BETTER CROPS
WITH PLANT FOOD

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In This Issue...

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BETTER CROPS
WITH PLANT FOOD

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2011 Scholar Award Recipients Announced by IPNI

The 2011 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The individual awards of USD 2,000 (two thousand dollars) are available to graduate students enrolled in science programs relevant to plant nutrition and management of crop nutrients.

"The Institute saw a large increase in the number of applications this past year and regional competition for the award was strong," explained Dr. Terry L. Roberts, IPNI President. "The selection process has once again assembled a most outstanding group of young scientists—this award continues to highlight the promising future for plant nutrition research throughout the world, and is an effort we are most proud to support."

The selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic achievements. Funding for the Scholar Award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers. Graduate students must also attend a degree-granting institution located in any country with an IPNI Program.

IPNI has named 20 (twenty) graduate students as recipients of the IPNI Scholar Award. A listing of the regional distribution of the IPNI Scholars and their respective university/institution is provided below.

Africa: Grace Kanonge, University of Zimbabwe, Harare, Zimbabwe
Waswa Boaz, Centre for Development Research (ZEF), Bonn, Germany

Australia/New Zealand: Brooke Ryan, University of Adelaide, Adelaide, Australia

China: Li Wang, Institute of Agricultural Resources and Regional Planning, Beijing, China
Limin Chuan, Institute of Agricultural Resources and Regional Planning, Beijing, China
Ying Xia, Wuhan Botanical Garden, Hubei, China

Eastern Europe and Central Asia: Elena Pavlova, Omsk State Agrarian University, Omsk, Russia
Dmitry Bozhkov, Soil Science and Land Resources Department, South Federal University, Rostov-on-Don, Russia

Latin America: Ceballos Darío Sebastián, Buenos Aires University, Campana, Argentina
Diogo Mendes de Paiva, Universidade Federal de Vicosa, Vicosa, Brazil
Maria Elena Cardenas, Universidad de Sonora, Pueblo Yaqui, Mexico

North America: Ronald Navarrete-Ganchozo, Purdue University, West Lafayette, Indiana, USA
Tyler Nigon, University of Minnesota, South Saint Paul, Minnesota, USA
Joshua Cobb, Cornell University, Brooktondale, New York, USA
Jared Crain, Oklahoma State University, Stillwater, Oklahoma, USA
Cameron Pittelkow, University of California, Davis, California, USA

South Asia: Gopal Ramdas Mahajan, Indian Agricultural Research Institute, New Delhi, India
Shahid Hussain, University of Agriculture, Faisalabad, Pakistan
Sumanta Kundu, Institute of Agricultural Sciences, Calcutta University, Kolkata, India

Southeast Asia: Tengoua Fabien Fonguimgo, Universiti Putra Malaysia, Serdang, Malaysia

Following is a brief summary for each of the winners.


Grace Kanonge

Ms. Grace Kanonge is working towards a Masters degree at University of Zimbabwe in Harare, Zimbabwe. Her dissertation is titled "A Fertilizer Management Strategy for Enhanced Legume-Cereal Based Productivity under Small-holder Farming Systems of Zimbabwe" which seeks to assess legume (cowpea and soybean) and cereal (maize) yields, and nitrogen and phosphorus benefits using integrated nutrient management (i.e. balanced use of fertilizers and manures). The concept involves not fertilizing the legume crop, but fertilizing the following cereal crop with phosphorus and top-dressing nitrogen at reduced rates. For the future, Ms. Kanonge hopes to develop her research capabilities further by pursuing a doctorate degree and publishing results of her research in peer-reviewed journals.


Waswa Boaz

Mr. Waswa Boaz is pursuing his Ph.D. at the Center for Development Research (ZEF) in Bonn, Germany. His dissertation is titled "Assessment of Land Degradation Patterns in Western Kenya: Implications for Restoration and Rehabilitation." The study aims to assess long-term spatial and temporal patterns of land degradation using multi-scale satellite data sets. Detailed field observations and measurements along with a socio-economic survey will help understand the decision-making process for regional land management. The principles learned could be applied to derive a set of recommendations needed for sustainable land management in Kenya. Mr. Boaz aspires to be a technical advisor to government or other agencies working in the areas of food security and environmental conservation.

(continued on next page)

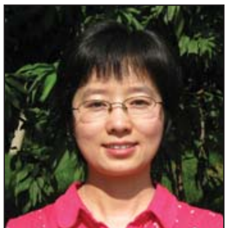
Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Brooke Ryan

Ms. Brooke Ryan is working toward her Ph.D. at the University of Adelaide in Adelaide, Australia. Her dissertation title is "The Isotopic Discrimination of Copper in Soil-Plant Systems" which aims to use stable isotopes of copper (^{63}Cu and ^{65}Cu) and their fractionation to examine the source, behavior, and plant uptake mechanisms of copper within the soil-plant environment. The information gained from this work could potentially be used to develop models to track natural and anthropogenic copper in terrestrial environments, and improve crop management practices for increased fertilizer efficiency, crop growth, and micronutrient content. For the future, Ms. Ryan's goal is to pursue a career in research working on environmental protection and remediation, especially in the area of heavy metal contamination.

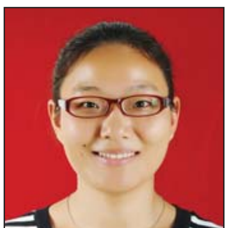
Li Wang

Mr. Li Wang started his Ph.D. program in 2010 at the Institute of Agricultural Resources and Regional Planning in Beijing, China. His dissertation is titled "Study on the Mechanism of Adaptation to Water and Low Potassium Stress of Different Potassium-Efficient Cotton Genotypes." Objectives of his study involve comparing two cotton genotypes for growth dynamics, biomass, potassium partitioning, potassium use efficiency, anatomical structure, root hair, quantity of soil microbes, and morphology of roots. For the future, Mr. Li intends to continue research and extension work on plant nutrition and soil fertility to help optimize fertilizer use.



Limin Chuan

Ms. Limin Chuan is pursuing her Ph.D. at the Institute of Agricultural Resources and Regional Planning, Beijing, China. Her dissertation title is "Nutrition Management and Fertilizer Recommendation in Wheat Based on Yield Response and Agronomic Efficiency." A native of Hebei, Ms. Chuan earned her Masters in 2010 at the Hebei Agricultural University of China. Her research is focused on using the QUEFTS (Quantitative Evaluation of Fertility of Tropical Soils) model to derive appropriate nutrient recommendations to maximize yield and optimize nutrient use efficiencies in wheat. In the future, Ms. Chuan hopes to be in a faculty position at a leading university of work in a scientific role with an international research institution.



Ying Xia

Ms. Ying Xia is working toward a doctorate degree at Wuhan Botanical Garden in Hubei, China. Her research work is on understanding the mechanism of utilization of potassium in cotton genotypes with different K efficiencies through root box, water culture, and grafting experiments. This research will provide more scientific information that could be used to develop new approaches to improve potassium use efficiency. Ms. Xia has an impressive resume of academic achievements, awards, patents, and publications. For the future, her goal is to become an agricultural scientist.

Dmitry Bozhkov

Mr. Dmitry Bozhkov started his Ph.D. degree in 2010 at the Soil Science and Land Resources Department of South Federal University in Rostov-on-Don, Russia. The focus of his research is "Optimization of Mineral Nutrition of New Grain Varieties". During his study he has received numerous awards, has already authored and co-authored a number of scientific works, and has demonstrated a strong commitment to involvement within the Russian soil science research community. After completing his Ph.D., Dmitry hopes to develop a related research career in Russia or abroad.

Elena Pavlova

Ms. Elena Pavlova is working towards her Masters degree at the Omsk State Agrarian University, Omsk, Russia. Her thesis title focuses on "The Influence of Different Methods of Zinc Application on Winter Triticale in West Siberia." Findings of investigation are already becoming a part of fertilizer rate assessments for winter triticale crops grown within the region. She has received many awards throughout her postgraduate career and she has described a great interest in participating within community awareness programs with global scope. Ms. Pavlova hopes to continue her postgraduate work within a Ph.D. program also at the Omsk State Agrarian University so she can expand her knowledge base and continue her interest in research.

Ceballos Darío Sebastián

Mr. Ceballos Darío Sebastián is completing requirements for his Master's program in Natural Resources at Buenos Aires University in Campana, Argentina. His thesis title is "Land Use Change and Nitrogen versus Phosphorus: Relative Limitation in Marsh and *Populus deltoides* Plantations in Drainage Soils in the Lower Delta of the Paraná River." His research work is aimed to understand nutrient dynamics in the vulnerable ecosystems of production forests in the lower delta of Paraná River. This work could help provide answers to the question of growing fiber and feed to favor the island families without changing their culture. Mr. Sebastián hopes to continue his research efforts on aspects of forest nutrition and change of land use.

Diogo Mendes de Paiva

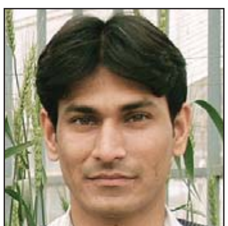
Mr. Diogo Mendes de Paiva is working toward his Ph.D. degree in soil and plant nutrition at Universidade Federal de Vicosa in Vicosa, Brazil. His dissertation title is "Reducing Ammonia Volatilization from Urea Fertilizer by Coating with Humic Acids Produced from Eucalyptus." His research work is intended to present an alternative for reducing ammonia volatilization from the most used nitrogen fertilizer worldwide by coating the urea with a polymer obtained from eucalyptus coal. Preliminary results have shown a decrease in ammonia volatilization of 43% when coating was used. Mr. Paiva is a co-author for a paper receiving the 2010 IPNI Brazil Plant Nutrition Award. His near future goal is to spend time abroad during his Ph.D. studies to refine the use of the proposed technique for reducing ammonia volatilization. His medium-to-long term goal is to progress as a researcher specialized in fertilizer technology and use.

Maria Elena Cardenas

Ms. Maria Elena Cardenas is pursuing her Masters degree in agricultural science at Universidad de Sonora in Pueblo Yaqui, Mexico. Her research work is focused on evaluating different wheat varieties as they respond to phosphorus application and on assessing the relationship between normalized difference vegetation index (NDVI) and phosphorus deficiency in wheat. The aim of this study is to develop a diagnostic tool to guide phosphorus fertilization in wheat based on the relationship between NDVI readings and phosphorus absorption. For the future, Ms. Cardenas wants to continue her research efforts aimed at developing new knowledge and tools to increase food production in a sustainable manner.

Gopal Ramdas Mahajan

Mr. Gopal Ramdas Mahajan is pursuing his Ph.D. in Soil Science and Agricultural Chemistry at the Indian Agricultural Research Institute (IARI) in New Delhi, India. His dissertation title is "Development of Site-Specific Integrated Nutrient Management for the Hybrid Rice-Wheat Cropping System Using Soil Test Crop Response Correlation Studies." Mr. Mashajan earned his Masters in 2009 from Banaras Hindu University, Varanasi, Uttar Pradesh and a Bachelors degree in 2007 at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra. Mr. Mahajan's research is focused on developing individual as well as whole crop system soil test-based recommendation systems for target yields of hybrid rice and wheat and to develop in-situ spectral methods of fertilizer recommendation for the same cropping system.



Shahid Hussain

Mr. Shahid Hussain is working toward a doctorate degree at University of Agriculture in Faisalabad, Pakistan. His dissertation is titled "Bioavailable Grain Zinc in Wheat Varieties of Pakistan and Strategies for Biofortification." This study aims to evaluate zinc fertilization and other agronomic means to increase grain zinc concentrations and to decrease the phytate-to-zinc molar ratio (an indicator of zinc bioavailability) in wheat grains. For the future, Mr. Hussain hopes to become an agricultural scientist and to continue his research efforts on biofortification of cereals.

Sumantu Kundu

Mr. Sumanta Kundu is completing requirements for his Ph.D. Program in Agronomy at the Institute of Agricultural Sciences in Calcutta University, India. He is working with Central Research Institute for Dryland Agriculture (CRIDA) in Hyderabad, India. His dissertation title is "Improving Nutrient Use Efficiency and Profitability through Conservation Tillage and Improved Nutrient Management in the Maize-Horsegram Cropping Sequence in Rainfed Alfisols." This research is aimed to develop a set of best management practices that include a sustainable nutrient management strategy in combination with conservation tillage and soil amendments.

Tengoua Fabien Fonguimgo

Mr. Tengoua Fabien Fonguimgo is pursuing his Ph.D. in soil fertility and plant nutrition at Universiti Putra Malaysia in Serdang, Malaysia. His dissertation title is "Nutritional Characteristics of Ganoderma Susceptible and Ganoderma Tolerant Oil Palm Seedlings." This research intends to reduce the incidence of basal stem rot disease in oil palms by improving its lignin content through manipulating nutrients involved directly or indirectly in lignin concentration, like boron, copper, and manganese. The study aims to determine the optimum concentration of these nutrients in oil palm and devise fertilizer recommendations based on this determination. In the future, Mr. Fonguimgo wishes to continue his research efforts and share the knowledge and experience gained through this process with students by teaching part-time in the university.

(continued on next page)

Ronald Navarrete-Ganchozo

Mr. Ronald Navarrete-Ganchozo is completing requirements for his Ph.D. in soil fertility and plant nutrition at Purdue University in West Lafayette, Indiana, USA. His dissertation is titled "Long-term Study of the Impact of Potassium Application Rates on Soil Potassium Bio-Availability in a Corn-Soybean Rotation: Effect on Critical Soil Test Potassium Values, Yield, and Net Soil Potassium Balance." A native of Ecuador, he earned his Masters degree in 2009 from Texas A&M University in Texas, USA. His research is focused on improving the ability to predict spatial and temporal variations in potassium bioavailability, which is critical to optimize fertilizer use and reduce production costs. For the future, Mr. Navarrete-Ganchozo aims to continue his research, education, and extension efforts to become a professional capable of understanding the complexity of processes in soil nutrient dynamics and its effect on plant nutrition at a global scale.

Tyler Nigon

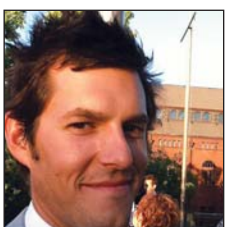
Mr. Tyler Nigon is working toward his Masters degree in land and atmospheric science at University of Minnesota, South Saint Paul, Minnesota, USA. His research work is focused on the fusion of airborne hyperspectral and thermal imagery for detecting spatial variation of nitrogen and water status in potato. At a commercial scale, this technology has the opportunity to allow increased spatial and temporal precision of nitrogen and water applications during critical growth stages of the crop. Mr. Nigon has an impressive resume of academic achievements and awards. For the future, Mr. Nigon's goal is to either pursue a Doctorate degree or a job in agricultural industry. He loves doing consulting work to assist growers with their management strategies.

Joshua Cobb

Mr. Joshua Cobb is pursuing his Doctorate degree in plant breeding and genetics at Cornell University in Brooktondale, New York, USA. His dissertation title is "Characterization of Natural Variation for Plant Mineral Nutrient Homeostasis in Domestic Asian Rice and its Wild Progenitors Using Genome-Wide Association Mapping." This research aims to extend the 4R Nutrient Stewardship Framework by also considering the range of generic variation for nutrient use efficiency that exists across varieties within a crop. In the future, Mr. Cobb intends to develop an internationally collaborative research program to investigate the potential of genetic variation and genotype by environment interaction to improve abiotic stress tolerance, nutrient use efficiency, and response to nutrient application in the major cereal grains.

