies

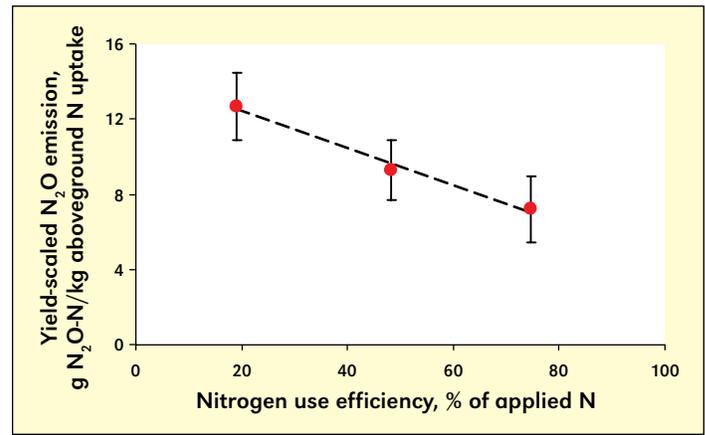


Figure 2. Meta-analysis results of the relationship between N use efficiency and yield-scaled N₂O emissions. NUE is expressed as apparent recovery efficiency (in %) of applied N.

to facilitate such an analysis. We postulate that, in a world with a growing demand for food, fuel, and fiber, expressing N₂O emissions as a function of land area or fertilizer application rate is not helpful and may even be counter-productive. Emissions of N₂O should be assessed as a function of crop N uptake and crop yield. 

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Nutritional Status of Cocoa in Papua New Guinea

By Paul Nelson, Michael Webb, Suzanne Berthelsen, George Curry, David Yinil, Chris Fidelis, Myles Fisher, and Thomas Oberthür

Leaf and soil nutrient status was surveyed at 63 cocoa sites in Papua New Guinea (PNG) to determine if productivity is nutrient limited and how these limitations might be overcome. Nitrogen and Fe were deficient in >89% of the sites and P was deficient in about 25%. Management of cocoa in PNG must improve dramatically for the industry to prosper. Successful management schemes should consider a full systems context due to the complexity of socio-economic-agronomic factors. Improved nutrient management will require development of tools directed towards better foliar analysis.

Cocoa is the primary cash crop in most coastal areas of PNG, growing on 100,000 to 130,000 ha. About 151,000 smallholder households, equaling 16% of the households in the country or about 1 million people, produce 80% of the crop. Many smallholders harvest the crop opportunistically with little or no management inputs. Shortages of land and labor, and lack of agronomic knowledge are major production constraints. Smallholder productivity, 0.3 to 0.4 t/ha/yr, is low compared with plantation yields of 1.5 to 2.5 t/ha/yr and the potential yield of 4.4 t/ha/yr from research plots.

World demand for cocoa is increasing, and PNG cocoa commands a premium for its 'Fine Flavor Status'. In 2007, exports were 35,000 to 40,000 t, with a value of PGK 168 million. However, the industry is threatened by cocoa pod borer, which is spreading rapidly in the country. In East New Britain, one of the worst affected provinces, production fell by about 60% to 8,000 t in 2009.

The objective of this study was to determine the nutrient status of cocoa trees and their soils throughout the cocoa-growing areas of PNG. At a workshop in March 2007, local and Australian scientists together with representatives of the local cocoa growers reviewed information on cocoa nutrition and related issues. They confirmed the need for a survey to determine current nutrient status, selected representative sampling sites, and designed the sampling protocol. At a second workshop a year later, a similar group including market-chain representatives reviewed the survey data. A total of 63 sites were surveyed, including: 48 smallholder lots, six plantations, and eight trials from the Cocoa Coconut Institute (CCI), covering the major cocoa-growing areas of the country (Figure 1).

Sampled plots were 6 x 7 trees. Two samples of the third leaf of a recently hardened leaf flush were selected at mid-canopy height on each of 20 trees, and their length, width, and fresh weight were recorded, together with the number of leaves in the sampled flush. The leaves were dried, weighed, ground, and bulked for each site. Ten ripe pods were sampled at eight sites, separated into beans and husks, dried, weighed, ground, and bulked for each site. Soils of each site were sampled by auger at 15 cm intervals to the 30 cm depth, and then at 30 cm intervals to 90 cm depth. Samples were taken 1 m from the tree trunk at nine trees for the two shallow depths and five trees for the two deeper depths. Samples were bulked by depth for each site.

Leaf samples were analysed for macronutrients and micronutrients. Soils were analyzed for texture, electrical conductivity, pH, cation and anion exchange capacity, exchangeable

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminum; Fe = iron; Mn = manganese; CaCO₃ = calcium carbonate; C = carbon; Zn = zinc.

Note: Monetary symbol PGK = Papua New Guinea Kina (PGK 1 ≈ USD 0.39).

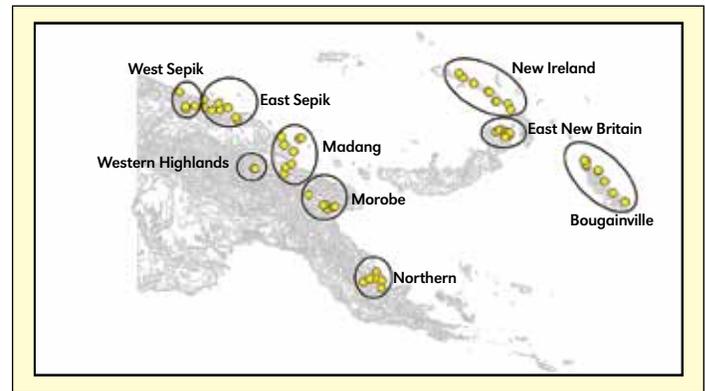


Figure 1. Location of the sites surveyed and the PNG provinces in which they were situated.

cations, extractable P (Colwell), extractable Al, organic C, and total N. Samples with pH > 6.5 were analyzed for CaCO₃.

Results

Management Only 15% of the sites had been farmed for less than 17 years and only 14% of the trees were less than 7 years old. The planting material was sourced from CCI with open-pollinated material before 1982, hybrids until 1994, and clones thereafter. Most smallholder sites were shaded with *Gliricidia*, coconuts, and other species, and food crops were common, especially in younger plantings. About a quarter had legume groundcover, mostly *Pueraria*. Most sites were flat or moderately sloping with reasonably deep soil.

Smallholder growers identified lack of knowledge, poor management, and scarce labor as the main constraints to productivity; less than a quarter were satisfied with their yields.

Table 1 summarizes smallholders' perceptions for good or poor yields. Lack of fertilizer application and poor soil fertility were cited in about a third of the cases.

Almost half the sites were poorly or very poorly pruned and shade management scored nearly as badly. Weed management was rated somewhat better, with less than 30% scoring



In a well-managed cocoa block, Marex Mareka is checking integrated pest management and disease management options in Madang Province. Good pruning, weed control, and disease prevention are key management factors.

Photo by Chris Fidelis

Table 1. Reasons cited by smallholders for good or poor yields. The numbers indicate the number of growers who gave that reason.

Reasons for good yield		Reasons for poor yield	
5	Labor: adequate, available	22	Lack of knowledge
5	Access good	18	Poor management
4	Land tenure secure: no disputes	17	Labor shortage/dispute/cost/other commitments
3	Planting material good (new)	11	Old planting material (Trinitario)
3	Knowledge/experience good	10	Diseases and pests
2	Management good	10	Lack of fertilizer
		6	Lack of finance for purchasing seedlings or tools
		5	Nutrient deficiency/soil exhaustion
		4 ea.	Theft of pods; Fermentary/dryer capacity/functioning limited
		3 ea.	Water logging/flooding; Low prices; Lack of government support
		2	Lack of other chemicals (not fertilizer)
		1 ea.	Land shortage; Bad weather destroying flowers; Poor access; Missing trees

very poor, although in many cases heavy shade reduced weeds more than farmers' management. Almost all sites were affected with black pod disease and canker and over half with pink disease and vascular streak disease.

One-third of both CCI plots and plantations received fertilizer. Almost one-third of smallholders had participated in district fertilizer trials so that part of their cocoa had received some fertilizer. But few had applied it elsewhere on their farms. Fertilizer gave better growth, flowering, and pod yield, but farmers thought it was costly.

Physical accessibility to ripe pods is critically important and is compromised when thieves steal the easily-accessible, low-hanging pods.