Jared Crain

Mr. Jared Crain is completing requirements for his Masters degree in plant and soil science at Oklahoma State University in Stillwater, Oklahoma, USA. His thesis title is "Evaluation of New Prototype NDVI Sensor for Improved Nitrogen Management." This research is focused on evaluating performance as well as environmental and user effects on an inexpensive version of NDVI sensor in corn and wheat with an aim to develop methods to use this sensor accurately. For the future, Mr. Crain wishes to pursue a doctorate in crop science and further his research interests to provide the world an adequate and safe food supply.



Cameron Pittelkow

Mr. Cameron Pittelkow is working toward his Ph.D. in agronomy at University of California in Davis, California, USA. His research is focused on nitrogen management practices to reduce greenhouse gas emissions while maintaining agronomic productivity in California rice systems. The primary goal of this research work is to address issues of crop production and environment from an agronomic approach (4R Nutrient Stewardship) by illustrating that yield increases and environmental protection can be achieved simultaneously. Mr. Pittelkow's career goal is to apply his agronomic knowledge and insights to international agricultural development efforts through research and extension.

The IPNI Scholar Award recipients are selected by regional committees of IPNI scientific staff. The awards are presented directly to the students at their universities and no specific duties are required of them. Graduate students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. More information is available from IPNI staff, from individual universities, or from the IPNI website: >www.ipni.net/awards<. BC

Soil Organic Matter Changes towards an Equilibrium Level Appropriate to the Soil and Cropping System

By Johnny Johnston

While soil organic matter (SOM) is an important aspect of soil quality it will never be easy to identify a critical level at which to maintain a soil. Nevertheless, the contribution of SOM to soil fertility, sustainable agricultural systems, and crop productivity cannot be over emphasized and every effort should be made to maintain, and if possible increase, SOM.

Photo by ars.usda.gov

The amount of organic matter in soil varies greatly; in agricultural soils increasing from that under permanent tillage crops to that under permanent vegetation. What is not generally recognized is that the amount reaches an equilibrium level specific to a soil type and farming system. This level depends on the input of organic material and its rate of decomposition, the rate at which existing SOM is mineralized, soil texture, and climate. All four factors interact so that, under very similar climatic conditions, for any one cropping system, the equilibrium level in a clay soil will be larger than in a sandy soil; for any one soil type, the equilibrium value will be larger with permanent grass than with continuous arable cropping. SOM changes slowly in temperate climates, often over many decades, and more rapidly in warm conditions.

The living part of SOM, the soil microbial biomass, is vitally important although frequently less than 5% of soil C. The C content of SOM is typically 58%. The largest proportion of SOM is the end product of the microbial decomposition of added organic materials; consequently the ratio (by weight) of organic C to organic N is relatively constant for many soils, ranging from about 9:1 to 14:1. The C:N ratio of added material determines whether N is released to or taken from the soil mineral N pool during microbial decomposition.

SOM increases rapidly when large amounts of organic matter are added, but decreases quickly when additions cease. When 37.5 and 75 t/ha (fresh weight) of farmyard manure (FYM), biosolids, vegetable compost, and a compost of biosolids/straw were added to a sandy loam soil at Woburn, SOM increased rapidly **(Table 1)**. The size of the increase depended on the amount and type of material added, and there was a linear relationship between the amount of C added and the increase in soil C. However, large amounts of C were lost during microbial decomposition of the added manures, 75% of that in FYM after 25 years, and after 18 years, 64% of that in biosolids and 60% of that added in the composts. Once manure additions ceased, SOM declined. The uniformity of the SOM produced by microbial decomposition of these different manures is shown by the fact that the eight individual exponential C decay curves (not shown) could be shifted horizontally to form a single decay curve **(Figure 1)**.

SOM changes towards and/or remains at an appropriate equilibrium level depending on the input of organic matter. On a silty clay loam soil (about 25% clay) at Rothamsted where spring barley has been grown continuously since 1852, crop residues ploughed in each year are small on soils without annual additions of fertilizer, but are slightly larger with fertilizers. SOM declined a little initially, but has been at an equilibrium level of about 1.0% and 1.1% organic C, respectively, for about 100 years **(Figure 2a)**. The much larger annual input of organic matter from 35 t/ha FYM increased SOM rapidly at first and then more slowly towards an equilibrium level for that soil, cropping, and organic input. Where FYM was applied for the first 20 years, but not since, SOM increased initially but has then declined slowly towards an appropriate equilibrium level **(Figure 2a)**.

On a sandy loam soil (about 10% clay) at Woburn, with much smaller organic matter inputs after 1876, SOM declined **(Figure 2b)** towards a new, lower equilibrium value, and this value was smaller than that with similar cropping on the

Common abbreviations and notes: N = nitrogen; C = carbon.

Table 1. Effect of type and rate of organic amendment on the C content of a sandy loam soil, Woburn.

Amendment	Years applied	Fresh weight, t/ha/yr 37.5	75.0
		--------- % C* ---------	
Farmyard manure	25	1.46 (AD1)	2.17 (AD2)
Biosolids	18	1.93 (AS1)	2.92 (AS2)
Vegetable compost**	25	1.70 (ADC1)	2.25 (ADC2)
Biosolids/straw compost	18	1.77 (AT1)	2.38 (AT2)

*In parenthesis: identification for the initial organic C levels in Figure 1. Symbols with "B" in Figure 1 are from a duplicate set of plots.
** Vegetable compost for the first 18 years followed by seven years with farmyard manure.

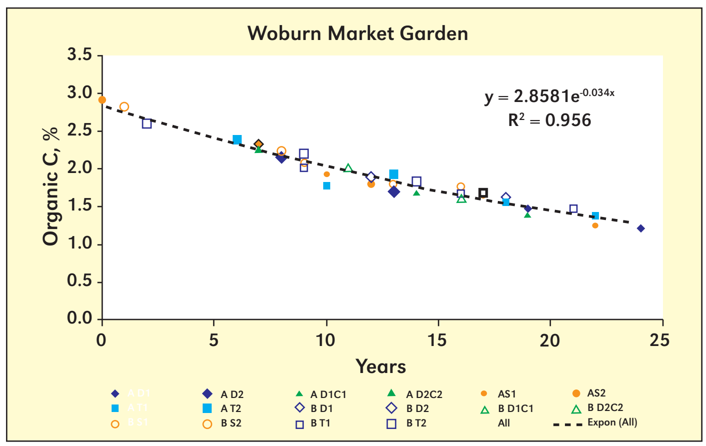


Figure 1. Regardless of the organic amendment, the decline in the resulting SOM due to microbial decomposition could be shifted horizontally to form a single decay curve.

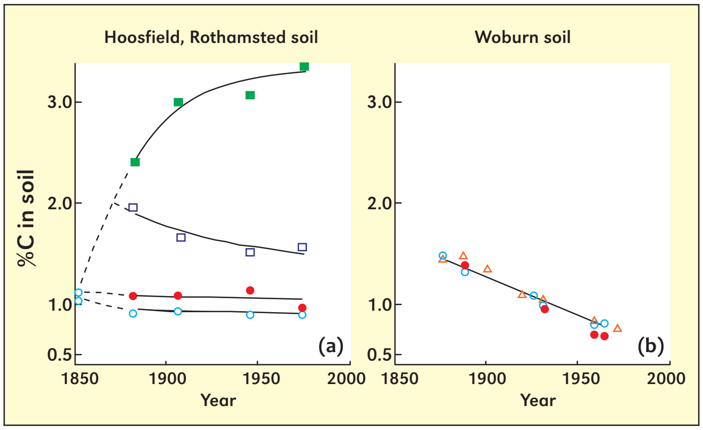


Figure 2. Changes in %C in the top 23 cm of soil at Hoosfield, Rothamsted (a) growing barley each year with annual treatments since 1852; unmanured ○, NPK fertilizers ●, 35 t/ha FYM ■, 35 t/ha FYM 1852-71, none since □; and Woburn (b). Cereals each year since 1876 unmanured ○, NPK fertilizers ●, manured 4-course rotation △.

silty clay loam at Rothamsted, where organic matter is held on clay particles.

SOM increases under permanent crops, partly because there is a greater turnover of roots, and with no soil cultivation and thus less aeration, microbial activity is less. On the silty clay loam at Rothamsted, the SOM equilibrium level where cereals are grown each year on soil that is ploughed to 23 cm is 1.0% organic C, while under permanent grassland for probably at least 400 years it is 2.7% C. Interestingly there are soils on the farm sown to permanent grass for various periods where SOM has increased and the data all fit on one curve **(Figure 3)**. This shows that when an arable soil is sown to permanent grass, it takes about 100 years for SOM to increase to that under permanent grassland. The increase in SOM was rapid initially then slower as a new higher equilibrium level was approached. It took about 25 years to get half the total increase in SOM.

On any one soil type, especially in temperate regions, farmers practice a wide range of cropping systems intermediate between the extremes of continuous arable and permanent grassland. Each farming system will have its equilibrium level of SOM and there will be slow changes when the cropping changes as illustrated in **Figure 4**. In 1938, an experiment comparing different 5-year cropping cycles was started on a sandy loam soil and changes in SOM in the top 25 cm soil were monitored for 60 years. Initially the soil contained 0.98% C, arable crops having been grown on the site for many years.

Where arable crops, wheat, barley, oats, potatoes, sugar beet and carrots, continued to be grown in rotation, SOM declined slowly to about 0.87% C (lower line in **Figure 4**). This decrease is probably due to deeper ploughing and more intensive cultivation.

The upper line in **Figure 4** shows SOM where the 5-year cropping cycle was 3 years grass with fertilizer N followed by 2 years of arable crops – a root crop and a cereal. SOM increased for about 40 years to reach an equilibrium level for that cropping system and soil type, and then remained unchanged at about 1.13% C for 20 years. In this second period, an equivalent amount of SOM accumulated during 3 years of growing grass was lost when arable crops were grown for 2 years.

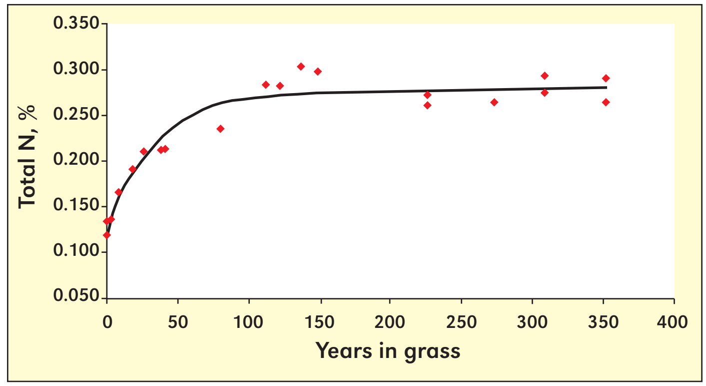


Figure 3. Increase in total soil N (as surrogate for SOM) under long-term permanent grassland, Rothamsted.

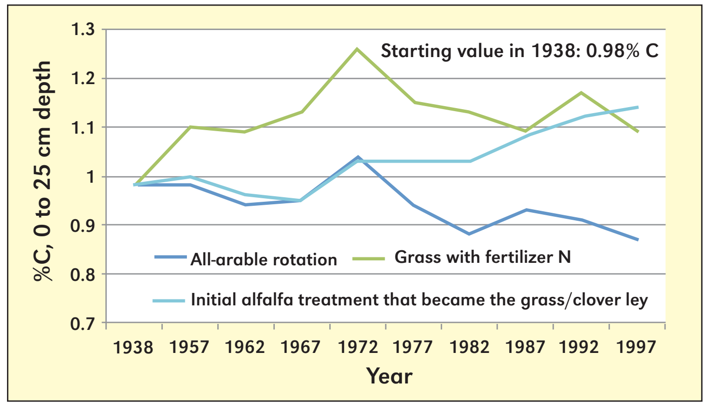


Figure 4. Changes in SOM in the top 25 cm soil within contrasted cropping systems over a period of 60 years.

The middle line in **Figure 4** is interesting because for the first 40 years the 5-year cropping cycle on this plot was 3 years alfalfa (lucerne) followed by two arable crops. Compared to the all-arable rotation (lower line) there was no increase in SOM from growing alfalfa for 3 years in each 5-year cycle. Then alfalfa was replaced by a 3-year grass/clover ley and SOM began to increase during the last 20 years and is now the same, 1.13% C, as in soils with 3 years of grass given fertilizer N.

There was another treatment (not shown) where in the last 30 years there was an all-arable rotation where no crop was grown for 2 of the 5 years of the 5-year cycle. The soil now contains 15% less SOM than the soil growing arable crops continuously.

Currently, there is a perceived need to remove carbon dioxide (CO_2) from the atmosphere to mitigate the effects of climate change, and that CO_2 can be stored in soil as SOM. However, there appears to be little awareness in these discussions that SOM does not increase above the equilibrium level specific to the local conditions of soil type, cropping, and fertilization; and that in temperate climates these changes often occur only slowly. BC

Johnny Johnston is a Lawes Trust Senior Fellow at Rothamsted Research, Harpenden, UK. AL5 2JQ. E-mail: johnny.johnston@rothamsted.ac.uk

This article is adapted from: Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. A. Edward Johnston, Paul R. Poulton and Kevin Coleman. Advances in Agronomy101, 1-57.

The Essential Role of Soil Organic Matter in Crop Production and the Efficient use of Nitrogen and Phosphorus

Photo by ars.usda.gov

By Johnny Johnston

The role of soil organic matter (SOM) in supporting the nutrient requirements of high crop yields is fundamental, especially as crop yield potential continues to improve. Lessons on N and P interactions with SOM and its support of high crop yields are well illustrated here through examples gleaned from long-term research conducted at Rothamsted.

A first example of the contribution of SOM towards enhancing crop productivity is provided here through use of data from the Hoosfield Continuous Barley experiment at Rothamsted. Started in 1852 on a silty clay loam soil, the Hoosfield site received annual application of NPK fertilizers, or farmyard manure (FYM) at 35 t/ha, which produced soils that now have 1.74 and 6.16% SOM, respectively. Each year since 1968, four amounts of fertilizer N (0, 48, 96, and 144 kg N/ha) are applied to these soils. Beginning in the mid 1970s, **Figure 1** plots changes in grain yield of three successive cultivars of spring barley, each with higher yield potential than its predecessor. On the soil with lower SOM, the crop responds to N and there is little difference in maximum yield of the three cultivars in the three periods. On soil with more SOM, the crop responds only a little to fertilizer N, but as the yield potential of the crop has increased, the maximum yield on this soil has increased—as has the benefit from having more SOM. The difference in maximum grain yield on the two soils is now more than 2.5 t/ha.

Similarly, on the Broadbalk winter wheat experiment, soils treated with fertilizers or FYM (35 t/ha each year) since 1843 now contain 1.93 and 4.87% SOM, respectively. Different amounts of N have always been tested with PK fertilizers and the resulting yields have compared with those given by FYM alone. In many years before 1967, grain yields with FYM were slightly better than with fertilizers (Garner and Dyke, 1969), but the yield increase due to FYM for winter wheat was not as large as that with spring barley, probably because winter wheat has a longer growing season in which to make a root system. Since 1968, when short-strawed cultivars were introduced with improved grain-to-straw ratios and higher yield potentials, yields have only been larger on FYM-treated soil if an additional 96 kg N/ha is given as fertilizer. Interestingly, when cv. Hereward began to be grown at Broadbalk in 1996, the addition of 96 kg N/ha with FYM no longer gave a larger yield than the optimum NPK fertilizer application (Johnston et al., 2009). Since 2005 it has been necessary to add 144 kg N/ha with FYM to give slightly larger yields than with fertilizers. It would seem that the available N from 35 t/ha FYM, and that mineralized from the accumulated SOM, is not sufficient to give maximum yields of a cultivar of winter wheat with a large yield potential. It would be interesting to speculate why this is so.

Common abbreviations and notes: N = nitrogen; P = phosphorus; C = carbon.

Soil Organic Matter and Nitrogen Interactions

At the present time there is considerable interest in the efficient use of N in agriculture. This arises not only because the different forms and pathways by which N can be lost from soil can have adverse environmental impact, but also because such losses are a direct cost to growers. There is much evidence to show that N is used more efficiently on soils with more organic matter, and presumably a better structure, so that roots explore the soil more effectively to find nutrients.

On a sandy loam soil with two levels of SOM, potatoes, spring barley, winter wheat, and winter barley have been grown in different years, each crop given four appropriate amounts of N (**Figure 2**).

Yields of the spring sown crops, potatoes and barley, were

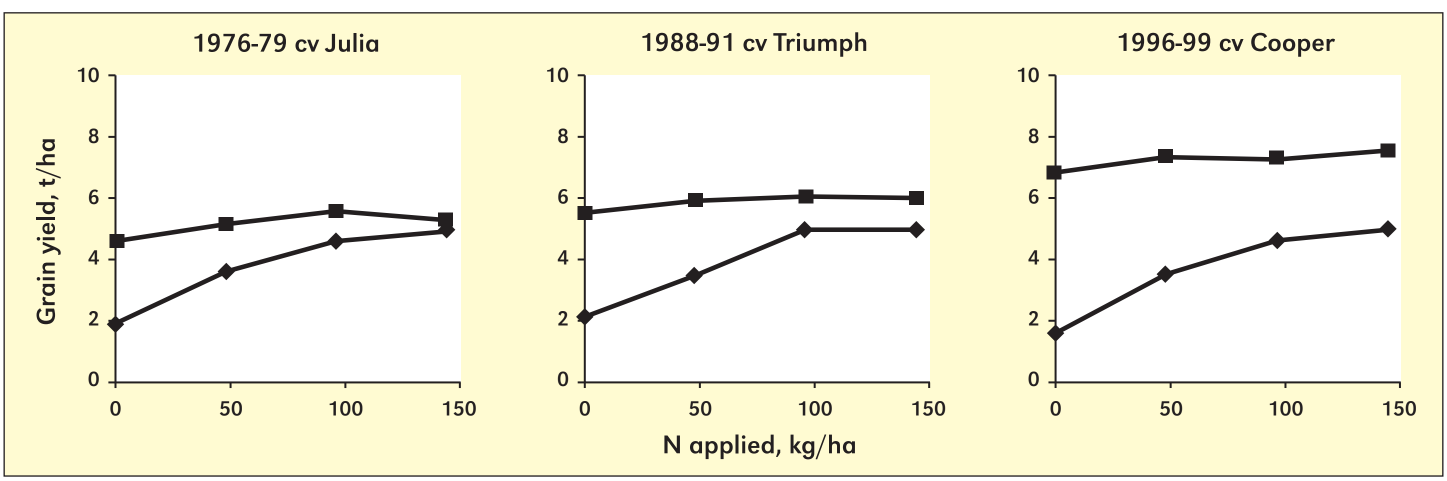


Figure 1. Grain yield response to applied N from three spring barley cultivars with increasing yield potential (left to right) grown on two soils with 1.74 (◆) or 6.16 (■) % SOM, Hoosfield Continuous Barley experiment, Rothamsted.

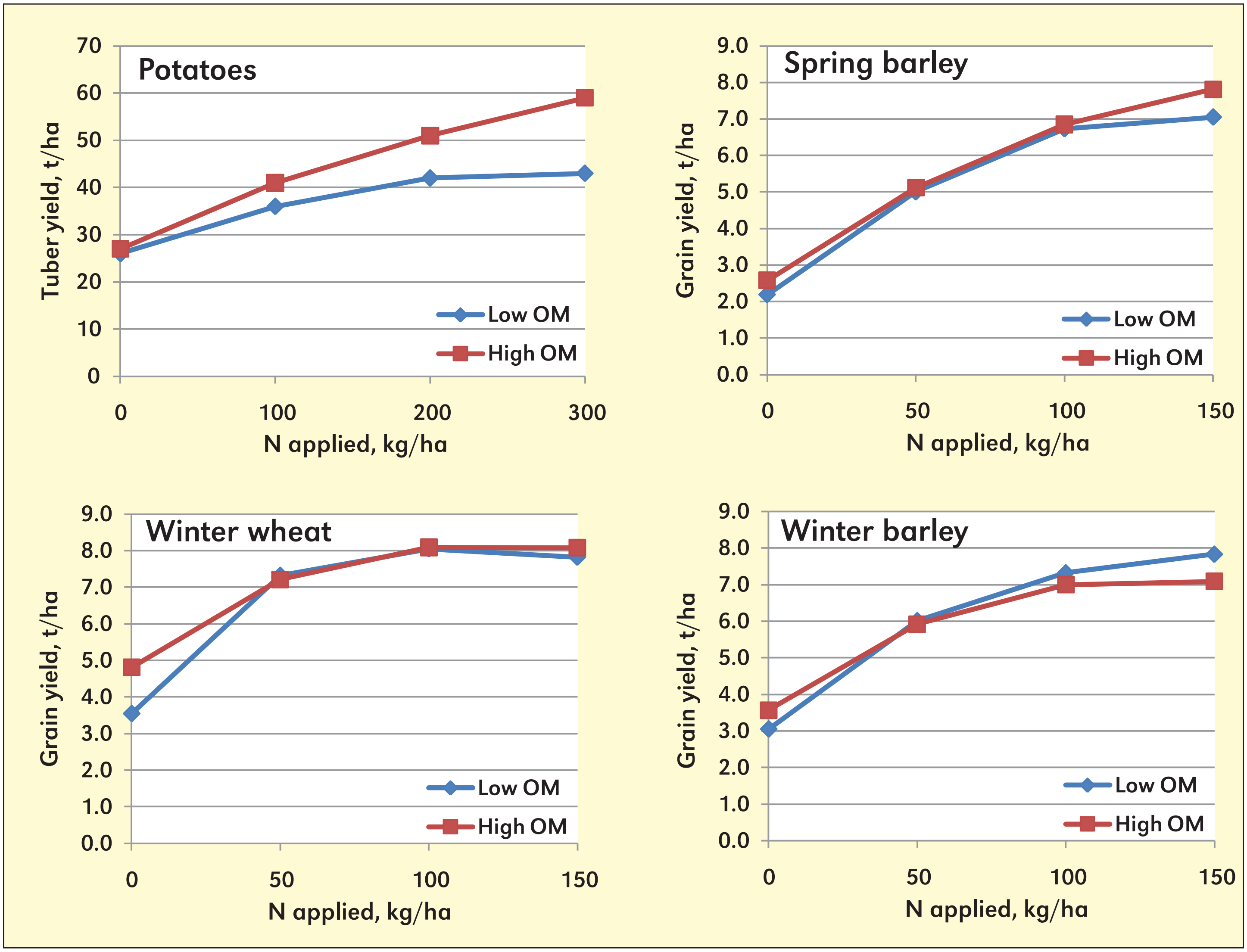


Figure 2. Yield response to applied N by spring and winter crops grown on a sandy loam soil with two levels of SOM, 1.3 and 3.4%, respectively.

always larger on the soil with more SOM irrespective of the amount of N applied, and the recovery of the applied N was greater where the yields were larger. A better soil structure with more SOM allowed for quicker root development and better exploration of the soil mass for nutrients. At each amount of applied N, the yields of the winter sown cereals, with a longer growing period than a spring-sown crop, were largely independent of SOM, probably because these autumn-sown crops had time to develop an adequate root system on the soil with less SOM.

In another experiment on a sandy loam soil, the effects of various organic amendments on SOM and yields of arable crops have been tested since 1964 with two periods of organic additions (the "treatment" period) and two periods of arable "test" cropping (Johnston et al., 2009). Annual organic treatments that were common to both periods of addition included incorporating straw (7.5 t/ha dry matter), applying FYM (50 t/ha fresh material) and growing and then incorporating a grass/clover ley (temporary pasture) before growing arable "test" crops to measure the effects of any additional SOM built up during the two "treatment" periods.

In 1986, C in the top 23 cm was 0.65% without organic addition—about the equilibrium level for this soil and treatment. The organic additions increased it to 0.85% with added straw, 1.06% with FYM, and 0.90% following the incorporation of an 8-year grass/clover ley. The yields of potatoes (in 1988 and 1989) and winter wheat (in 1987 and 1988), each testing six amounts of N, are compared with those on soils without extra organic matter addition in **Figure 3**. Yields were always smallest on soil with least SOM and generally largest on soils ploughed out from the grass/clover ley. In all comparisons, less N was needed to achieve optimum yield on soil with more SOM.

There are two interesting features in these results. First, in **Figure 3a**, the largest winter wheat response to the maximum amount of N tested was on the FYM treatment—an effect similar to that on the Broadbalk experiment discussed earlier, and perhaps explained for the same reason. Second, following the ploughed-in grass/clover ley, the largest yields were with the second increment of N tested, suggesting that there could have been some beneficial effect late in the growing season from N mineralized from the N-rich ley residues ploughed-in the previous autumn. If this mineralized N is lower down in the soil profile, where roots are actively taking up nutrients, then such a beneficial effect would be difficult to mimic with fertilizer N applied on the soil surface.

Two further comments about these results; first, although best yields followed the grass/clover ley, having a ley for 3 years must be economically viable within the whole farm budget. Second, there was continued beneficial effects from straw incorporation, one of the few methods available to many farmers for slightly increasing or maintaining SOM, and perhaps preventing SOM decline.

Soil Organic Matter and Phosphorus Interactions

In addition to important interactions between SOM and the response to N, there are equally important interactions between SOM and plant-available P in soil. In an experiment on a silty clay loam soil, known to be difficult to cultivate, especially in spring, plots were established over a 12-year period with two levels of SOM, 1.5% (the arable plots) and 2.4% (the grass plots), and 24 levels of Olsen-P at each level of SOM. After the 12-year preparatory period, potatoes, sugar beet, and spring barley were each grown twice in rotation in 3 years. The 2-year average yield of each crop was plotted against Olsen-P, and the response curve fitted statistically to determine maximum yield and Olsen-P associated with 95% of the maximum yield (**Table 1**).

Table 1. Crop yield and Olsen-P associated with 95% of the maximum yield determined by plotting the 2-year average crop yields against Olsen-P.

Crop yield	Soil organic matter, %	Yield at 95% maximum, t/ha	Olsen-P associated with 95% yield, mg/kg	R^2
	---------- Field experiment ----------			
Spring barley grain, t/ha	2.4	5.00	16	0.83
	1.5	4.45	45	0.46
Potatoes tubers, t/ha	2.4	44.7	17	0.89
	1.5	44.1	61	0.72
Sugar beet sugar, t/ha	2.4	6.58	18	0.87
	1.5	6.56	32	0.61
	---------- Pot experiment ----------			
Grass dry matter, g/pot	2.4	6.46	23	0.96
	1.5	6.51	25	0.82

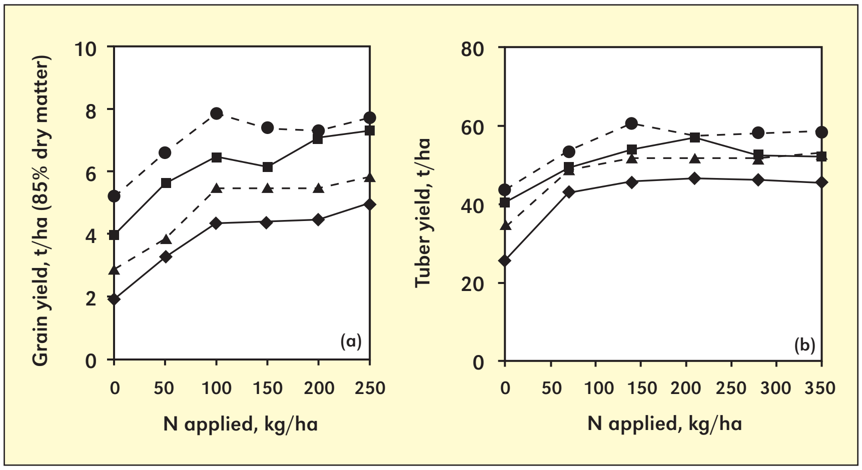


Figure 3. Yield response to N rate for winter wheat in 1987/88 (a) and potatoes in 1988/89 (b) after periods of various organic treatments (see text). Treatment and % SOM: No organic amendment, 0.65% SOM (◆); incorporating straw, 0.85% SOM (▲); adding FYM, 1.06% SOM (■); incorporating a grass/clover ley, 0.90% SOM (●).

The 95% yield of spring barley was appreciably smaller on soil with low SOM compared to that on soil with high SOM, but potatoes and sugar beet gave similar yields on both soils because better seedbeds could be prepared for these two crops sown later than spring barley. Of great importance, however, the level of Olsen-P associated with the 95% yield was much lower on soil with more SOM. The effect of SOM was to improve soil structure so that roots could grow more freely and explore the soil more thoroughly to find plant-available P.

Subsequently, soil samples from all 48 plots (two levels of SOM x 24 levels Olsen-P) were cropped with ryegrass under uniform conditions in the glasshouse. The cumulative yields from four harvests were plotted against Olsen-P and the response curves on soil with the two levels of SOM were not visually different. The 95% yields were virtually the same as were the Olsen-P levels associated with these yields (**Table 1**) strongly suggesting that soil structure in the field was the explanation for the large differences in Olsen-P associated with the 95% yields.

Summary

It is not easy to increase SOM in many arable cropping systems unless it is possible to add large amounts of organic materials. However, every attempt should be made to conserve and increase SOM wherever possible because it improves soil structure and thus the ability of plant roots to grow through the soil to find the nutrients required to optimize growth and yield. This is especially so in relation to the acquisition of N and P and thus their efficient use in agriculture. BC

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Climate Change and Wheat Crop Responses—*FACEing the Future*

By Rob Norton, Glenn Fitzgerald, and Michael Tausz

Climate change, with higher temperatures and lower rainfall is challenging us now and will continue to do so in the future. However, some of the adverse effects of changing weather patterns may be reduced through the beneficial effects of higher carbon dioxide (CO_2), even in low yielding environments. There are traits in current varieties that could provide keys to develop varieties better adapted to a warm, hot, and carbon-rich future.