Nutrient status We used Wessel's (1985) critical values for macronutrients and data for micronutrients based on survey information by Southern and Dick (1969). Most sites were deficient in N (**Figure 2a**) with a low mean N:P ratio of 10.4, indicating N was more deficient than P. Only 10% of sites were K deficient despite low soil K analyses, possibly because the widespread N deficiency was more limiting and masked its expression. Calcium and Mg were generally satisfactory. About a quarter of the sites indicated P deficiency, uniformly distributed over the survey area. There was no indication of other macronutrient deficiencies. Iron deficiency appears to be widespread (**Figure 2b**), although the critical value needs to be reassessed as does its relation with Mn concentrations. Other micronutrients did not appear to be deficient. Black pod disease, caused by *Phytophthora palmivora*, was more prevalent on plants growing on low-Zn soils. Leaf analysis showed little pattern with respect to dominant soil classification or landform.

Both N and Fe deficiencies showed regional grouping, and hence site specificity, with N deficiency occurring rather more generally in all but the Sepik. Iron deficiency followed a similar regional pattern, but with some occurrences in the Sepik and none in Morobe.

Soil physical properties Root growth was restricted in almost 60% of sites; at eight sites by poorly-drained soils, at

13 sites (mainly in Bougainville and New Ireland), by heavier-textured soils, and at another 13 sites (mainly in the Northern Province), by gravelly and stony soils. There was little physical limitation to root growth at about 40% of sites, mainly in East New Britain, Morobe, and Madang.

Soil chemical and biological fertility Most soils were reasonably fertile with high exchangeable cation contents and acceptable pH. Biological fertility, as indicated by organic C, was generally good for most of the surface soils examined. Ratios of Ca:K >20 and Mg:K >10, which are unfavorable to K uptake, were measured at 75% and 45% of sites, respectively. There was a reasonable relationship between soil and leaf nutrient levels for K and P, but not for other nutrients. All sites having leaf P concentrations less than the critical level of 0.16% had soil Colwell P contents less than 25 to 50 mg/kg, which is the range of critical levels commonly cited for other crops as deficient (Moody and Bolland, 1999).

Discussion

This is the first survey in PNG in which soil and cocoa leaf analyses have been carried out at the same locations, along with information on block management and history. Nitrogen and Fe deficiencies in particular appear to be widespread in cocoa in PNG, with 95% of the sampled sites falling below the critical level for N and 89% for Fe. Phosphorus deficiencies were encountered in only about a quarter of the blocks sampled. Nitrogen deficiency is likely to limit the yield increasing potential of other nutrients.

Agronomic aspects Root growth of cocoa is strongly influenced by the texture and structure of the soil profile (Freyne et al., 1996). Wood (1985) suggested that the ideal soil for tap root penetration and lateral root distribution should be composed of approximately 30 to 40% clay, 50% sand, and 10 to 20% silt, but more important is the vertical distribution of textures throughout the soil profile. Only 40% of the profiles examined were found to be free of physical limitations to root growth.

There is no definitive evidence to show that nutrient depletion is the cause of the onset of tree senility after 8 years, but it seems plausible that it contributes. It is likely that nutrient management, together with sound agronomy such as control of weeds and shade, the type of shade, suitable pruning of the cocoa trees and control of pests and diseases, could improve tree health, productivity, and longevity.

Cocoa production falls into three stages depending on age of the stand: less than 3 years old there are few beans but smallholders integrate cocoa into food-crop gardens which are well managed with low levels of pests and diseases. The second stage from 3 to 8 years is when the cocoa reaches full production, with a high demand for labor to harvest large quantities of ripe pods, which are readily accessible. The incidence of pests and diseases rises during this stage, but the cocoa generates high income. In the third stage, the trees advance into senility with lower yields of less accessible pods, declining management inputs, and high levels of pests and diseases. Most smallholder plots in PNG are in this latter condition.

Technical aspects Leaf age and light intensity



usually override the nutritional effects on leaf nutrient composition except when there are marked deficiencies (Wessel, 1985). We controlled for leaf age in the sampling protocol, but we could not fully control for light. This remains an unknown variable.

Growers and researchers discuss constraints to cocoa productivity in East New Britain. David Yinil, Senior Agronomist, Cocoa Coconut Institute, is second from right.

Although concentrations of a particular element may not be deficient at the time of sampling, correction of other deficiencies may cause that element to become deficient in the future. In particular, N was deficient at almost all sites, and correcting it is likely to result in deficiency of other elements.

As with other crops and elsewhere there are indications that deficiencies are site-specific (**Figure 2**). More intensive work is required for definitive analysis such as nutrient response trials on different soil types.

Sustainable intensification Of the smallholder sites surveyed, 85% had been in agricultural production for more than 17 years, with no application of fertilizers. The nutrient-supplying capacity of the soil will run down over time, and long-term sustainability of cocoa production will require that depleted nutrients be replaced.

Nutrient exports were similar to those elsewhere (Hartemink, 2005), but were at the low end for N and higher than the reported range for K. Cocoa beans from PNG have higher K content than beans from other places, indicating higher export per tonne of beans. This needs to be kept in mind for the longer term future of the industry. The nutrients removed per 1,000 kg of dry beans are 18 to 22 kg N, 3 to 5 kg P, 11 to 15 kg K, 1 to 2 kg Ca, and 3 to 4 kg Mg. At the average yield of 0.4 t/ha/yr, a total of 120 kg N, 24 kg P, 78 kg K, 9 kg Ca, and 21 kg Mg would be removed from each hectare in 15 years. The amount removed by plantation crops would be 5 to 6 times these quantities, and for crops achieving potential yield would be 10 to 11 times.

It is generally agreed that management of cocoa blocks in PNG must improve dramatically for the cocoa industry to prosper, and perhaps even to survive, particularly with the rapid spread of cocoa pod borer. If improved management is implemented, it is likely that limitations due to nutrient deficiencies will become more important, also with respect to the crop's disease resistance. Foliar analysis is a key tool for site-specific nutrient management.

Socioeconomic considerations often weigh more heavily with smallholders than high-quality crop husbandry. Nevertheless, there is a clear need to define the crop husbandry that will give optimum crop productivity in relation to other constraints. **DC**

Photo by John Armour

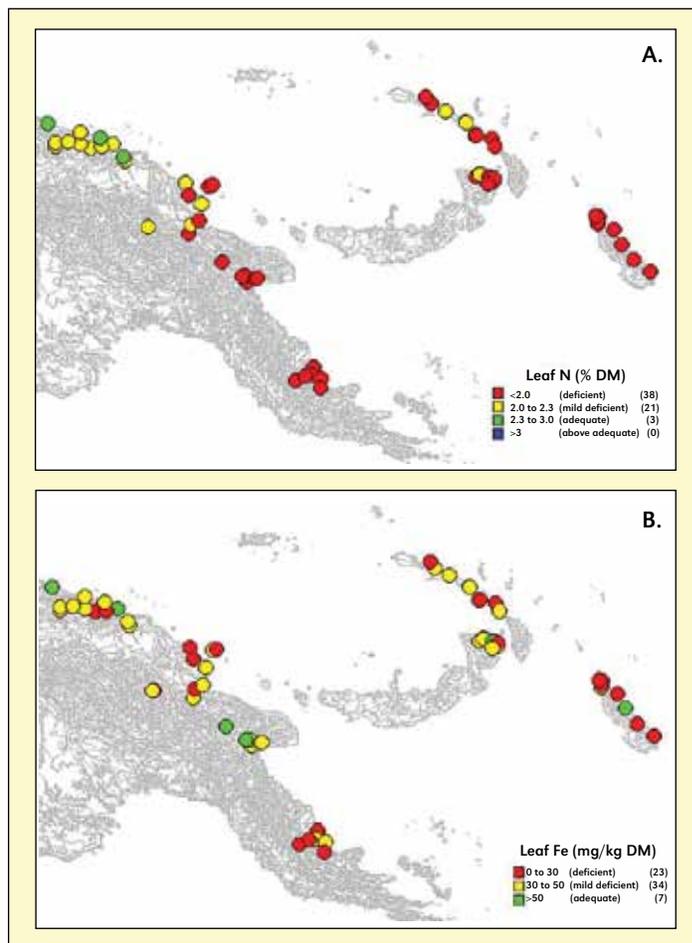


Figure 2. Maps of leaf (A) N and (B) Fe concentrations at the surveyed sites.

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Dr. Nelson and Ms. Berthelsen are with James Cook University, Townsville and Cairns, Australia. Dr. Webb is with CSIRO Land and Water, Townsville, Australia. Prof. Curry is with Curtin University of Technology, Perth, Australia. Mr. Yinil and Mr. Fidelis are with the Cocoa Coconut Institute, Tavilo, Papua New Guinea. Dr. Fisher is with Centro Internacional de Agricultura Tropical, Cali, Colombia. Dr. Oberthur is Director, IPNI Southeast Asia Program, Penang, Malaysia; e-mail: toberthur@ipni.net.