The past decade has seen difficult seasonal conditions in many areas, including southeastern Australia. This region has seen a string of below average rainfall years, coupled with warmer temperatures. Weather records held by the Bureau of Meteorology show that since the 1970s, the decade leading up to 2010 has seen around 60 mm less annual rainfall in the rainfed cropping regions of South Australia, Victoria, and southern New South Wales **(Figure 1)**.

It is predicted that changes in greenhouse gases such as CO_2 will continue to increase temperatures and interfere with weather patterns (Carter et al., 2007). Predictions for much of the grain producing regions of southern Australia suggest that by 2050, rainfall will decline by around 5 to 10% and temperature will rise by 1 to 2°C (CSIRO, 2011).

Farmers have adapted to these changes through careful crop selection and management, adopting flexible programs to deal with uncertain seasons. A recent survey of growers in the Victorian Mallee showed that farmers have changed their management practices by a combination of increasing pasture or fallow frequency, reducing plant density, selecting shorter season crops, and increasing residue retention. As well, fertilizer N management is focused on rainfall which alters the yield potential and so the nutrient demand. Such changes are really risk management strategies to deal with drier and warmer seasons.

But the real question is will this be enough to adapt to a future climate and keep farm business productive and profitable?

Role of Carbon Dioxide

Carbon dioxide is part of the cause of global warming, but rising levels also have a positive effect. This trace gas, which makes up around 0.04% of the atmosphere, is used by plants as the building block of sugars and other plant materials in the process of photosynthesis. Research supports this view and has documented crops like wheat (C3 plants) showing increased growth and yield (up to 30%) in their varieties. However, other plants such as sorghum (C4 plants) do not show this response as their carbon capture mechanisms are much more efficient than C3 plants. Elevated CO_2 also causes the pores in the leaf (stomata) of both C3 and C4 plants to close—a mechanism that allows plants to conserve water.

The outcome of these responses is that wheat crops should show high water use efficiency when grown under the higher CO_2 expected in the future. Present research on this topic also shows that temperature and water availability could affect the response expected to high CO_2. The actual impact of higher temperatures and reduced water availability may in fact reduce any growth benefit from the high CO_2. This research investigates how crops will respond to a future climate that is warmer, drier, but has more CO_2 in the air.

Common abbreviations and notes: N = nitrogen; FACE = Free Air Carbon Dioxide Enrichment.

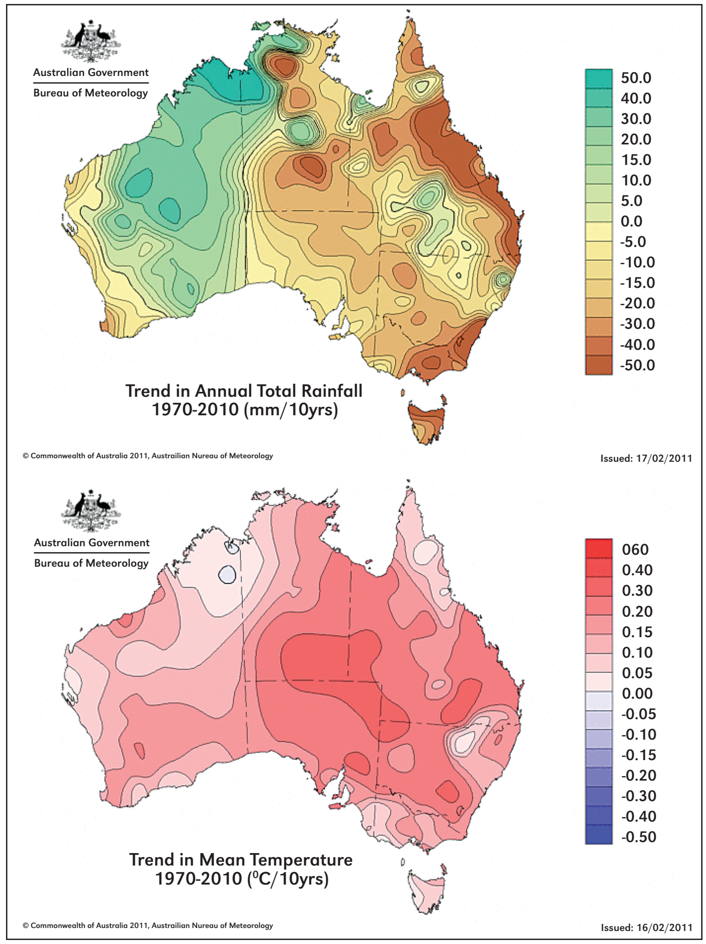

Figure 1. Decadal changes in annual total rainfall (top) and mean temperature (bottom) for South Australia for the period 1970 to 2010.
(Source: Bureau of Meteorology – http://www.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi, last accessed August 2011).

FACE Study Sites

In 2007, the University of Melbourne and the Victorian Department of Primary Industries with support from the (then) Greenhouse Office and Grains Research Development Corporation commissioned the Australian Grains Free Air Carbon Dioxide Enrichment (AGFACE) facility to test the interaction of water, temperature, and CO_2. Two facilities were established, one at Horsham in the Wimmera and the other at Walpeup in the Mallee.

Figure 2. One of the eight free-air CO_2 enrichment rings in the field at Walpeup, Victoria. Eight normal plot areas well spaced from these rings were used as comparisons.

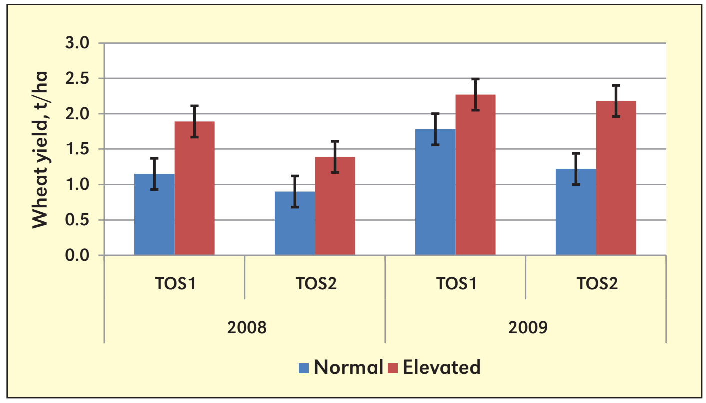

Figure 3. Mean wheat grain yield response to elevated CO_2 (550 ppm versus 385 ppm) with two sowing times (TOS1 and TOS2) at Walpeup in 2008 and 2009. Standard error for yield is 0.22 t/ha.

At these FACE sites, the crop is grown in the open air and normal soil, and the CO_2 level is raised by fumigating those treatments through distributors around the area's perimeter **(Figure 2)**. Every 2 seconds, the level of CO_2 is measured and adjusted to a target of 550 ppm. This compares to the current day time level of 385 ppm in the field.

At Walpeup, the rings were sown with wheat at normal sowing rates, but at two different sowing times—either at the traditional time in mid-May, or late-June to force crop growth from the later sowing into relatively warmer conditions during grain fill. Growth, yield, quality, N dynamics, and water use were all measured on the experiments in 2008 and 2009.

Results

Crops grown under high CO_2 gave, on average, about a 50% increase in yield. This increase occurred irrespective of the sowing time or year **(Figure 3)**. The May to November rainfalls were a dry 148 mm in 2008 and a more normal 264 mm for 2009. The harvest index of these crops—the proportion of growth that goes to grain—was not reduced with high CO_2 so the plants were actually operating more efficiently with the extra carbon available to them in the atmosphere.

The yield response suggests that CO_2 will help reduce the impact of higher temperatures and lower rainfalls, even in the low rainfall regions of Australia. However, higher yields come with lower grain protein content which is part of a physiological adaptation to having more CO_2. The plant invests less N in proteins associated with photosynthesis so that when grain filling starts, there is less N to move to the grain. Our sites were well-fertilized with N, but the grain protein contents still slipped from 15.3% (2008) and 15.5% (2009) under normal conditions to 13.4% (2008) and 13.5% (2009) under elevated CO_2. Reductions in grain mineral content and changes in other aspects of grain quality were also noticed.

The research has moved to investigate strategies to adapt wheat to produce high quality grain. In 2009 and 2010 at Horsham, a range of varieties were evaluated for their comparative growth, yield, and quality. To date, even with the small number of varieties tested, there are differences that will help develop better adapted types.

What we have reported here is only a small part of a large multi-discipline research project that seeks to identify and develop strategies to cope with impacts of climate change in the grains industry. Other research at the FACE site is on soil nutrient cycling processes, responses of legumes, and pest and disease impacts. The data are also being used to calibrate crop simulation models to develop adaptation strategies needed for the warm, dry, and carbon-rich world which seems to await us. BC

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High Yield Corn Production Can Result in High Nitrogen Use Efficiency

By Charles Wortmann, Charles Shapiro, Achim Dobermann, Richard Ferguson, Gary Hergert, Daniel Walters, and David Tarkalson

Articles such as "Fixing the Global Nitrogen Problem" by Townsend and Howarth in Scientific American, Feb 2010, are common. Alarm is expressed about the environmental impact of the increasing amount of reactive N in the atmosphere and in terrestrial and marine ecosystems around the globe. Much of this increase is attributed to production and use of N fertilizer. Use of fertilizer N is essential to meet growing global demand for agricultural commodities. Management is key to increasing productivity while also increasing N use efficiency and reducing N losses.

A team of University of Nebraska-Lincoln scientists, with partial funding from the Nebraska State Legislature, addressed this challenge. They conducted 32 irrigated trials across diverse production conditions of Nebraska from 2002 to 2004 to evaluate corn response to rates of split-applied N. The results were reported in two papers published in the January-February 2011 issue of *Agronomy Journal*.

The average maximum yield in these trials was 240 bu/A. When the previous crop was corn (CC) and soybean (CS), the respective mean yields with no N applied were 155 and 165 bu/A, and the mean grain yield increases to reach the yield plateau were 88 and 63 bu/A, respectively. The average economically optimal N rates (EONR) were 155 lb/A for CC and 110 lb/A for CS; this assumed the value of 1 bu of grain was equal to the cost of 8 lb of fertilizer N **(Figure 1; Table 1)**. The mean yield at EONR was 233 bu/A.

Yield with no N applied averaged >160 bu/A with approximately 160 lb/A of N uptake. However, we know from other trials that these levels of yield and N uptake cannot be sustained over several years of no N application, especially for continuous corn. Similar yields and N uptake, with no N applied, are unlikely to occur with similar soil organic matter levels if there is:

- less crop residue return to the soil,
- more ancient soil organic matter with a relatively great proportion in recalcitrant forms, and
- less vigorous crop and root growth with less capacity for nutrient uptake due to various biotic and abiotic constraints.

Such a contrasting situation exists for corn production in Africa, where in a recent study across 22 site-seasons in Uganda, mean grain yield and N uptake with no N applied were 29 bu/A and 41 lb/A, respectively.

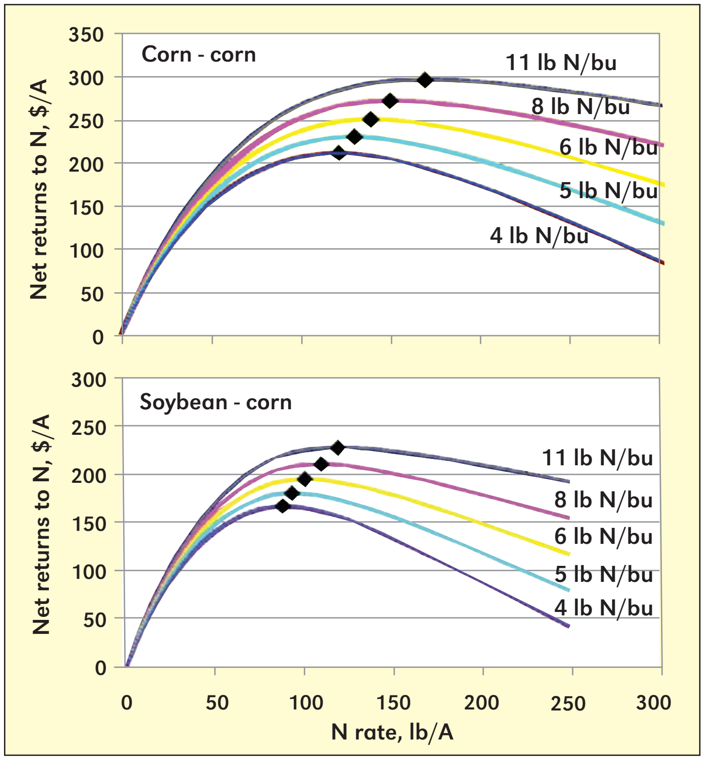

Figure 1. Returns to fertilizer N application as affected by N rate and the price of fertilizer N compared with grain. Black diamonds indicate each economically optimal N rate (EONR).

Table 1. Corn yield, fertilizer N use efficiency, and percent of applied N recovered when N was applied at the economically optimal N rate (EONR).

	Corn-corn n = 12	Soybean-corn n = 16
Yield, bu/A	237	231
EONR, lb/A	155	110
N uptake, grain	152	143
N uptake, stover	82	80
Grain:fertilizer NUE, lb/lb	85	115
Recovery efficiency, %	67	76

An overall measure of N use efficiency is the amount of grain produced per unit of N applied. This averaged 1.5 and 2.1 bu grain per lb N applied for CC and CS, respectively **(Table 1)**. The Nebraska average is about 1.1 bu of grain per lb of N applied. Therefore, N use efficiency at EONR was much higher in these high yield situations than is commonly achieved in Nebraska.

One component of N use efficiency is crop recovery of applied N (i.e. the difference in plant N uptake with and without N applied, divided by the N application rate). Mean fertilizer N recovery in above-ground biomass at EONR was 67% for CC and 76% for CS **(Table 1)**. This is almost double the national mean recovery efficiency for corn, which is about 40%. There was a linear decline in recovery efficiency of 0.2% per lb/A of N for application rates in excess of EONR.

High recovery efficiency implies little loss of applied N,

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur.

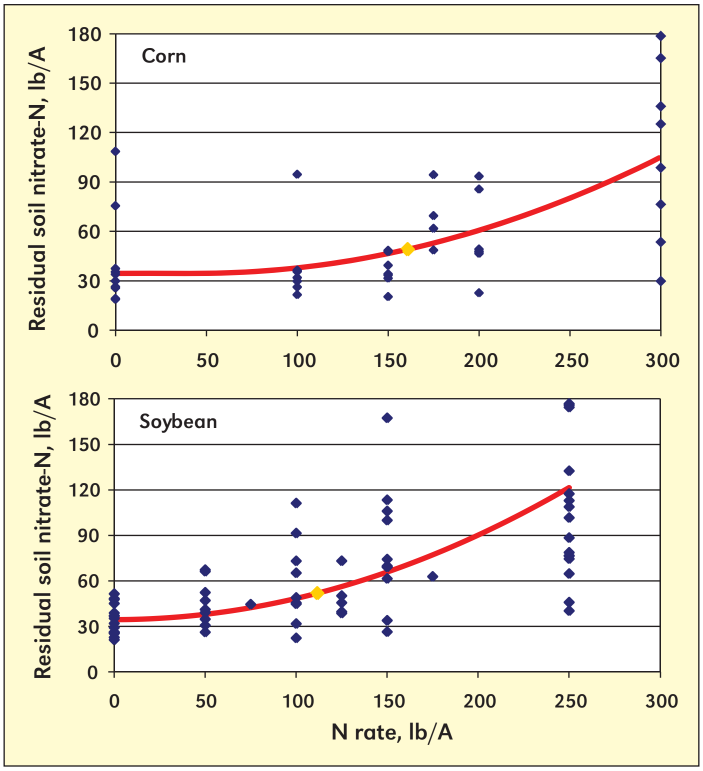

Figure 2. Effect of N rate on residual soil nitrate-N to a 4-ft depth following harvest. The gold points on the lines indicate the EONR when 8 lb N equals the value of 1 bu of corn.

and little residual soil nitrate-N remaining after harvest. Residual soil nitrate-N may be of value to a subsequent cereal crop if not lost to leaching or denitrification, but will be of little or no value to a subsequent legume crop. Mean post-harvest residual soil nitrate-N at EONR was 49 lb/A (sampled to 48 in., analyzed using water extraction and cadmium reduction) and just 14 lb/A more than with no N applied **(Figure 2)**. Residual soil nitrate-N increased greatly with N rates in excess of EONR.

Another component of N use efficiency is the conversion of plant N to grain N, or physiological efficiency. This is a function of N harvest index and grain N concentration. Grain contained 64% of the plant N. The average grain protein level at EONR was above 8%, as indicated by a grain N concentration of 1.3%, an increase from 7% protein with no N applied. Mean physiological efficiency at EONR was approximately 42 lb of grain per lb of N.

The results demonstrate the potential to achieve high N use efficiency by corn in high yield situations, compared with typical efficiencies, provided N was applied near EONR. Calculation of EONR in Nebraska considers corn yield history, previous crop, residual soil nitrate-N, and soil organic matter. Efficiency was greater with corn following soybean compared

Irrigated corn trial sites were established across Nebraska to evaluate crop response to split-applied N.

with continuous corn. Several factors contributed to high fertilizer N recovery: no fall N application; split application of N; avoiding sites prone to water-logging and leaching to minimize nitrate-N losses; crop management to have a healthy crop with a vigorous root system efficient in both nutrient uptake and conversion of nutrients and carbohydrates to grain; and irrigation management to avoid leaching and denitrification losses and to avoid crop stress. High yield corn responses to applied P, K, and S were also determined with the results reported in an *Agronomy Journal* 2010 paper. Changes to the Nebraska fertilizer recommendations for corn resulting from this research have been incorporated into several decision tools including: an on-line tool for determination of fertilizer rates (http://soiltest.unl.edu); an N rate calculator (http://cropwatch.unl.edu/web/soils/resources); the Manure Management Planner (http://cropwatch.unl.edu/web/soils/resources); and the Maize-N model (http://www.hybridmaize.unl.edu/maizeN.shtml). BC

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Potassium Fixation and Its Significance for California Crop Production

By Stuart Pettygrove, Toby O'Geen, and Randal Southard

The fixation of potassium in the interlayers of soil minerals has been the subject of interest for fertilizer management. This review highlights the mechanism of K fixation and a case study from Central California where K-fixing soils are common.

Potassium is always present as K^+ in soils, but it is found in several fractions including: (1) solution K, which is plant-available; (2) exchangeable K held weakly on cation exchange sites—also plant-available; (3) fixed K in interlayer minerals, a portion of which is available depending on soil clay mineralogy; and (4) matrix K in rocks and minerals, which is not plant-available except very slowly. In most soils, the solution and exchangeable K constitute only a few percent of the total soil K **(Figure 1)**.

Potassium fixation occurs when K^+ ions form a surface complex with oxygen atoms in the interlayers of certain silicate clay minerals **(Figure 2)**. A portion of the K held between the layers of some clays, such as smectitic clays (montmorillonite), will readily diffuse back into solution as the K is depleted due to plant uptake or leaching. However other soil minerals, especially vermiculite, will strongly complex K in the interlayer region, releasing it only very slowly back into solution.

Vermiculite is a weathering product of biotite mica and is commonly found in soils on the east side of the California San Joaquin Valley. These soils are formed in alluvium derived from granitic parent material arising from igneous intrusive rocks (**Figure 3**). An example of such a soil that fixes K is the San Joaquin series. This soil was formed from old (130,000 to 330,000 years) alluvium on low terraces bordering the eastern margins of the Central Valley floor **(Figure 4)**. This soil strongly fixes K and is generally less fertile than soils formed on younger alluvium. The region where this soil occurs was historically used for cattle grazing, but in recent decades it has become important for wine grape production, as well as for urban development.

In California, soils formed from volcanic or metavolcanic parent material, or weathered soils with kaolinitic mineralogy do not usually fix K. Soils dominated by smectitic clays, or formed in very young, coarse-textured alluvium also do not consistently fix K. However, because of spatial variability in deposition and erosion patterns, it is common to find both K-fixing and non-fixing soils in the same field.

One important finding of our work is that vermiculite most often occurs in the silt and fine-sand size fractions of the soil (Murashkina et al., 2007a). We also found that the highest percentage of added K was fixed by the silt-sized fraction, with significant fixation also occurring in the very fine and fine sand fraction. Some of the soils have non K-fixing smectite material mixed with K-fixing vermiculite in the silt and sand fractions. This is consistent with frequent observations by cotton growers in the San Joaquin Valley on sandy loam and loam soils where repeated, large doses of K fertilizer are required to correct deficiencies.

Common abbreviations and notes: K = potassium; KCl = potassium chloride; NH_4OAc = Ammonium acetate.

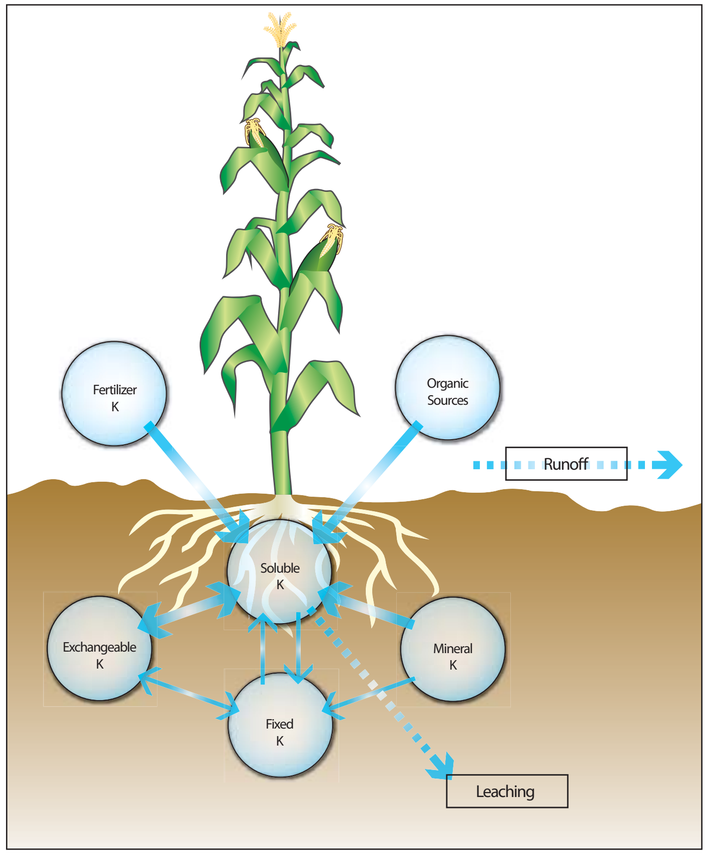


Figure 1. Although potassium can be present in several pools in soil, it is always in the form of monovalent K^+. Only a small fraction of the total K is soluble and available for plant uptake at a given time. In addition to plant uptake, leaching and runoff can also remove K from the root zone.

Importance of K Fixation for Crop Production

Late-season K deficiency in cotton in California and response to heavy applications of K fertilizer was first reported by researchers in the early 1960s. These deficiencies are widespread on the east side of the San Joaquin Valley, reflecting the prevalence of parent material derived from Sierra Nevada granitic alluvium, which contain significant amounts of vermiculite, hydrous biotite, and biotite mica at different weathering stages. Where cotton is produced on these soils, fertilizer inputs in excess of 1,500 lb K_2O/A may be required to achieve maximum yields (Cassman et al., 1990; Miller et al. 1997).

The significance of K fixation has not been studied as much for other crops in California. In UC Cooperative Extension

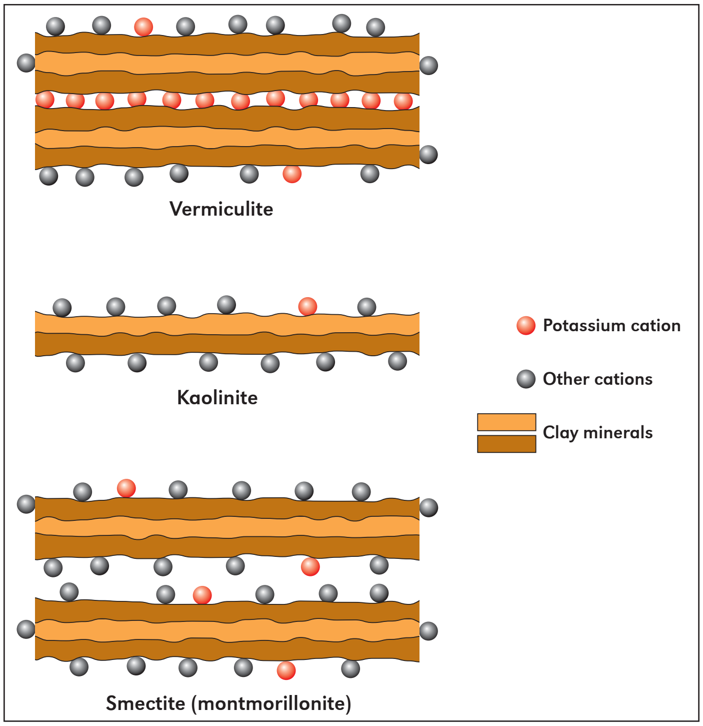


Figure 2. Fixation occurs when K is held in highly charged sites in the interlayer region of vermiculite and mica minerals. This differs from exchangeable K which is held at lower charged sites, on the surface and edges of clay minerals such as kaolinite and montmorillonite.

experiments in commercial walnut orchards in the Central Valley (Olson et al., 1990), heavy applications of 1,000 lb KCl/A did not completely correct K deficiency and did not provide a benefit for more than a few years, which suggests that K was being fixed by soil minerals.

With the widespread adoption of drip irrigation and fertigation, less K fertilizer may be needed to meet the nutritional demand of crops because the nutrients are directed to a concentrated zone beneath the plant where most of the root activity occurs. However during periods of peak nutrient demand, especially when fruit loads are heavy, this restricted root zone could lead to K deficiencies.

Changes in fertilization and irrigation practices reinforces the need to better characterize the phenomenon of K fixation. For example, the widespread conversion of processing tomatoes to drip irrigation and fertigation has prompted a re-examination of fertilization practices in K-fixing soils. Large orchards of fruit and nut trees now receive nutrients through micro-sprinklers. Cotton grown with furrow irrigation and pre-plant K fertilization may be more subject to K deficiency in fixing soils than fertigated crops.

In grapes, a careful approach is needed for K management because while wine grapes grown in this region can experience K deficiency, a high concentration of K in juice can be a problem during winemaking. The San Joaquin soil series and other similar soils are almost always deep ripped in preparation for vineyard establishment, and the vineyards are most commonly drip fertigated. The implications of K fixation for vine nutrition, rootstock selection, and fertilizer management in such a setting are not completely known. Fixation is usually greatest below a depth of 8 in., but in some vineyards the surface soil layer also fixes K. **(Figure 5)**.

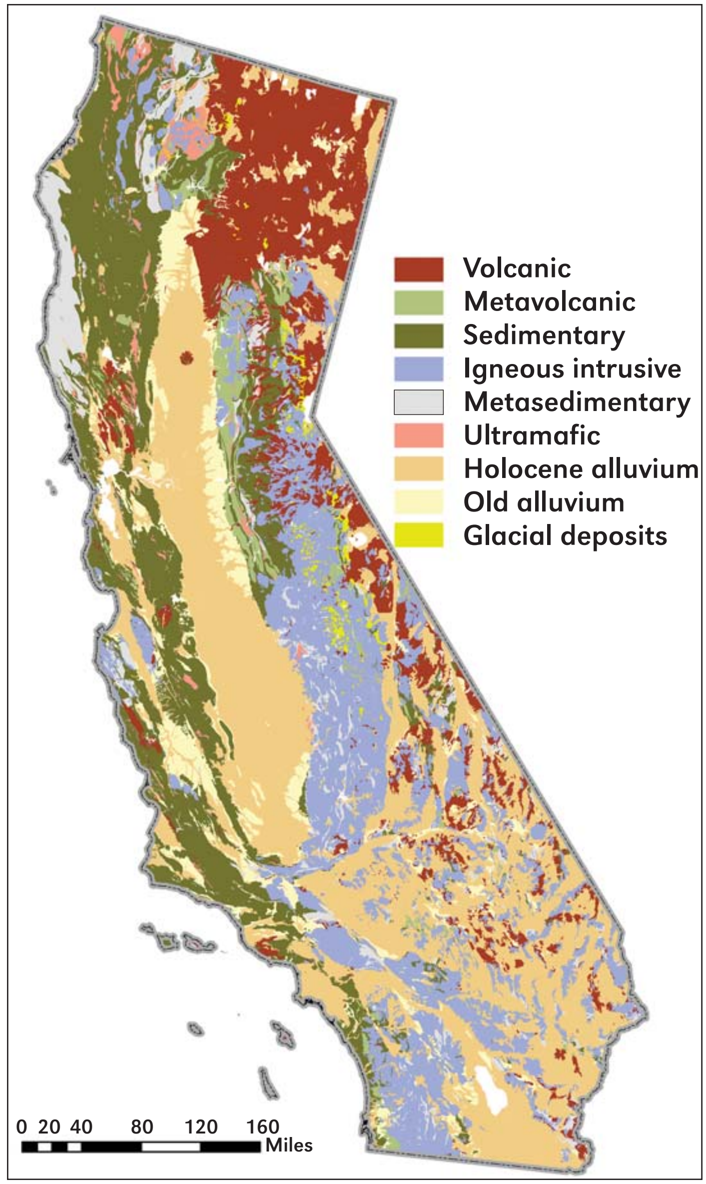


Figure 3. The soils of the Central Valley of California are primarily derived from granitic material from the East and sedimentary material from the West. Potassium-fixing soils are typically associated with granitic (igneous intrusive) parent material.

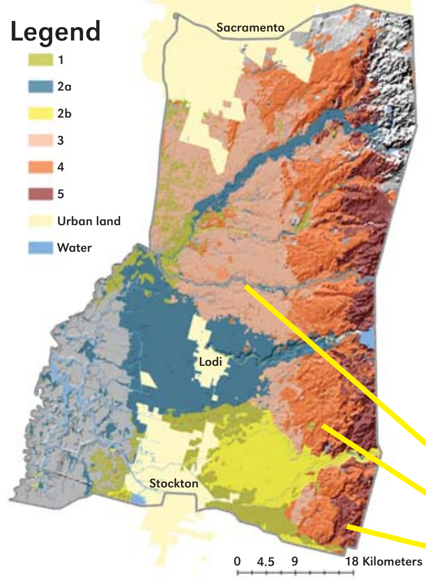
Measuring Potential Fixation

There is a wide range of K-fixation potential among soils that contain significant amounts of K-depleted mica and vermiculite (O'Geen et al., 2008). In some K-fixing soils, the subsequent release of K is significant during a growing season. In other soils, the K present in interlayer fixation sites may be very slowly released and not be a significant source of plant nutrition.