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Nitrogen Utilization by Western U.S. Cotton

By Jeffrey C. Silvertooth, Kevin F. Bronson, E. Randall Norton, and Robert Mikkelsen

An adequate supply of N is essential for successful cotton production. Sufficient N initially supports rapid development of leaves and roots. Later in the season, most of the N is found in the seeds. Understanding cotton development aids in efficient nutrient management.



Cotton growers have long recognized the vital role N plays in fiber production. They have learned to manage the N supply to provide adequate N for boll filling, but minimize any excess soil N present prior to harvest.

An inadequate N supply during the vegetative period will slow or stop leaf development. Healthy leaves provide the photosynthetic capacity needed to support the growing bolls.

Excess amounts of N can be associated with boll shedding, but the primary detriment is when surplus N encourages excessive vegetative growth. When this occurs, the poor boll set is caused by vegetative shading and increased insect attractiveness, not the excess N. Too much N also causes delays in maturity and difficulty in defoliation.

For optimal N management, it is important to understand the relationship between the morphological and physiological changes as a crop grows. Individual plant species can vary tremendously in physiological behavior over their life cycle and their nutrient requirements will change during various stages of growth.

Nitrogen Uptake and Assimilation Supplying cotton with adequate N first involves transferring the dissolved nutrient from the soil solution across root membranes and then into plant cells. Next, assimilation involves a series of biochemical reactions that convert the N into a form that can be incorporated into plant structures and/or biologically active forms.

Nitrate (NO_3^-) is the dominant form of N acquired by cotton. Following uptake into the root, NO_3^- is transported in the xylem to the photosynthetically active green leaves (**Figure 1**). The xylem is the principle pathway for long-range transport of N from roots to the leaves and bolls. It is notable that some N transport will occur in the phloem and it is bidirectional. In cotton, over 95% of the xylem N is in the NO_3^- form. This physiological tendency of loading NO_3^- into the xylem and petioles facilitates the petiole NO_3^- test as an assessment of plant N fertility status, commonly used as an N fertilization guide. The NO_3^- is loaded into the mesophyll cells of leaves where it is reduced first to amino-N compounds and then combined into proteins.

Multiple studies have shown similar patterns where cotton has an initial period of rapid N accumulation in the vegetation, beginning at approximately the formation of the first pinhead squares (**Figure 2**). Rapid N uptake continues to the time of peak bloom, when accumulation reaches its maximum daily N uptake (flux of 4 to 5 lb N/A/day). Following peak bloom,

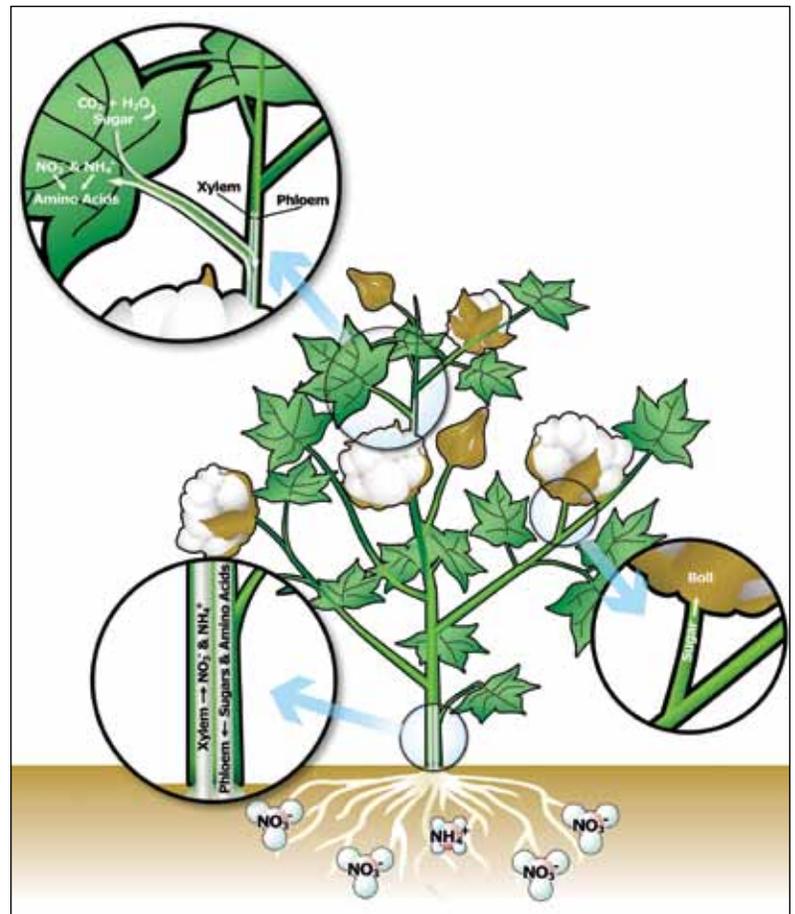


Figure 1. Prior to bloom, most of the N is used in the rapidly growing vegetation and root system. Later in the season, the developing bolls are the largest sink for N, as leaf and root growth declines.

N uptake continues at a diminished rate and N translocation from vegetative to reproductive plant parts becomes a dominant process (**Figure 3**). Studies have consistently shown that the seeds are the primary sink for N in the bolls (> 50% of the total N) for both Upland (*G. hirsutum* L.) and American Pima (*G. barbadense* L.) cotton (Unruh and Silvertooth, 1996; Bronson, 2008; Fritschi et al., 2004). Boll walls (burrs) have low N concentrations at maturity and N removal in the fiber is negligible.

Monitoring Crop Growth Cotton development is typically described as a function of heat units (HU) or degree days (DD) to track growth stages. This allows crop development to be standardized among different years and locations. Heat units more accurately track cotton development than merely counting days after planting, since crops respond to environmental conditions and not calendar days. This approach of using phenological timelines or baselines works best for irrigated conditions where crop vigor and environmental growth

Abbreviations and notes: N = nitrogen; K = potassium; ppm = parts per million.

conditions are more consistent than in non-irrigated situations.

Estimating the N Requirement A common approach for managing N is the use of a “yield goal” to match estimated crop N requirements to projected plant demand. From soil test information and the analysis of the irrigation water, the amount of available N can be calculated and then subtracted from the total amount required for the crop. This is a useful guideline for N fertilization, but the amount of N required per bale of lint is not constant and it increases as yields increase.

It is estimated that the total crop N demand ranges from 40 lb N/bale (18 kg N/bale) in Texas and California (Yabaji et al., 2009; Fritschi et al., 2004) to 75 lb N/bale (34 kg N/bale) in Arizona (Unruh and Silvertooth, 1996). As much as 70% of the total N uptake ends up in the mature cotton seed (Bronson, 2008). To achieve the greatest efficiency for N uptake and utilization, fertilization practices are synchronized to meet periods of crop demand. When available, fertigation provides an excellent way to supply additional N at rates and times that best match the crop requirements.

Water There are several important implications regarding water availability and N fertility in cotton. First, N nutrition is negatively affected by water stress. Uptake of N is diminished under water stress conditions because of a reduction in energy necessary for active uptake due to reductions in photosynthesis. The transpirational stream will be diminished under drought stress due to stomatal closure, limiting the upward flow of N to the leaves. Additionally, water stress and reductions in photosynthesis will limit the amount of chemical energy necessary for the conversion of NO_3^- to amino acids. Therefore, maintaining adequate moisture in the rootzone will improve N efficiency. Less than optimal management of either N or water will have a negative impact on the other input.

Implications for Fertilizer N Management Studies in California (Hutchmacher et al., 2004) and in Texas (Bronson et al., 2009) have indicated that it is advisable to measure the soil NO_3^- content in the rootzone (2 to 3 ft.) prior to cotton planting. Unlike the humid southeastern USA, NO_3^- leaching losses are generally low and soil profile NO_3^- concentrations can be substantial.

Calculating the N fertilizer recommendation for cotton in the western U.S. usually involves a yield goal and mass balance approach. A producer would start with a yield goal and analysis of soil NO_3^- . Nitrogen credits from the soil and irrigation water will be subtracted from the N fertilizer recommendation. In addition to the “per bale” N requirement already mentioned, the final information needed is the recovery efficiency of N fertilizer added. This can range from 20% in some furrow-irrigated cotton fields to over 70% when N is supplied through drip irrigation (Bronson et al., 2008). When N is carefully managed, fertilizer recovery by furrow-irrigated cotton can also exceed 70% (Navarro et al., 1997).

Another N fertilizer management tool is monitoring the plant N status during the growing season. Petiole sampling is routinely used in the western U.S. to verify the presence of adequate N. Since NO_3^- is the dominant form of N taken up by the roots and transported to the leaves, petiole analysis provides a guide to determine the available N supply in the soil. Skill is needed to collect and interpret petiole NO_3^- data. For example, the time of day and the position on the plant for collecting petioles can all be important in the interpretation.

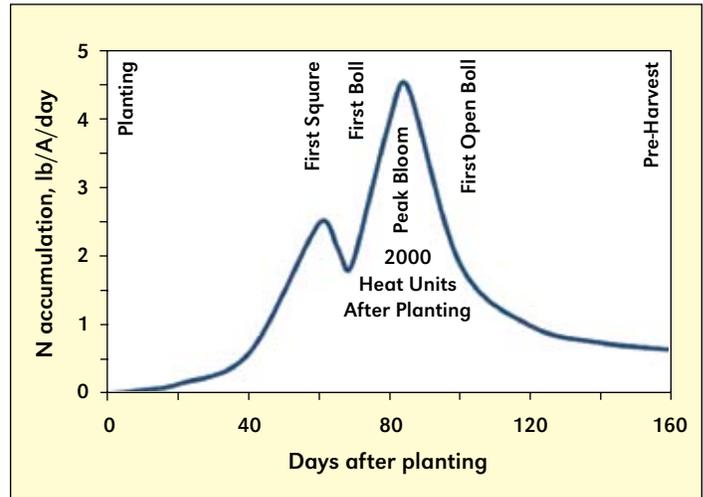


Figure 2. Daily N accumulation rate of upland irrigated cotton during the growing season in Arizona. Silvertooth and Norton, 2011

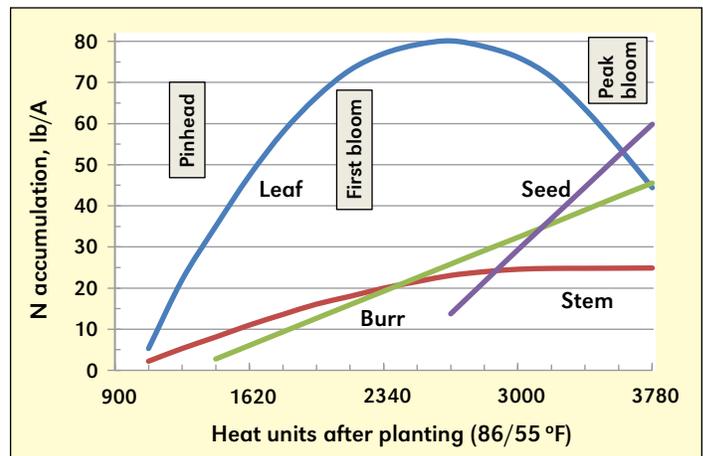


Figure 3. Seasonal pattern of N uptake and accumulation in irrigated cotton in Arizona (Upland “Delta Pine 90”). Unruh and Silvertooth, 1996.

To avoid premature cutout due to N deficiency, the California and the Arizona Extension services recommend keeping petiole NO_3^- concentrations above 2000 ppm during the fruit set period. The effect of N deficiency on fruit set is two-fold. N-deficient cotton plants stop developing new nodes and squares, and enter premature cutout. Furthermore, N deficiency can increase the shed of young bolls.

Foliar applications of N are sometimes used to supplement the soil supply, especially when expected yields are large and the soil supply of N is low. The balance between N demand and supply is determined by the number of bolls, the soil supply, and the plant N supply that can be remobilized to the boll without impairing photosynthesis. Urea or other soluble N sources are commonly sprayed onto foliage at a rate of 5 to 10 lb N/A, sometimes with multiple applications during boll maturation.

Emerging technologies to rapidly assess in-season cotton N status include the chlorophyll meter and canopy-level spectroradiometers. Studies in West Texas indicate that these sensors can result in modest savings of N fertilizer without reducing lint yields, compared to soil-based N management (Yabaji et al., 2009; Bronson et al., 2011).

Definitions Unique to Cotton Development

Bale: 480 to 500 lb, or 218 to 225 kg of cotton lint.

Boll: The cotton fruit consisting of seeds, fibers, and burrs. Bolls begin to develop following pollination in three phases: enlargement (3 weeks), filling (3 weeks), and maturation. Under typical conditions it requires approximately 50 days after pollination occurs for a boll to “open” prior to harvesting.

Cut out: Growth stage when flower development ceases.

Defoliation: Defoliating chemicals are applied to terminate growth and make machine harvesting easier.

First square: The initial square formed on a fruiting branch.

Flowering: The period when the cotton plant is still blooming. This stage can last for 6 weeks or more.

Heat units (degree days): The accumulated temperature effect when growing conditions are between 55 and 86 °F.

Match head: The second stage of square development, following the pinhead stage.

Peak bloom: Period of maximum bloom production, preceded by stages of early bloom and cut out.

Pinhead: The first stage where a new square can be identified.

Square: A fruiting bud that forms at the initiation of a fruiting branch.

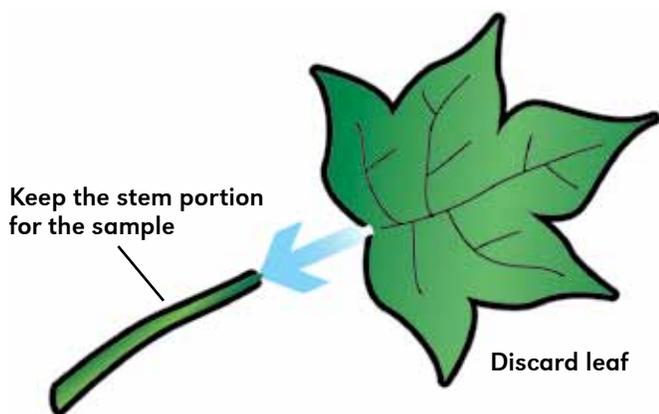
Summary

While an adequate supply of all plant nutrients is essential for successful cotton production, management of N is especially important. Both pre-season and in-season monitoring of N is needed to maximize N efficiency. A shortage of adequate N during intense demand periods of peak bloom and first boll opening will reduce yields. An excess supply of N during early vegetative stages and in the late season cut-out will be detrimental to yield and quality. **BG**

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Petiole Testing and Tissue Sampling

Tissue testing is used to analyze the entire leaf blade for all of the essential nutrients that might be of concern. Leaf tissue testing is generally done before first bloom to detect any nutritional shortage. Petiole sampling begins around the first bloom and continues for the next 8 to 10 weeks. Nitrate is the major constituent, but P and K are sometimes monitored too.

Petioles are collected from areas that are representative of management zones in the field. Petioles are removed from the most recently fully matured leaf, usually the 4th and 5th leaf from the top of the plant. The lab needs 25 to 35 petioles for analysis.

Following are selected sufficiency guidelines used for monitoring petiole NO₃-N concentrations in the uppermost fully developed leaf during critical stages of growth. Nitrate concentrations will decline during the growing season and critical concentrations are general benchmarks. Additional concentrations can vary among varieties and between species (e.g. Upland and Pima cotton).

California				
	----- ppm NO ₃ -N -----			
Range	First squares	First flowers	First bolls	First open bolls
Should be sufficient	18,000	12,500	7,000	3,500
May be deficient	12,000	7,500	3,000	1,500

Source: Basset and MacKenzie, 1983. Acala variety, SJ2

Arizona				
	----- ppm NO ₃ -N -----			
Range ¹	First squares	First flowers	First bolls	First open bolls
Variety				
Pima	>10,000	>8,000	>4,000	>2,000
Delta Pine	>18,000	>14,000	>8,000	>4,000

¹Contents of petioles from uppermost, fully developed leaves from Upland and Pima cotton grown under irrigated conditions. Source: Pennington and Tucker, 1984

Crop Yield and Soil Fertility as Influenced by Nutrient Management in Rainfed Inner Mongolia

By Yu Duan, De-bao Tuo, Pei-yi Zhao, Huan-chun Li, and Shutian Li

Traditional nutrient management within the rainfed regions of Inner Mongolia usually results in poor crop productivity. In this study, six successive crop seasons found N, P, and K fertilizer to be responsible for a range of crop yield increases between 5 and 50%. The combined use of recommended NPK rates with manures sustained crop yields and improved soil fertility, but caution must be exercised to avoid the overuse of P and, in turn, the over accumulation of P in soil.

The Inner Mongolia Autonomous Region (IMAR) is a relatively arid, but yet important crop production zone of China. About 70% of its crops are rainfed, including cereals, potato, rapeseed, and sunflower, which are often grown with under 350 mm of annual rainfall (**Table 1**). Most farmers in IMAR do not use fertilizer and crop yields are low. Little biomass production within this dry climate also results in inadequate recycling of straw to farm fields. This scenario results in the gradual decline in soil fertility and crop productivity. A prominent research priority is to develop the steps required to reverse this trend of declining soil fertility through improved nutrient management.