The ammonium acetate extract (1 M NH_4OAc, pH 7) is a widely used soil extractant to estimate both soluble and exchangeable K. However this procedure is inadequate for soils that have micaceous or vermiculitic mineralogy, which can release some non-exchangeable (fixed) K when the solution and exchangeable K pools are depleted.

An alternative method for measuring non-exchangeable plant-available K in soils (i.e. the plant-available portion of fixed K) is using the sodium tetraphenylboron extraction. A practical version of this procedure involves a 5-minute incubation (Cox et al., 1999). They report that in Midwest US soils, this procedure extracted 1.5 to 6 times more K than did NH_4OAc and closely correlated with plant uptake of K. However, this method did not adequately measure K fixation capacity in California's K-fixing soils (Murashkina et al., 2007b). Our procedure for measuring K fixation capacity requires a 1-hr incubation and is suited to commercial laboratory usage. We are currently working to measure the relationship between soil K fixation capacity and K fertilizer response for a variety of crops.

The extent of K fixation is largely determined by the soil mineralogy. When vermiculitic clay and mica-based parent material are present, K fixation can be a significant barrier to meeting the nutritional requirements of crops. In most other soils, K-fixation should not be a significant factor to consider. New laboratory techniques for estimating both the K-fixation potential and the release rate will help with K management decisions. BC



	Description	Soil, example	K fixing soil?
1	Clayey, basin alluvium	Stockton clay	Usually not
2a	Coarse, fans	Columbia sandy loam	Commonly, but variable with depth
2b	Clayey, Calaveras R.	Archerdale clay loam	Uncertain
3	Low, moderately old terraces	San Joaquin loam	Yes
4	Gravelly weathered old terraces	Redding gravelly loam	Usually not
5	Volcanic, eastern part of district	Pentz sandy loam	No

Figure 4. An example of mixed soil mineralology and its impact on K-fixation potential in the Lodi Winegrape District in Central California.

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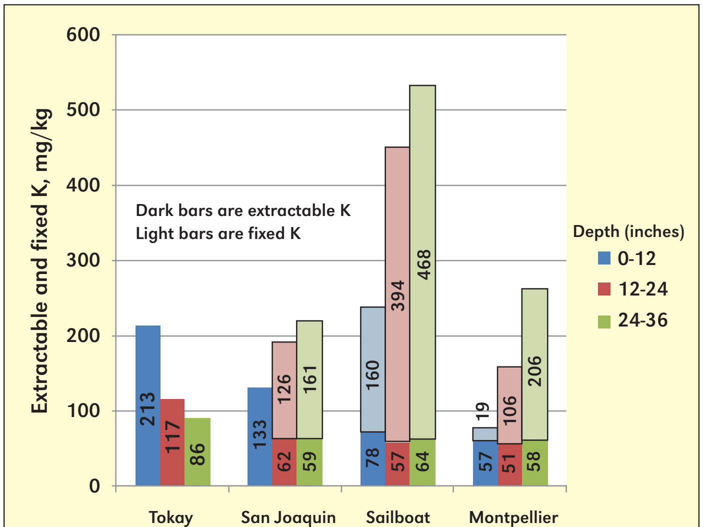

Figure 5. Examples of extractable K (NH_4OAc) and fixed K (Murashkina et al. 2007b) of four soils in Lodi winegrape district in Central California

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Crop Responses to Fertilization in the Eastern Plains of Bolivia

By Jorge Terrazas, Grover Guaygua, Estanislao Juárez, Mauricio Crespo, and Fernando García

The eastern plains of Bolivia is an important area of grain crop production. A network of exploratory experiments conducted from 2005 to 2008 focused on crop nutrient deficiencies and responses to applied P, K, S, micronutrients, and N. Results of these experiments are presented in this article. A high probability of grain yield response to P was measured when Olsen P tested less than 6 mg/kg. Potassium, S, and micronutrients might be deficient under certain conditions.

Bolivia is one of the main grain (i.e. cereal and oil crop) producing countries of South America with an estimated total production in 2008 of 3.65 million (M) t within an area of 2 M ha (INE, 2010). Soybean is the most important grain crop with a production in 2008 of 1.2 M t on 835,000 ha—an average yield of 1,468 kg/ha. Grain production is largely carried out in the eastern plains in the Department of Santa Cruz **(Figure 1)**. The northern and eastern regions of the plains have distinct soil characteristics, soil fertility, and weather conditions which transition towards its central regions.

Poor native soil fertility in some areas, generally low fertilizer use, and continuously high nutrient removal brought about by 30 years of intensified cropping have made the appearance of nutrient deficiencies commonplace. However, most of the research has been limited to a few annual experiments that examine specific nutrients and areas.

In the winter of 2005, the farmers' organization Fundacruz (the Foundation for the Agricultural Development of Santa Cruz), started a network of exploratory field experiments with the collaboration of IPNI to evaluate deficiencies and responses to P, K, S, and micronutrients (i.e. B, Cu, Zn) in the northern, central, and eastern regions of Santa Cruz de la Sierra. Evaluation of N responses were carried out when maize and wheat crops were included in the rotation.

A total of seven field experiments were established: four in the northern region at Mónica Norte, Nuevo Horizonte, El Porvenir, and Cauce Viejo farms, two in the central region at CAICO, and El Paraíso farms, and one in the eastern region at Curichi farm. Soil analyses at the beginning of the experiments are shown in **Table 1**.

Treatments evaluated included: 1) Check; 2) PK (20 kg/ha P + 50 kg/ha K); 3) PS (20 kg/ha P + 10 kg/ha S); 4) KS (50 kg/ha K + 10 kg/ha S); 5) PKS (20 kg/ha P + 50 kg/ha K + 10 kg/ha S); and 6) PKS+Micros (20 kg/ha P + 50 kg/ha K + 10 kg/ha S + 0.2, 0.1, and 0.3 kg/ha of B, Cu, and Zn, respectively). Fertilization rates were repeated every season in the same plots to allow for the evaluation of direct and residual fertilization effects. Nitrogen fertilization was evaluated in the maize and wheat

Figure 1. Map of Bolivia showing the Department of Santa Cruz de la Sierra*. Source: Google Earth ©2010. *The yellow circle includes most of the agricultural region of the department.

Common abbreviations and notes: N = nitrogen; P = phosphorus; S = sulfur; K = potassium; B = boron; Cu = copper; Zn = zinc.

Table 1. Soil chemical properties of the A horizon (0 to 20 cm) at the establishment of the field experiments.

	----------- Northern region -----------				--- Central region ---		Eastern region
Property	Monica Norte	Nuevo Horizonte	El Porvenir	Cauce Viejo	Paraiso	CAICO	Curichi
pH	8.0	7.7	6.5	6.8	7.0	7.2	7.0
EC, dS/cm	226	86	105	59	20	75	93
Clay, %	14	9	11	10	9	17	29
Silt, %	85	75	87	82	51	80	68
Sand, %	1	16	2	8	40	3	3
Organic matter, %	1.7	1.1	2.0	1.4	1.2	2.5	2.9
Total N, %	0.13	0.08	0.15	0.12	0.17	0.27	0.23
Olsen P, mg/kg	1.8	3.1	7.8	5.5	5.3	2.2	37
Sulfate-S, mg/kg	10	4	4	7	3	33	48
Exchangeable K, $cmol_+$/kg	0.15	0.32	0.34	0.35	0.18	0.72	0.73

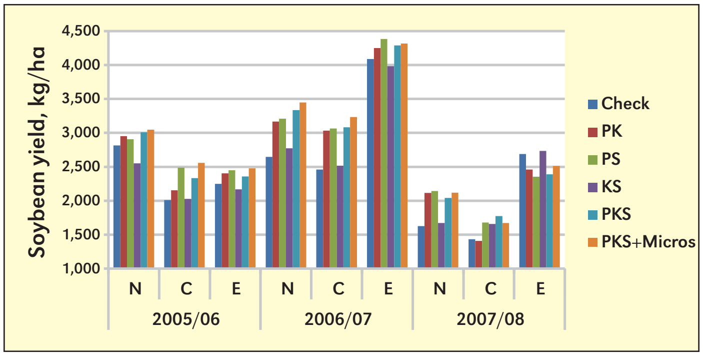

Figure 2. Soybean grain yield, averages of the sites of each region, for the six treatments evaluated in the summer seasons 2005/06, 2006/07, and 2007/08. N, C, and E stand for northern, central, and eastern regions, respectively.

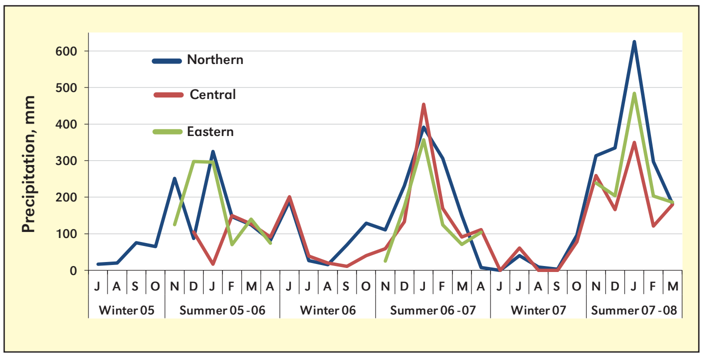

Figure 3. Monthly precipitation in the three regions from July 2005 through March 2008.

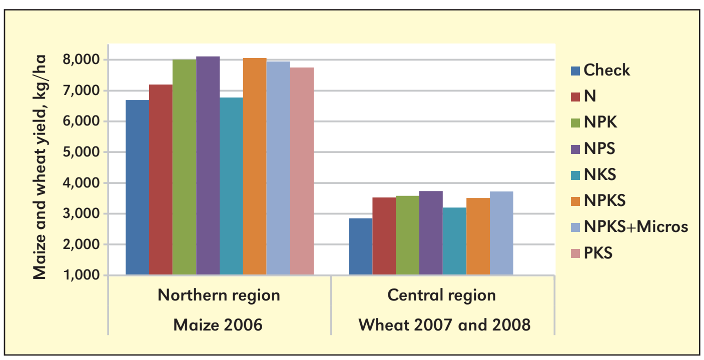

Figure 4. Grain yields of maize in the 2006 winter season, averages of four sites, and of wheat in the 2007 and 2008 winter seasons, averages of two sites, for eight fertilization treatments.

crops by introducing additional treatments with (60 kg N/ha) and without N in some experiments according to field rotation.

In the northern region, two crops are planted every year: winter and summer cropping seasons. In the central and eastern regions, the main season is the summer and planting in the winter season depends on soil water availability at planting. Crop management (i.e. varieties/hybrids, planting dates, pest management, etc.) was optimized and carried out by the farmers according to best management practices (BMPs) known for the region. All sites were managed under no-tillage. Soybean seeds were inoculated with *Bradyrhizobium* strains adapted to the region. Fertilizers were applied at planting, 3 to 4 cm below and to the side of seeds.

Phosphorus deficiency in a maize crop at Monica Norte, Winter 2006.

Results

Soybean grain yields were affected by flooding and soybean Asian rust in the 2007/08 summer season and by a dry period in the 2007 winter **(Figure 2)**. Differences in soybean grain yield among regions were related to disease pressure, soil conditions, and crop management. In the northern region, soybean yields performed similarly in the winter and summer seasons, despite the difference in precipitation between seasons **(Figure 3)**. Adequate weather conditions contributed to excellent grain yields of maize in the 2006 winter season, and wheat in the 2007 winter season **(Figure 4)**.

Phosphorus was the main nutrient deficiency with significant responses in 24 of a total of 32 site/years. These responses are attributed to the low Olsen P levels of most of the sites **(Figure 2 and 4)**. No responses were observed at Curichi, the only site with high soil Olsen P availability.

Relating relative yields (i.e. grain yield of the KS treatment/grain yield of the PKS treatment) and soil Olsen P, allowed estimation of a critical Olsen P level of 5 to 6 mg P/kg **(Figure 5)**. This critical level would be an initial tool for the region on deciding BMPs for P fertilization. The average response for 20 site/years of soybean below 6 mg P/kg was 268 kg/ha. For maize (4 site/years), the average response was 1,542 kg/ha. The estimated agronomic efficiencies (AE) were 13.4 kg soybean and 77.1 kg maize per kg P, which compare to fertilizer/grain price ratios of 8.3 and 15.9 kg soybean and maize, respectively, per kg P (considering prices of USD 3.5/kg P, USD 0.42/kg soybean, and USD 0.22/kg maize). Thus, the net return for P fertilization under soil Olsen P below 6 mg/kg would be USD 1.6/USD and USD 4.8/USD for soybean and maize, respectively.

The statistical analyses also showed significant responses to micronutrients at one site in the 2005 winter season soybean and to S at one site in the 2007/08 summer season soybean. These responses could not be confirmed in other seasons at the same sites. The low exchangeable K levels of Monica Norte and Paraiso **(Table 1)** would suggest a high probability of response to K fertilization, however no responses were observed at either of these two sites.

Nitrogen fertilization significantly increased grain yields in the 2006 winter maize at two sites, and in the 2007 winter wheat at one site **(Figure 3)**. Nitrogen fertilization produced no significant differences at the other sites.

Dr. Garcia (right) visiting one of the seven field experiments established within the Fundacruz network. This site (El Porvenir) was located in the northern region of eastern plains of Bolivia.

Summary and Conclusions

The Fundacruz network of exploratory experiments allowed determination of P deficiencies and a high probability of grain yield response in soils with Olsen P below 6 mg P/kg, contributing to the development of BMPs for fertilizer use in the region. Research also showed that K, S, and micronutrients might be deficient under certain soils and management conditions.

Further research will address the determination of right rate, source, time, and place of P fertilization under responsive situations. Also, exploration of K, S, and micronutrient deficiencies and responses should be continued. Fertility management should be integrated with soil management practices, and overall crop management to develop sustainable cropping systems in the eastern plains of Bolivia.