A 6-year fixed experiment was initiated in 2004 at the Arid Crop Station of IMAR, Wuchuan, to study changes in crop response and nutrient balance resulting from selected nutrient management practices. The site evaluated the application of a NPK recommendation (OPT), OPT-N, OPT-P, OPT-K, sheep manure (M), OPT+M, N alone, and a zero input check (CK).

Rates within the OPT were recommended based on soil analysis using Agro Services International (ASI) procedures (Portch and Hunter, 2002) and realistic yield targets for each crop tested. Beginning in 2004, the 3-year crop sequence was potato-rapeseed-oat.

Notes and abbreviations: N = nitrogen; NH_4^+ = ammonium; NO_3^- = nitrate; P = phosphorus; K = potassium.

Table 1. Rainfall from 2004 to 2009 compared with the average from 1961 to 2008 at the experimental site.

Year	2004	2005	2006	2007	2008	2009	Average 1961-2008
Annual rainfall, mm	397	279	223	223	419	199	346
Rainfall during growing season (May to August), mm	298	211	173	83	309	158	295

Application of N, P, or K fertilizer resulted in improved yields during the timeframe of the field study (**Table 2**). In the startup year, potato yields increased by 4.3%, 14.4% and 11.6% after application of N, P, and K fertilizer, respectively. After 2004, the recommended NPK treatment produced 10 to 20% more yield than the N, P, or K omission plots, except in 2008 when N and P omission especially affected rapeseed production through 50% and 30% yield reductions, respectively. These larger than average responses are most probably a reflection of higher rainfall at the site, which produced more favorable growing conditions and a higher crop requirement for N and P. Yields under the combined application of NPK and sheep manure were similar or above that achieved with NPK alone. Application of manure alone failed to positively affect potato or oat yields, and reduced rapeseed yields by 20 to 30%. Reliance on N application alone decreased crop yield by 5 to 22%, while the CK reduced crop yield by 15 to 54%.

The nutrient balances calculated after the six successive crops suggest that recommended rates for N or K were not sufficient to balance crop removal, but the P recommendation was excessive and resulted in its accumulation in soil during

Table 2. Crop yield response to different nutrient management practices.

Treat.	Potato '04		Rapeseed '05		Oat '06		Potato '07		Rapeseed '08		Oat '09	
	t/ha	%	kg/ha	%	kg/ha	%	t/ha	%	kg/ha	%	kg/ha	%
NPK (OPT)	14.4b	100.0	1,476b	100.0	1,906a	100.0	13.9ab	100.0	1,458a	100.0	1,266ab	100.0
OPT-N	13.8bc	95.6	1,239cd	84.0	1,630b	85.5	12.4bc	89.3	883c	49.1	1,140bc	90.0
OPT-P	12.6bc	87.5	1,315c	89.1	1,557bc	81.7	12.4bc	89.5	1,029bc	70.6	1,133bc	89.5
OPT-K	12.9bc	89.5	1,271cd	86.1	1,573bc	82.5	11.4bc	82.3	1,417a	97.1	1,153bc	91.1
M ¹	13.9bc	96.2	1,182de	80.1	1,667b	87.4	13.5bc	97.5	1,038bc	71.1	1,270ab	100.4
OPT+M	17.1a	118.2	1,648a	111.7	2,005a	105.2	16.3a	117.7	1,483a	101.7	1,335a	105.5
N	13.2bc	91.5	1,240cd	84.0	1,490bc	78.1	12.0bc	86.7	1,167b	80.0	1,199abc	94.7
CK	11.9c	82.2	1,105e	74.9	1,354c	71.0	10.8c	78.0	671d	46.0	1,076c	85.0

¹Sheep manure with 0.78-0.35-0.89% of N-P₂O₅-K₂O, 7,500 kg/ha each year, except in 2006 when 15,000 kg/ha was applied.

Randomly designed treatments (three replicates) applied to a plot area of 50 m². Numbers within each column followed by the same letter are not significantly different at p = 0.05.



Researchers characterized the impact of improved nutrient management within a three-crop rotation system including potato, rapeseed, and oat.

Table 3. Nutrient input, output, and balance during the six successive crops.

		OPT	OPT-N	OPT-P	OPT-K	M	NPK+M	N	CK
Nutrient input, kg/ha	N	395	0	395	395	411	806	395	0
	P ₂ O ₅	320	320	0	320	185	505	0	0
	K ₂ O	250	250	250	0	468	718	0	0
Nutrient removal by crop seed and straw, kg/ha	N	497	353	381	433	348	562	426	298
	P ₂ O ₅	173	129	122	144	125	198	117	102
	K ₂ O	439	334	317	304	329	517	319	290
Nutrient balance, kg/ha	N	-102	-353	14	-38	62	243	-31	-298
	P ₂ O ₅	147	191	-122	176	60	307	-117	-102
	K ₂ O	-189	-84	-67	-304	139	201	-319	-290

the years of study (**Table 3**). Accumulated recoveries for N, P, and K from the six crops were 36%, 16%, and 54%, respectively. Omission plots for N, P, and K generated large deficits of 353 kg N/ha, 122 kg P₂O₅/ha, and 304 kg K₂O/ha during this timeframe. Although manure applications did not affect the crop yields, soil N, P, and especially K were in surplus. Larger accumulations were created under continuous application of the NPK recommendation plus manure.

Soil testing (0 to 20 cm) at the end of the experiment found mineral N (NH₄⁺+NO₃⁻) to be lower in all treatments compared with that measured prior to the trial's initiation (**Table 4**). The recommended NPK treatment maintained the highest mineral N content followed by NPK plus manure. Soil Olsen-P increased in all treatments with the exception of the N or OPT-P treatments. NPK with manure resulted in the highest Olsen-P values after six crop seasons. Exchangeable soil K in all fertilizer treatments did not change significantly, while the manure-supplying treatments had a measurable positive impact on exchangeable K.

Under this rainfed rotation system the recommended NPK alone could not sustain the N and K balance, and only its combination with manure led to improved crop yields and soil fertility. It should be highlighted that although the combined use of recommended rates of NPK with manure supported yields and improved soil fertility under these conditions, special caution must be taken against the overuse of all nutrients and excessive accumulation in soil. Careful monitoring of soil P accumulation is stressed when fertilizer P is used in combination with manure. 

Table 4. Surface soil (0 to 20 cm) nutrient levels before and after 6 years of experimentation.

Treat.	Mineral N ¹ mg/L	Olsen-P, mg/L	Exchangeable K, mg/L
NPK (OPT)	33.4	28.5	73.0
OPT-N	23.2	22.8	64.7
OPT-P	18.7	10.6	73.8
OPT-K	18.5	25.9	70.9
M	21.1	16.5	83.5
OPT+M	25.9	34.5	103.9
N	25.2	12.4	67.0
CK	18.4	16.3	63.4
Soil before trial	75.0	14.5	70.4

¹Mineral N includes NH₄⁺-N and NO₃⁻-N. The general critical values for soil fertility evaluation are 20 mg/L, 12 mg/L, and 78 mg/L for mineral N, Olsen-P, and exchangeable K, respectively.

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Fertilizer Use and Human Health

Once again, food prices have been climbing. A growing human family seeks more and better food. Farmers, already under pressure to reduce impact on the environment, are pushed to produce more. Responsible stewardship of plant nutrition has never been more important.

The issue of food security comprises more than just quantity. Quality is just as crucial. Plant nutrition impacts both, ensuring that plant products nourish people. To meet the nutritional needs of expected population growth, global cereal production is forecast to increase by 70% by 2050. Important components of these nutritional needs include carbohydrates, proteins, oils, vitamins, and minerals. Plant nutrition affects them all.

Many of the healthful components of food are boosted by the application of nutrients. Since most farmers already fertilize for optimum yields, these benefits are easily overlooked. Applying N to cereals adds to the protein they produce, as well as their yields. Phosphorus, K, and S can all enhance the biological value of the protein in potatoes. Trace elements important to human nutrition, especially zinc, selenium, and iodine, can be optimized in the diet by applying them to food crops. Plant nutrition can impact the plant diseases that cause degradation of food products and mycotoxin risks.



USDA-ARS photo/Peggy Greb (D1448-2)

Applied with responsible nutrient stewardship, fertilizer contributes to the production of healthful food.

and managed. For decades, nitrate in drinking water has been a concern. While new evidence shows a positive role for nitrate in cardiovascular health, and the occurrence of methemoglobinemia has been rare in developed countries, questions remain regarding its potential relation to carcinogenic nitrosamines. More recent questions have arisen as to whether ammonia emissions from fertilizer could contribute to the formation of unhealthy levels of smog. Eutrophication leading to harmful algal blooms has been attributed in many places to losses of agricultural nutrients.

Even though questions remain regarding the degree to which agricultural nutrients are responsible, it must be acknowledged that the perturbations arising from the globally unprecedented, large-scale increase in the use of fertilizer in the past 50 to 100 years are worthy of careful attention and study. Those engaged in research and development for cropping systems recognize the multiple benefits of increasing nutrient use efficiency, and have already made considerable progress in reducing surpluses and losses of nutrients. Continued progress is needed to ensure optimum human health on both sides of the equation: the provision of adequate quantities of nutritious food, and the avoidance of harm to the environment upon which all life depends.

Responsible nutrient stewardship, based on the 4R concept (right source, rate, time, and place), has great potential to continue providing benefits to the health of humanity. The International Fertilizer Industry Association (IFA) and IPNI are working on a scientific publication on fertilizer and human health. It will provide details on the impacts mentioned above, and more. The intent is to inform the industry and others interested in fertilizer use impacts, correct misperceptions with a credible science-based approach, and to invite constructive contributions from science toward enhancing the benefits and resolving the issues. 

This topic is adapted from a Plant Nutrition TODAY article written by Dr. Tom Bruulsema, IPNI Northeast Region Director, located at Guelph, Ontario; e-mail: tom.bruulsema@ipni.net.



Photo by Dr. K. Majumdar

The World Health Organization defines human health as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.

Where rice is the most common staple and where intake of milk products is low, Ca deficiency can be quite common. Broccoli and soybeans are examples of plants that can contribute Ca and Mg to the human diet. When crops like these are grown in acid soils of limited fertility, applying lime can boost the levels of these minerals. Applying K can increase the K concentration of fruits and vegetables, along with qualities like sweetness, texture, color, vitamin C, beta-carotene, lycopene, and folic acid contents.

Fertilizer use may also be associated with a number of negative factors that need to be properly understood

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium.

How Does One pH Compare to Another?

Soil pH. It is one of the most important chemical properties that affect nutrient interactions in soils and plants. It is, however, one of the most misunderstood measurements, particularly when comparing one pH value to another.

A question that is often asked is, “How many times more acid is one pH than another?” This question is not so straightforward to answer, because pH is not on a linear scale, like a ruler. Instead, it is on a negative log scale. Soils that are higher in acidity actually have smaller pH values, thanks to the negative log scale. The pH scale goes from 0 to 14. The 0 end of the scale is more acid. The 14 end is basic, and a pH of 7 is neutral, dividing acidic from basic. So we know that a pH of 5.8 is more acid than a pH of 6.6. But how many more times acid is it?

To get at the answer to this question, we must first recognize that pH is a transformed measure of the concentration of acid. To find out “how many more times acid” one pH value is than another, we have to do some mathematical manipulations to get us out of the negative log scale and back to a linear scale where such comparisons make sense.

The table in the next column was developed from these mathematical manipulations and is provided to allow you to quickly determine how many times more acid a lower pH value is than a higher one. To use the table, take the higher pH value and subtract the lower one. Look up the difference in the table, under the heading “pH difference.” Then look at the corresponding number in the

pH difference	Times more acid	pH difference	Times more acid	pH difference	Times more acid
0.1	1.3	1.1	13	2.1	126
0.2	1.6	1.2	16	2.2	158
0.3	2.0	1.3	20	2.3	200
0.4	2.5	1.4	25	2.4	251
0.5	3.2	1.5	32	2.5	316
0.6	4.0	1.6	40	2.6	398
0.7	5.0	1.7	50	2.7	501
0.8	6.3	1.8	63	2.8	631
0.9	7.9	1.9	79	2.9	794
1.0	10.0	2.0	100	3.0	1000

column to the right labeled “Times more acid.”

Using our example, we want to compare pH 5.8 and 6.6. We take the higher value and subtract the lower one: $6.6 - 5.8 = 0.8$. When we look up 0.8 in the table, we get 6.3. So the lower pH of 5.8 is 6.3 times more acid than the higher pH of 6.6. Using this table, you can easily determine how two pH values compare to one another, up to a difference of 3 pH units. For a more complete set of units, visit <http://nanc.ipni.net/articles/NANC0022-EN>. 

This topic is adapted from a Plant Nutrition TODAY article authored by Dr. T. Scott Murrell, IPNI Northcentral Region Director, located at West Lafayette, Indiana; e-mail: smurrell@ipni.net.

IPNI Awards Available to Graduate Students and Scientists in 2011

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

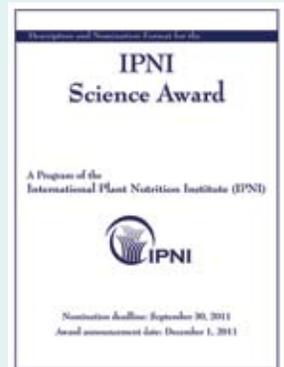
“We receive very favorable reaction to these awards each year and they clearly have many positive benefits,” said IPNI President Dr. Terry Roberts. “It is important to encourage talented young people in their studies of agronomic and soil sciences, while established scientists also deserve recognition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

The Scholar Award requires students who are candidates for either a M.S. or Ph.D. degree in agronomy, soil science, or related fields to submit an application and supporting information by June 30. Individual graduate students in any country where an IPNI

program exists are eligible. Only a limited number of recipients are selected for the award, worth USD 2,000 (two thousand dollars) each. The application process is available on-line only. Recipients are announced in September.

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

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



Maximizing Productivity and Profit through Site-Specific Nutrient Management in Rice-Based Cropping Systems

By V.K. Singh, K. Majumdar, M.P. Singh, Raj Kumar, and B. Gangwar

More comprehensive nutrient use strategies are required to offset the rates of nutrient depletion and emergence of multi-nutrient deficiencies within the western Indo-Gangetic Plain (IGP) region. This study's site-specific nutrient management (SSNM) strategy increased crop yield, system productivity, and profitability within different rice-based systems compared with treatments based on existing recommendations or farm practice.

Depletion of native nutrient reserves, emergence of multi-nutrient deficiencies, and decline in factor productivity of applied nutrients – the latter a measure of nutrient use efficiency defined by Snyder and Bruulsema (2007) as yield of harvested portion divided by amount of fertilizer nutrient applied – are major reasons for productivity stagnation in rice-based systems in the Upper Gangetic Plain region of India (Yadav 2000; Tiwari et al., 2006). Surveys conducted by the Project Directorate for Cropping Systems Research (PDCSR) in different agro-climatic regions indicate that current N-based farmer fertilization practices are creating nutrient imbalance in soil-plant systems, besides increasing pest incidence, cost of production, and environmental problems (Dwivedi et al., 2001). On the other hand, long-term experiments and other studies indicate that crop productivity can be sustained with balanced fertilization. SSNM can take into account all nutrient deficiencies to ensure crop demands are met and soil fertility is improved, which in turn ensures higher nutrient use efficiency, higher crop productivity, and higher economic returns (Dobermann et al., 2004).

Field experiments were conducted during 2008-09 at PDCSR Modipuram, Meerut, to evaluate the agronomic performance of five nutrient management options: (1) Farmer fertilizer practice (FFP), (2) State fertilizer recommendation (SR), (3) Improved State recommendation (ISR) providing 25% more N and 50% more P and K than the SR, (4) State soil testing laboratory recommendation (STLR), and (5) SSNM in systems growing wheat-rice, potato-rice, garlic-rice, chickpea-rice, mustard-rice, and berseem-rice.

The experimental site was located at 29° 4' N latitude, 77° 46' E longitude in western Uttar Pradesh on a Typic Ustochrept (Sobhapur sandy loam) soil within the Upper Gangetic Plains Region. The region has a semi-arid and sub-tropical climate with dry, hot summers and cold winters. The average annual rainfall is 810 mm, 75% of which is received between July and September. Initial soil samples were collected randomly from the experimental field. Soil analyses were done by Agro Services International Inc., per methods described by Portch and Hunter (2002) and SSNM recommendations were developed from soil test values and nutrient uptake requirements for the expected yield of different crops. The experimental site was alkaline in reaction and low in organic carbon (0.48%), available K (166 kg/ha) and S (4 mg/kg), and high in P (30 mg/kg). Available micronutrient contents including: Zn, Mn, Cu, Fe, and B were low to medium at 0.6, 12, 2, 47, and 0.4 mg/kg, respectively.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Zn = zinc; Mn = manganese; Cu = copper; Fe = iron; B = boron; DAP = diammonium phosphate; KCl = potassium chloride; INR = Indian rupee.