More information on this research project (Bol-01) is available from the IPNI Research Database found at www.ipni.net/research BC

Mr. Jorge Terrazas, Grover Guaygua, Mauricio Crespo, and Estanislao Juarez are former research staff members with Fundacruz (Foundation for the Agricultural Development of Santa Cruz), website: www.fundacruz.org.bo/. Dr. Garcia is Director, IPNI Latin America-Southern Cone, e-mail: fgarcia@ipni.net

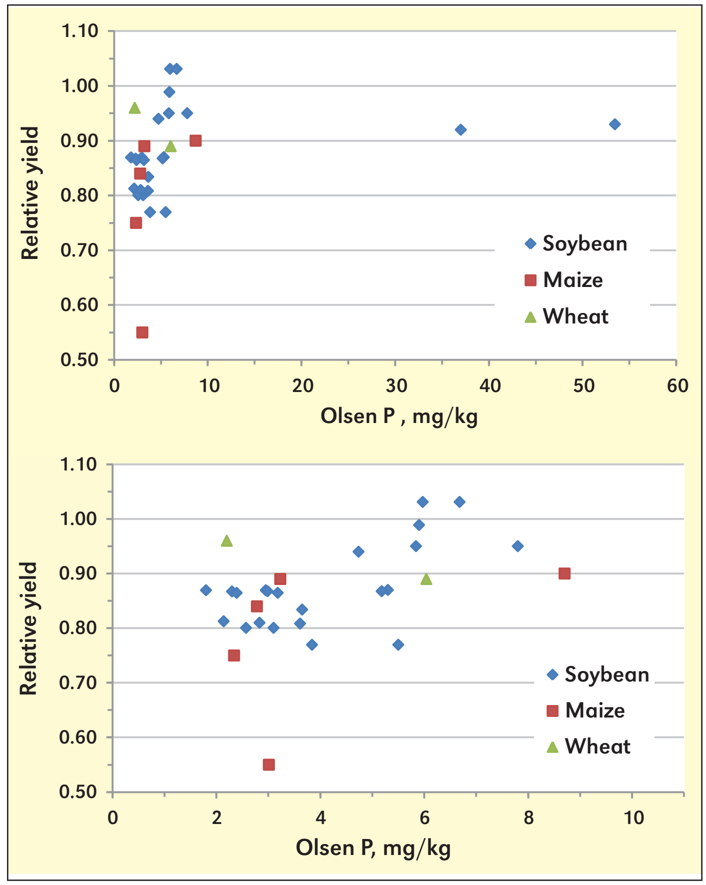

Figure 5. Relationship of relative yield of soybean, maize, and wheat with soil Olsen for 32 site-years of the Fundacruz network. Top figure shows the relationship for all site/years, and lower figure shows the relationship for sites with Olsen P below 10 mg P/kg.

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Study Guide for International Certified Crop Adviser Exam

The publication titled Preparing for the 2012 International Certified Crop Adviser Exam (Item #50-1000) is available for purchase from IPNI. The price of USD 50.00 (fifty-dollars) includes shipping and handling.

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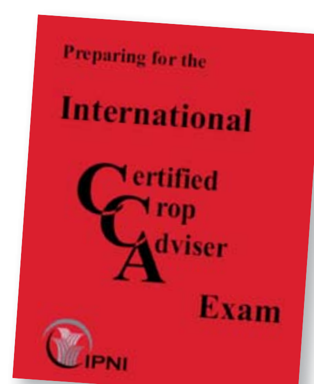

Soil Acidification under Oil Palm: Rates and Effects on Yield

By Paul N. Nelson, Tiemen Rhebergen, Suzanne Berthelsen, Michael J. Webb, Murom Banabas, Thomas Oberthür, Chris R. Donough, Rahmadsyah, Kooseni Indrasuara, and Ahmad Lubis

Field experiments in Papua New Guinea have shown strong effects of fertilizer type and placement on soil acidification in oil palm plantations—a potential degradation issue that may eventually have an adverse effect on yields. However, measurements at four sites in Indonesia show that relatively high yields are possible on soils with a low pH, and that best management practices can actually increase pH at low values. It is concluded that current pH levels in major growing areas of oil palm in Southeast Asia can be managed such that they do not prevent relatively high oil palm yields.

Being a perennial tree crop, oil palm is an ideal plant for sustainable agricultural cropping systems. Since the introduction of ammonium fertilizers in the 1980s, however, soil acidification under oil palm has been a potential degradation issue. This study assumes a dual approach to understand the problem through 1) experimental work looking at effects of fertilizer on soil acidity on relatively high pH soils in Papua New Guinea (PNG) and 2) measurements of yield at low soil pH values (in Indonesia) typical of those used in large oil palm growing regions in Southeast Asia.

In PNG, most oil palm is grown on fertile volcanic ash soils with addition of N fertilizer (mostly ammonium-based). Because of high rainfall rates and permeable soils, nitrate losses are promoted by leaching and soil acidification is likely as a result of that leaching. In addition, removal of base cations in harvested product is expected to accelerate acidification. These cations are returned as by-products from the oil-mill only to fields close to the mill.

Results are presented here from two fertilizer trials designed to determine the rate of soil pH decline and acidification under oil palm grown on recent volcanic ash soils of PNG. The objectives of the trials were to determine a) the effect of fertilizer type on acidification, and b) the effect of fertilizer placement on acidification and pH buffering capacity (pH BC).

The fertile soils of PNG are not necessarily representative of the major growing areas of the crop in Southeast Asia. Mutert (1999) has estimated that about 95% of oil palms are grown on acid, low fertility soils in Southeast Asia. We therefore discuss the data from PNG within the wider context of Southeast Asia using information from a general literature review of pH values, and from preliminary results from plantations in major growing areas of Indonesia where the Southeast Asia Program (SEAP) of the International Plant Nutrition Institute (IPNI) has developed Best Management Practices (BMPs).

Papua New Guinea Sites

The effect of fertilizer type was measured at Ambogo plantation, Oro Province (Trial A), PNG. The site has an annual average rainfall of 2,214 mm with silt or sandy loam soil derived from alluvially re-deposited volcanic ash. The trial was a Latin square design with five treatments, five replicates, and 36-palm plots, of which the central 16 palms were monitored. Treatments included application of no fertilizer, ammonium chloride (AC) at 3.2 kg/palm/yr, ammonium sulfate (AS) at 4.0 kg/palm/yr, and AS (4.0 kg/palm/yr) together with either potassium chloride (KCl, 4.4 kg/palm/yr) or bunch ash (BA, 8.8 kg/palm/yr). The BA, which supplied the same amount of K as the KCl, was produced by burning empty fruit bunches (EFB). The trial was conducted in a field that had been planted in 1980 with 143 palms/ha, and treatments ran from 1990 until 2001. In 1989 and 2002 (before and after treatments), soil samples were taken from each plot (0 to 0.2 m depth). Each sample was a composite of five sub-samples. The sample pits were located in the corners and the middle of the plot, exactly between two palms (equivalent to the BP zone in **Figure 1**). This zone received some fertilizer, with most of the remainder falling on the frond pile (FP) **(Figure 1; Photo)**.

The effect of fertilizer placement and EFB application was measured at Kumbango plantation, West New Britain

Common abbreviations and notes: C = carbon; Ca = calcium; Mg = magnesium; N = nitrogen; Na = sodium.

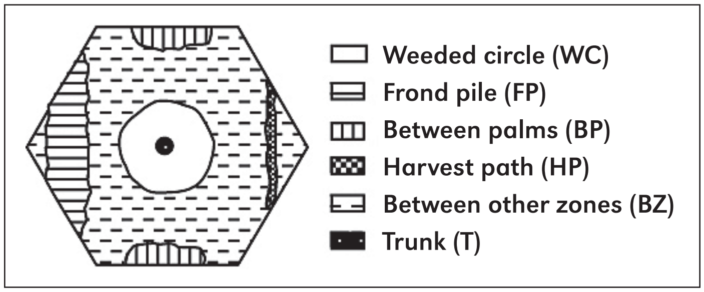

Figure 1. Surface management zones in the fertilizer trials. The hexagon, whose perimeter is defined by the midpoint between adjacent palms, represents the repeating unit in oil palm plantations. Empty fruit bunches (EFB) were applied to the Between palms (BP) zone in some treatments in Trial B, but none in Trial A.

Oil palm plantation managed under the BMP program developed by IPNI SEAP. The weeded circle surrounding the palm as well as the frond pile stack (on left) are clearly visible.

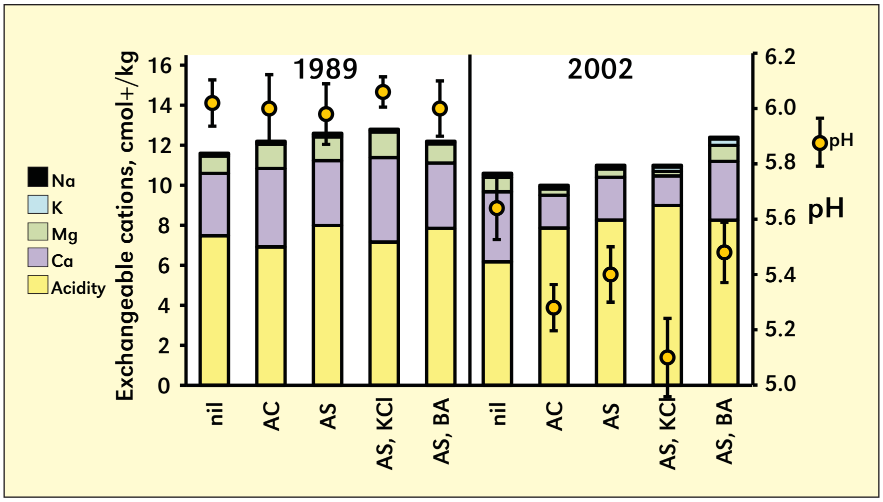

Figure 2. Mean exchangeable cation content (bars) and mean pH_{water} (circles ±s.d.) of soil in the BP zone of Trial A (0 to 0.2 m depth).

Province (Trial B), PNG. The site has an annual average rainfall of 3,248 mm, and clayey recent volcanic ash soils with some inter-bedded pumice. The trial was a randomized complete block design, with four replicates of 36-palm plots, of which the central 16 were monitored. Treatments included placement of fertilizer onto the 'weeded circle' (WC), the 'frond pile', or in the 'between palms' (BP) zones **(Figure 1)**. The BP zone had EFB applied (50 t/ha/yr) in some plots and not in others. The fertilizer applied was AC (3 kg/palm/yr) plus kieserite ($MgSO_4 \cdot H_2O$, 3 kg/palm/yr). The trial was conducted in a field that had been planted in 1994 with 135 palms/ha, and treatments were applied from 1998 until 2004. In 2004, soil was sampled from all application zones at depth increments of 0 to 0.05 and 0.05 to 0.1 m. Each sample from each plot, zone, and depth increment was a composite of eight samples taken from two points adjacent to each of four different palms.

In both trials, soils were analyzed for pH (1:2 soil to water for Trial A and 1:5 for Trial B), exchangeable cations, cation exchange capacity (CEC) and organic C content. Selected samples were analysed for bulk density and pH BC by titration (calculated by linear regression of titration curves). In Trial A, net acid addition rate (NAAR) was calculated by multiplying the pH change by pH BC (24.6 mmol/kg per pH unit) and bulk density (1.14 Mg/m^3).

Indonesian Sites

The Indonesian results were generated at sites that IPNI SEAP uses to develop BMPs for sustainable intensification of oil palm. IPNI SEAP developed the BMP concept as a management tool for yield gap correction and yield intensification in mature oil palm plantations (Donough et al. 2010). In this concept, a set of site-specific BMPs are identified and implemented in a number (five minimum) of full-sized management blocks representative of a plantation. A parallel set of comparable blocks under standard practice are monitored as reference (REF) blocks for comparison. Measurements of soil pH were taken at the beginning and at the end of a 4 year BMP implementation cycle in four plantations in major growing areas of Southeast Asia (i.e. two sites in north Sumatra, one site in south Sumatra, and one site in west Kalimantan). In these plantations, N is predominantly applied as urea within the weeded circles of the REF blocks, and partially as AS in the BMP blocks. Timely pruning contributes a consistent source of nutrients and organic matter (Goh and Härdter, 2003).

Results

In Trial A in PNG, soil pH declined and exchangeable acidity increased in all treatments, with pH of the 0 to 0.2 m layer dropping by 0.38 units in the nil fertilizer treatment and 0.52 to 0.96 units in the fertilized treatments **(Figure 2)**. Addition of AS or AC accelerated pH decline by 0.023 units/year compared to the control treatment (nil fertilizer). Addition of AS together with KCl accelerated pH decline by 0.042 units/year compared to the control, whereas BA had an ameliorative effect on pH compared to AS alone. There were substantial decreases over time in exchangeable Ca and Mg and effective CEC (sum of cations) in all fertilized treatments except AS+BA. NAARs for the top 0.2 m were 1.6, 3.1, 2.5, 4.2, and 2.3 kmol/ha/year for the nil, AC, AS, AS+KCl, and AS+BA treatments, respectively. In the fertilized plots, the NAARs were less than the potential NAAR calculated from nitrification and uptake or leaching loss of nitrate (8 to 17 kmol/ha/yr), possibly because the 0 to 0.2 m depth layer of the BP zone was not representative of the whole field.

In Trial B in PNG, pH and the effects of fertilizers on pH differed markedly between management zones **(Table 1)**. Without the addition of fertilizer, pH was lowest in the WC (which had the lowest organic matter content of all the zones) and highest in the FP and BP+EFB zones (which had the highest organic matter contents). In all zones pH was lowest in the surface layer. The decrease in pH of the 0 to 0.05 m layer due to fertil-

Table 1. Effect of fertilizer (fer.) application and placement on soil properties in Trial B (Values are the mean of four replicates).

	Values in 0 to 0.05 m depth				Values in 0.05 to 0.10 m depth			
	WC	FP	BP+EFB	BP-EFB	WC	FP	BP+EFB	BP-EFB
pH water (-fer.)	5.5	6.0	6.0	5.8	5.7	6.0	6.4	5.9
pH water (+fer.)	5.0	4.8	5.3		5.1	5.0	5.5	
Org C (-fer.), %	3.9	10.4	11.4	4.0	2.7	4.9	5.1	3.1
Org C (+fer.), %	3.3	9.3	14.4		2.6	5.1	6.1	
CEC (-fer.), $cmol_+/kg$	6.5	28.4	26.5	10.1	5.7	16.5	18.5	7.6
CEC (+fer.), $cmol_+/kg$	2.9	10.1	22.8		2.1	6.0	13.6	
ExCa (-fer.), $cmol_+/kg$	24.8	27.8	28.2	36.1	20.2	26.3	25.2	33.5
ExCa (+fer.), $cmol_+/kg$	2.2	8.0	19.0		1.8	4.4	9.9	
ExMg (-fer.), $cmol_+/kg$	0.7	4.1	4.5	1.4	0.6	2.3	4.2	1.1
ExMg (+fer.), $cmol_+/kg$	0.4	3.5	9.8		0.4	1.7	6.0	
ExK (-fer.), $cmol_+/kg$	0.4	1.3	0.7	0.6	0.4	1.3	1.5	0.6
ExK (+fer.), $cmol_+/kg$	0.3	0.8	0.8		0.2	0.5	0.7	

Table 2. Yield and pH values measured at four plantation sites in "Best Management Practices (BMP)" blocks and "Estate Reference Practices (REF)" blocks.