Table 1. Treatment details of different winter season crops.

Treatments	----- Rate applied, kg/ha -----					
	N	P ₂ O ₅	K ₂ O	S	ZnSO ₄	Borax
Wheat						
FFP	150	60				
SR	120	60	40			
ISR	150	75	60			
STLR	150	45	50			
SSNM	150	75	90	30	25	5
Potato						
FFP	250	150	40		25	
SR	180	80	100			
ISR	225	100	150			
STLR	225	60	125			
SSNM	210	100	150	40	40	10
Garlic						
FFP	22.5	58				
SR	125	60	60			
ISR	156	75	90			
STLR	156	45	75			
SSNM	150	90	120	45	25	
Chickpea						
FFP	22.5	58				
SR	20	50	30			
ISR	25	62.5	45			
STLR	25	37.5	37.5			
SSNM	30	75	75	20	40	5
Mustard						
FFP	60	60				
SR	120	50	40			
ISR	150	62.5	60			
STLR	150	37.5	50			
SSNM	150	75	90	45	15	5
Berseem (fodder crop)						
FFP	75	50				
SR	30	60				
ISR	37.5	45				
STLR	37.5	45				
SSNM	40	100	100	20	20	5

Note: Rice was grown after each crop with same treatments structure following the general recommendation for rice.

The experiment used a split-plot design with three replications. The treatment details for winter season crops are given in **Table 1**. A succeeding rice crop was grown in the same

Table 2. Effect of nutrient management options on productivity (kg/ha) of different rice-based cropping systems.

Nutrient management options	Mustard	Chickpea	Garlic clover	Berseem green (fodder)	Potato tuber	Wheat
FFP	1,688	1,970	4,512	75,050	17,900	5,029
SR	2,090	2,188	6,575	85,101	22,600	5,610
ISR	2,240	2,442	7,022	87,772	24,200	6,071
STLR	2,105	2,210	6,640	80,029	21,800	5,658
SSNM	2,312	2,652	7,534	92,219	27,500	6,255
CD<0.05	126	214	512	-	2,010	416
----- Residual rice yield -----						
FFP	6,745	6,839	7,070	7,161	7,248	6,790
SR	7,276	7,903	7,329	8,071	8,115	7,237
ISR	8,145	8,111	8,023	8,524	8,456	7,745
STLR	7,771	8,042	8,469	8,386	8,310	7,027
SSNM	9,041	9,250	9,025	9,338	9,542	8,836
CD<0.05	772	823	664	938	734	543

CD denotes critical difference, which is similar to the least significant difference.

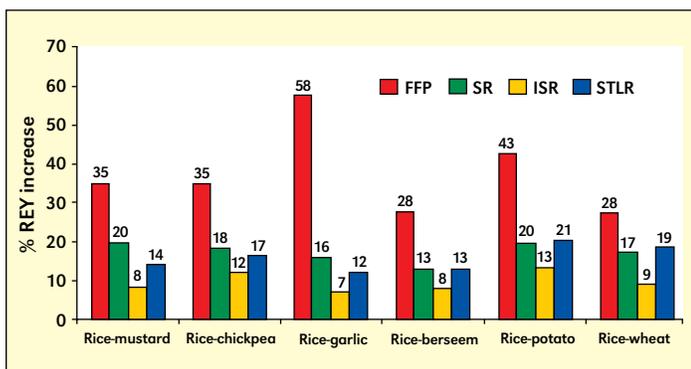


Figure 1. Percent increase in system productivity (Rice equivalent yield) generated by the SSNM treatment over other nutrient management options applied in different cropping systems.

layout, using NPK fertilizer only, to assess the carry-over effect of secondary and micronutrient applications. Fertilizer sources included urea, DAP, KCl, gypsum, zinc sulphate ($ZnSO_4$), and sodium tetra-borate (Borax).

Application of the ISR and SSNM treatments both had a significant influence on mustard productivity. However, significant gains over FFP, the SR, and the STLR were only generated with SSNM (Table 2). In chickpea, SSNM produced the highest grain yield followed by ISR, STLR, SR, and FFP. The effect of SSNM on garlic was more pronounced than in other crops as about 67% more clove yield was obtained in SSNM than with FFP. Clove yield with ISR was 56% higher than with FFP. Number of cloves/bunch and weight of clove bunch/plant were the important yield contributing parameters, when considering the effect of SSNM on crop growth and development (data not shown). Use of either the ISR or SSNM not only enhanced potato tuber yield, but also had pronounced effect on total dry matter content, tuber size, and specific gravity (data not shown). Tuber yields resulting from SSNM and the ISR were 54% and 35%, 22% and 7%, and 26% and 11% higher than

FFP, the SR, and STLR, respectively. Berseem fodder yield increased up to the third cutting and thereafter it declined with age. Green fodder yield from SSNM, the ISR, the SR, and the STLR were 23%, 17%, 13%, and 7% higher yield than FFP. Wheat yield under SSNM and the ISR were 24% and 21% higher than FFP. This increase was ascribed to greater head length, higher grains/head, and higher numbers of effective tillers per m^2 . Application of fertilizer according to the SR or STLR certainly out-yielded FFP, but these treatments generated 0.6

t/ha less grain compared to SSNM.

Rice grown on the same layout after different winter season crops was markedly influenced by the different nutrient management options (Table 2). Averaged across the cropping system, yield gain over FFP was 0.68 t/ha, 1.19 t/ha, 1.03 t/ha, and 2.20 t/ha due to the SR, ISR, STLR, or SSNM, respectively. The significant difference between SSNM and other nutrient management options may be ascribed to the residual effect of nutrients applied to previous winter crops, particularly secondary and micronutrients. Among the various cropping systems (averaged over the nutrient management options), the higher rice yield was recorded under rice-potato (8.33 t/ha) followed by rice-berseem (8.3 t/ha), rice-chickpea (8.0 t/ha), rice-garlic (8.0 t/ha), and rice-mustard (7.8 t/ha). It was lowest under rice-wheat. Lower productivity with the rice-wheat system was probably due to adverse effects of biotic and abiotic stresses associated with growing two cereal crops in sequence. On the other hand, component crops like potato and chickpea have different root feeding zones within the soil profile and can leave sufficient residual nutrient to a succeeding rice crop. The necessity for crop diversification along with appropriate nutrient management options is highlighted by this result.

The average system productivity across the treatments, in terms of rice equivalent yield (REY) [(kg yield x unit price/unit price of rice) + rice yield], was highest in rice-garlic (40.34 t/ha) followed by rice-potato (17.55 t/ha), rice-berseem (15.52 t/ha), rice-wheat (13.70 t/ha), and rice-chickpea (12.0 t/ha). It was lowest in rice-mustard (11.62 t/ha). SSNM out-yielded the other nutrient management options and had 28 to 58% extra REY when compared to FFP (Figure 1). The second most promising option was ISR, which gave 5 to 10% additional yield over the SR, 4 to 10% yield over the STLR, and 17 to 47% over FFP. The advantage of SSNM over the ISR is mainly attributed to better balance and adequate application of all yield-limiting nutrients. These results corroborated earlier work done under rice-wheat and rice-rice system by Singh et al. (2008, 2009) and Gill and Singh (2009).

Implementation of SSNM involved an added expense, which ranged between INR 1,210 in rice-potato to INR 4,488 in rice-garlic (**Table 3**). SSNM was most beneficial within the rice-potato system through its highest additional return over FFP as well as its lowest extra cost. INR return per INR invested in SSNM were calculated at 13.3 in rice-wheat, 50.2 in rice-potato, 37.1 in rice-garlic, 10.2 in rice-chickpea, 10.3 in rice-mustard, and 9.8 in rice-berseem.

Widespread multi-nutrient deficiencies (K, S, Zn, and B) within the soils of the intensively cultivated IGP, owing to constant depletion, have become major constraints to improving productivity. These results underline the significance of soil test-based SSNM in augmenting crop yields, system productivity, and net returns. Generalized recommendations prove to be suboptimal and insufficient for high yielding varieties grown under intensive cropping systems. Such recommendations require an upward revision as well as more inclusive consideration of all yield-limiting nutrients.

Although implementation of SSNM involved added expense, it was offset by substantial yield responses (direct as well as residual) to secondary and micronutrients (S, Zn, and B in this present study). This suggests that balanced fertilization within the region no longer means application of NP or NPK. There is further need to study the impact of each primary, secondary, and micronutrient included within the SSNM recommendation to establish their individual significance in balanced fertilization. 

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Table 3. Extra cost and returns due to fertilization (INR/ha) over farmer fertilizer practice.

Nutrient management options	Rice-wheat	Rice-potato	Rice-garlic	Rice-chickpea	Rice-mustard	Rice-berseem
----- Extra cost -----						
SR	285	-1,840	1,418	739	345	831
ISR	698	-662	2,219	1,110	1,016	1,157
STLR	128	-1,510	1,611	642	529	662
SSNM	2,388	1,210	4,488	3,224	3,110	2,876
----- Extra return -----						
SR	10,985	29,518	104,196	14,204	12,610	13,547
ISR	20,178	38,093	137,717	19,955	23,804	19,195
STLR	8,541	27,950	118,861	15,539	17,210	14,260
SSNM	31,946	60,765	166,478	33,034	31,904	28,163

Notes: The prices (INR per kg) for input materials were: N = 11.15; P = 46.11, when applied with SSP and 47.46 when applied with DAP; S = 26.43; Zn = 76.19; and B = 76.19. The cost of N supplied through DAP was subtracted from the cost of N supplied through urea. The prices (INR per kg) of produce were 10 for rice, 18.3 for mustard, 17.3 for chickpea, 50 for garlic clove, 0.50 for berseem fodder, 4 for potato, and 10.8 for wheat. 1 USD is approximately 45 INR.

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Acknowledgment

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A Guide to Identifying and Managing Nutrient Deficiencies in Cereal Crops

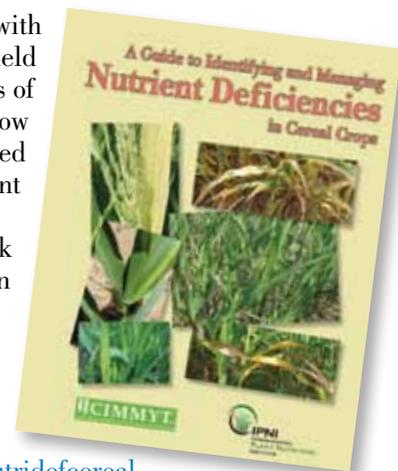
A new booklet has been developed by the IPNI South Asia Program in cooperation with the International Maize and Wheat Improvement Center (CIMMYT). It is a 50-page field guide (8 1/2 x 11 in. size, wire-o bound) designed to describe the underlying causes of nutrient deficiencies in maize, wheat, rice, sorghum, pearl millet, and barley, with tips on how they might be prevented or remedied. Hundreds of excellent deficiency photographs provided by the authors and IPNI will allow the user of this field guide to understand the development of nutrient deficiency symptoms through the growth stages of the crop.

Titled *A Guide to Identifying and Managing Nutrient Deficiencies in Cereal Crops*, this book should be a useful reference for researchers and extension staff involved in cereal production and knowledge dissemination. It will help minimize cereal yield losses.

Within India only, inquiries related to this publication should be directed to:
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354, Sector-21, Huda Gurgaon 122016, India

Phone: 91-124-246-1694 Fax: 91-124-246-1709 E-mail: kmajumdar@ipni.net

For more details and purchase information outside of India, visit: <http://info.ipni.net/nutridefcereal>



Gavin D. Sulewski Becomes Editor at IPNI as Don Armstrong Retires

The International Plant Nutrition Institute (IPNI) has selected Gavin D. Sulewski to become Editor of *Better Crops with Plant Food* magazine and other Institute communications effective June 1, 2011. He succeeds Donald L. Armstrong, who is retiring effective May 31 after nearly 30 years with the organization. Mr. Sulewski had served as Agronomic and Technical Support Manager in the Saskatoon, Saskatchewan, office of IPNI.

“We are happy to announce that Gavin has accepted this new responsibility and will now be located in the headquarters office. With his educational background and years of experience with the Institute, he is well qualified to move into this new role,” said IPNI President Dr. Terry L. Roberts. “This responsibility covers an increasing range of communications options, including electronic and social media as well traditional print publication.”

A native of Saskatchewan, Mr. Sulewski grew up on a wheat and canola farm. He received a B.S.A. degree in Agronomy in 1991 and later earned his M.Sc. in Soil Science in 1996 at the University of Saskatchewan. He joined the staff of the Potash & Phosphate Institute of Canada (PPIC) in 1996, providing technical assistance to programs in China, India, Southeast Asia, Latin America, and others. Later, PPIC was superseded by IPNI and his role expanded. In recent years, he has had significant involvement in development of database resources, technical review and development of many publications, staff training, and a range of other duties.



Gavin D. Sulewski



Donald L. Armstrong

Mr. Armstrong, a native of Indiana, is a 1967 graduate of Purdue University in Agriculture/Horticulture. He was Field Editor for *Indiana Prairie Farmer* magazine from 1976 to 1981 before joining the staff of the Potash & Phosphate Institute (PPI) in 1981. In 1992, his title was expanded to Editor/Manager Editorial Group at PPI. Mr. Armstrong also previously worked for the information department of the Indiana Farm Bureau organization, for Meredith Corporation in Des Moines, Iowa, and with Purdue University Cooperative Extension. After completing college, he was a delegate to Peru through the International Farm Youth Exchange program.

In addition to serving as editor of *Better Crops* magazine, Mr. Armstrong was involved with publication of the book *Southern Forages* and numerous other manuals, books, proceedings, reports, and informational materials related to plant nutrition. He also handled a range of responsibilities in support of Institute scientific staff and programs, as well as assisting in member services and other assignments. **DC**

Conversion Factors for U.S. System and Metric

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

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

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

¹The 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.

LOOKING BACK AND INTO THE FUTURE

In Latin class many years ago, we learned about mythology ... including the Roman god called Janus. With the unique ability to look forward and backward at the same time, he has been associated with the concepts of beginnings and endings, transitions, gates, and doorways. As I complete my tenure here with IPNI and *Better Crops with Plant Food*, I find myself wishing we all had the skills of clearly viewing the past and future, as well as the present time, all concurrently.

With completion of this edition of *Better Crops with Plant Food*, I will turn over the primary responsibility for the publication to a new editor. Gavin Sulewski has served as Agronomic and Technical Support Manager for IPNI in the Saskatoon, Saskatchewan, office for several years. He now moves to the headquarters office in Norcross, Georgia, and will also have responsibility as Editor for a wide range of other communications for IPNI. His unique combination of background, education, and experience with the Institute will enable him to hit the ground running.

My association with *Better Crops with Plant Food* goes back to the latter part of 1981. So, through the years, I have been involved with completion of nearly 120 issues of this publication. Also, for a series of several years, the Institute offered a separate publication called *Better Crops International*, accounting for another 35 issues. During this same time frame, we have also produced numerous other reports, proceedings, regional publications, and special interest communications pieces.

Of course, I did not accomplish this alone. Since the early 1990s, Assistant Editor Katherine Griffin has handled a tremendous amount of the coordination required to produce publications and other information materials and educational tools. Carol Mees has handled Circulation responsibilities for *Better Crops* and IPNI. And Institute leaders, particularly IPNI President Dr. Terry Roberts and Senior Vice President Dr. Paul Fixen over the past several years, have guided the ship and enabled this publication to flourish. IPNI scientific staff and other support staff have been wonderful. Our graphics and format specialists and the printer of *Better Crops* give this publication special attention. We have found great cooperation of researchers and authors from around the world who have contributed articles and other input. The IPNI member companies and Board of Directors have enabled this publication to maintain its unique identity and purpose.

My early years with the Institute and with *Better Crops* responsibilities overlapped briefly with the last stages of Mr. Sanford Martin's career. Well known as one of the last of the great letter writers, here is a sentence he wrote on the eve of his retirement after more than 30 years as an editor of this magazine: "As we all know, there's a time to be born, a time to grow up, a time to achieve and contribute, and a time to step down." That time has now come for me.

With the recent passing of highly respected agricultural leaders including Dr. Bob Wagner, Dr. E.T. York, and others, there is a signal that inspires us all to carry on the high standards they adhered to.

Looking back, I am amazed at the changes in agriculture, the fertilizer industry, communications, and the world in general during my nearly 30 years with the Institute. The advances in precision agriculture, nutrient use efficiency, biotechnology, yield levels, and other aspects of production agriculture have truly changed the world. And yet many of the same challenges and opportunities are still out there, but perhaps with a different look. The quest for food security in many parts of the world, the environmental concerns, the never-ending need for greater efficiency, and the importance of profitability for farmers will go on. Forward-looking concepts such as 4R Nutrient Stewardship will be key to finding the balance in science-based agriculture.

So, as I pass through the doors of transition to retirement, it is good to take a last, quick look backward and a view to the future. It has been an honor and privilege to be involved with this publication for so many years, and I truly hope *Better Crops with Plant Food* will continue for many more. Thanks to all and best wishes for the future.



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