			-------- Soil pH (KCl) Frond Pile[1] --------			------ Soil pH (KCl) Weeded Circle[1] ------		
T[2]	Area[3]. ha	FFB[4]. kg/ha	Start (S) Avg	End (E) Avg	E-S[5]	Start (S) Avg	End (E) Avg	E-S
BMP 1	158.8	26,338	3.9	4.5	0.6	3.8	4.2	0.4
REF 1	162.7	23,123	3.9	4.3	0.4	3.8	4.2	0.4
BMP 2	177.7	27,360	3.8	4.1	0.2	3.8	4.0	0.2
REF 2	171.1	23,042	3.8	4.2	0.4	3.8	4.1	0.3
BMP 3	164.3	25,950	3.8	4.1	0.3	3.7	3.9	0.2
REF 3	162.7	22,442	3.7	4.1	0.4	3.7	4.0	0.4
BMP 4	183.6	25,430	3.7	4.1	0.4	3.7	4.1	0.3
REF 4	193.3	22,859	3.8	4.2	0.5	3.8	4.1	0.3
BMP 5	135.5	27,187	3.6	4.0	0.4	3.6	4.0	0.4
REF 5	157.7	23,488	3.6	4.1	0.4	3.6	4.0	0.4
BMP All	819.9	26,453	3.8	4.1	0.4	3.7	4.0	0.3
REF All	847.5	22,991	3.7	4.2	0.4	3.7	4.1	0.4

[1] Soil pH determined at start (July 2006) and end (= final = July 2010); Average values for 0 to 20 and 20 to 40 cm depth, representing four blocks from four locations.
[2] Treatments include five "Best Management Practices (BMP)" blocks and five control "Estate Reference Practices (REF)" blocks at each of the four plantation sites
[3] Aggregated areas for each respective BMP and REF treatment from four plantation sites: two in north Sumatra, one in south Sumatra and one in west Kalimantan
[4] Fresh Fruit Bunch weight, annual average data of four years data
[5] Average at End minus Average at Start
General notes: Years of planting between 1994 and 2001 at site 1, 1992 and 1998 at site 2, 1989 and 1992 at site 3, and 1998 and 1999 at site 4; 134 palms per hectare (average across sites and blocks); Seed material included LonSum, Dami, SocFin at site 1, Marihat, SocFindo at site 2, Marihat, Dami at site 3, and DxP Hybrid seeds from ASB Costa Rica at site 4.

izer addition was least (0.52 units) when fertilizer was applied in the WC and greatest (1.17 units) when fertilizer was applied in the FP. The difference in pH decline between zones may have been due to differences in N transformations and fluxes, or to differences in pH BC. Soil pH BC did indeed differ between application zones; it was highly correlated with organic matter content. The greatest decline in pH occurred in the FP and BP zones, despite their high organic matter content and pH BC. Therefore, the difference in acidification rates between zones appears to have been primarily due to differences in N cycling processes. The pH decline due to fertilizer addition in Trial B was accompanied by large decreases in exchangeable cation contents, especially Ca **(Table 1)**. Addition of EFB (without fertilizer) resulted in an increase in pH, CEC, and exchangeable Mg and K, but in a decrease in exchangeable Ca **(Table 1)**.

In contrast to PNG, Indonesia's low soil pH values are typical of those used for most oil palm production. Information from the four sites is summarized in **Table 2**. The data provide no evidence that application of fertilizer to relatively low fertility soils leads to further acidification or yield reduction. Relatively high yields are obtainable on soils with pH values lower than those reported for the PNG trials. Furthermore, during the 4 year implementation cycles, pH values increased on average by almost half a unit in BMP and REF blocks. Parallel yields in the BMP blocks also increased substantially. BMPs were strictly adhered to in these plantations, and while these practices are likely to have contributed to differences in pH values, the BMP work has just been concluded and no specific explanation for these trends can be provided prior to detailed analysis of the entire dataset.

It is difficult to accurately assess acidification of soil under oil palm, due to the large spatial variability in through fall, water uptake, fertilizer application, and organic matter content (due to placement of pruned fronds in FP, prevention of understory growth in the WC, and application of EFB to the BP zone in some plantations). Yet, the results of the PNG trials outline clear trends:

1. Under oil palm in PNG, there was significant acidification of volcanic ash soil with time, with or without fertilizer application, despite the soil's relatively high CEC and organic matter content.
2. Addition of ammonium-based fertilizers significantly accelerated pH decline, with combined addition of KCl enhancing the decline. However, the degree of acidification can be reduced by adding bunch ash to the fertilizer applications.
3. Application of the fertilizers in Trial B was accompanied by a decrease in exchangeable cation content. Except for Ca, bunch ash application reversed this trend.
4. The effect of fertilizer addition on acidification was spatially variable, being greatest when fertilizer was applied in the FP and BP zones, probably due to a high proportion of N being lost by leaching in those zones.

However, the trends identified here merit careful consideration to avoid making assumptions about oil palm production systems elsewhere, where soil properties differ. Furthermore, the management practices that resulted in the reported reduction in pH value are similar to those developed by IPNI SEAP for sustainable yield intensification in oil palm plantations using BMP (Donough et al. 2010). Specifically, the BMP concept promotes (Rankine and Fairhurst, 1998):

1. Placing of pruned palm fronds between rows and in the space between palms within rows,
2. Applying AS over the edge of the weeded palm circles and the adjoining frond stacks,
3. Spreading urea evenly within the weeded palm circle,
4. Applying straight and compound P fertilizers over the edge of the weeded palm circles and over the inter-row spaces,
5. Spreading straight and compound K fertilizers in a wide band around the weeded palm circles, and
6. Using EFB as organic fertilizer to replace bunch ash.

One might deduce from the results of the fertilizer studies in PNG that the listed BMPs may contribute to a reduction in pH over time. If evidence exists for such change, the BMP implementation process should address it so as not to jeopardize sustainable yield intensification. However, the fact that pH of the Indonesian soils did not decline over time suggests that they have reached a pH at which pH BC is effectively infinite (Nelson and Su, 2010) and little or no further decline in pH will occur under normal agricultural practices.

Based on an extensive literature review, we conclude that oil palm can tolerate fairly low values in pH. Commonly reported pH values in the range between 4 and 5 are considered favorable for commercial oil palm production in Southeast Asia (von Uexkull and Fairhurst, 1991; Goh 1995; Mutert 1999; Corley and Tinker, 2003; Paramananthan, 2003). Mutert (1999) listed eight representative soil types commonly used for oil palm in Southeast Asia and he further stated that all of these soils have a pH less than 5.0, six of the eight soils have low to very low contents of N, available P, and exchangeable K, and half of the soils have low to very low content of exchangeable Mg, when evaluated for oil palm fertility parameters.

Conclusions

Experiments in PNG have shown a strong acidifying impact of fertilizer application in oil palm plantations, alerting practitioners to the potential risk of adverse impact on yields. However, a literature review and preliminary data from BMP implementation at four sites in Indonesia illustrate that relatively high yields are obtainable on soils with a low pH. Plantation managers are advised to monitor and evaluate soil fertility characteristics in both the weeded circles and frond deposition areas to determine the relationship between acidification and yield trends.

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Nutrient Management for Alfalfa Grown on Acid, Hilly Regions of Chongqing

By Jia Zhou, Wei Li, Henglin Dai, Guangqun Dong and Shihua Tu

Researchers found that the optimal fertilizer treatment for alfalfa production in the hilly areas within Chongqing, China included not only N, P, and K, but also Mg — at a frequency of once every 2 or 3 years. While not impacting yield, inclusion of Mo in the balanced, optimal treatment may result in cases of higher crude protein and enhanced palatability of alfalfa forage.

Alfalfa is an important forage used for livestock and poultry feed in China. Recently, the area under alfalfa cultivation has been expanding rapidly within the "hilly regions" of Chongqing located in southwest China. However, little information is available on the best nutrient management practices for alfalfa and this is resulting in a continuation of low yields and farmer profitability.

A project was launched in 2007 to investigate the optimal fertilizer rates and combinations for high yielding, profitable alfalfa. The study was conducted on a slightly acid, purple soil in Gaojia village, Bishan county. Surface (0 to 15 cm) soil samples were collected from the field after harvesting the previous mustard (*Brassica juncea var. foliosa*) crop. These samples were then analyzed by the National Laboratory of Soil Testing with ASI method (Portch and Hunter, 2005) **(Table 1)**. The soil was determined to be high in P, K and Zn, medium in N, but deficient in Mg and B.

Table 1. Some selected properties of the experimental soil (ASI method).

OM, g/kg	pH	NH_4-N	P	K	B	Mg	Zn
		mg/L					
15.8	6.2	73	28	117	0.1	87	2.5

The experiment was set up in a randomized complete block design with three replications. An OPT NPK treatment was identified by soil test as 90-120-150 kg N-P_2O_5-K_2O/ha **(Table 2)**. The inclusion of N in the treatment set is based on prior field research with alfalfa (and peanut), which indicates that fertilizer N is required to maximize biomass production of legumes in Chongqing. Other treatments described here include the combination of 90 kg N/ha with three rates of P (0, 60, 120 kg P_2O_5/ha), three rates of K (0, 75, 150 kg K_2O/ha) and either Mg (15 kg Mg/ha), B (15 kg borax/ha), or Mo (5 g ammonium molybdate/kg seed). Other sources of fertilizers were urea for N, single superphosphate for P, potassium chloride for K, and magnesium sulfate for Mg. All the fertilizer P, Mg, and B were applied at seeding (a basal dose). Fertilizer N application was split between basal (60%) and topdress (20% each at the 2-leaf and shoot branching stages) applications. Fertilizer K was split between a basal dose (50%) and a topdressing (50%) at the shoot branching stage. Ammonium molybdate (Mo 54%) was applied as a seed treatment coating. The alfalfa was seeded at a rate of 22.5 kg/ha in March, 2007.

During the growing season the forage was weeded manually four times and harvested four times in early May, early June, mid-August and mid-October. Since fresh forage was used to feed animals, the alfalfa yield was recorded on a fresh weight basis. Plant samples were collected at early flowering to mid-bloom stages, oven dried, and analyzed for crude protein, crude fat, N-free extract, water, Ca, and P.

Forage Yield

Fertilizer treatment had a significant effect on fresh alfalfa yields, but the effect varied greatly between years **(Table 2)**. In 2007, the OPT+MgMoB produced significantly higher alfalfa yields than the OPT. Other treatments supplying at least 150 kg K_2O/ha were on par with the OPT. No significant yield response was observed for P, but yields did differ among K rates. The higher alfalfa yield generated from the OPT+MgMoB treatment could be attributed to the addition of Mg and/or a synergistic interaction of the three nutrients when applied together; however, since neither the OPT+Mo or OPT+B significantly increased alfalfa yield relative to the OPT. As was mentioned previously, soil testing did indicate a soil Mg deficiency.

In 2008, the effects of the fertilizer treatments differed somewhat as alfalfa significantly responded to both P and K

Common abbreviations and notes: B = boron; Ca = calcium; K = potassium; Mg = magnesium; Mo = molybdenum; N = nitrogen; P = phosphorus; S= sulfur; Zn = zinc; OPT = optimal (fertilizer) treatment; OM = organic matter.

Table 2. Fresh yields of alfalfa as affected by different fertilizer treatments, Chongqing, China.

	2007		2008		Average	
Treatment	Yield, kg/ha	Relative yield, %	Yield, kg/ha	Relative yield, %	Yield kg/ha	Relative yield, %
90-120-150 (OPT)	37,589 b	100	45,107 a	100	41,348 a	100
90-60-150	38,833 b	103	40,996 b	91	39,914 b	96
90-0-150	37,166 b	99	38,941 c	86	38,054 c	92
90-120-75	35,777 c	95	38,885 c	86	37,331 c	90
90-120-0	35,222 c	94	37,496 d	83	36,359 c	88
90-120-150+MgMoB	41,277 a	110	43,662 a	97	42,470 a	103
90-120-150+B	37,722 b	100	41,551 b	92	39,637 b	96
90-120-150+Mo	36,944 b	98	41,496 b	92	39,220 b	95

Means in each column followed by the same letter are not significantly different at P = 0.05.

Table 3. Effects of fertilizer treatment on quality of alfalfa (Average of 2 years), Chongqing.

Treatment	Crude protein	N-free extract
	----------- % -----------	
90-120-150	17.8	36.1
90-60-150	15.8	37.6
90-0-150	15.1	36.7
90-120-75	16.8	33.9
90-120-0	15.7	39.7
90-120-150+MgBMo	16.7	38.4
90-120-150+B	16.9	41.3
90-120-150+Mo	18.2	39.9

fertilizer. A 14% yield increase was obtained between the OPT and OPT-P treatments; and a 17% yield increase was found between the OPT and OPT-K. Yield under the OPT and OPT+MgMoB treatments were equally superior to all other treatments.

As a result of higher yields across treatments in 2008, the 2-year average yields were considerably higher than initial yields obtained in 2007. The addition of B and Mo alone to the OPT treatment for two consecutive years resulted in lower relative yields compared to the OPT. This occurred in a field where B was considered deficient by soil test, and while soil Mo fertility was not tested, it is often considered deficient on these acid soils. From these results, it is concluded that alfalfa only responded positively to Mg when supplied within the OPT+MgMoB combination.

Effects of P and K on Alfalfa Yield

The alfalfa yield was obviously affected by P and K rates in the experiment. The lack of a response to added P in 2007 could be attributed to the high residual soil P carried over from the previous vegetable crop. This phenomenon was also observed for the alfalfa response to K fertilization. In 2007, increased K application resulted in a non-significant yield increase from 0 to 75 kg K_2O/ha, and a significant increase was observed from 75 to 150 kg K_2O/ha. In 2008, a significant yield increase occured with every increment of K. This result does highlight that residual P and K from the previously fertilized crops, though sufficiently high, could be significant for only one subsequent crop at the most.

Alfalfa Quality

Table 3 presents 2-year average indicators of alfalfa quality as affected by fertilizer treatment.

Among quality parameters, alfalfa crude protein and N-free extract are most important. The former governs feed value and the latter is proposed to influence feed palatability.

Data were insufficient for statistical analysis of alfafa quality. However, the percentage of crude protein appeared to increase with P rate, while N-free extracts did not show an obvious P response. In response to K, percent crude protein also appeared to increase, while N-free extract seemed to decline under higher K rates. A K source comparison between potassium sulfate (K_2SO_4) and KCl was tested (data not shown), but produced equal results regarding alfalfa quality, although it should be noted that this site was not S deficient. Inclusion of Mo within the OPT, may be capable of producing higher crude protein in alfalfa, which is a result that is inferred from the nutrient's important role in N metabolism.

Summary

Alfalfa yield significantly responded to the rates of P and K in 2008, but not in 2007 due to residual effects carried over from the site's previous cropping history of significant fertilization of mustard grown prior to alfalfa establishment. This study stresses the importance of applying appropriate amounts of P and K under such conditions in order to sustain higher crop yields after short-term effects of residual soil fertility. Magnesium appears to have a role to play in alfalfa grown in the hilly region of Chongqing based on the yield advantages gained with its inclusion within an adequate NPK recommendation. It may be good practice to apply Mg once every 2 or 3 years when a soil deficiency is determined.

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Cotton Yield and Quality Responses to Sulfur Applications

By X.H. Yin, C.L. Main, and C.O. Gwathmey

More attention needs to be paid to S requirements of no-till cotton in Tennessee and other cotton-producing states where S deficiencies may occur. Applying about 20 lb S per acre can increase lint yields and fiber micronaire of cotton on no-till fields with low S levels in Tennessee and similar environments.

Sulfur deficiencies in cotton have been observed more frequently in recent years due to increased use of S-free fertilizers, greater removal of S from soil by crops with higher yields, lower S deposits to soil from the atmosphere, and less use of S-containing pesticides. Crop-available S is relatively low in some Cotton Belt soils due to low soil organic matter and the high likelihood of sulfate leaching. Light-textured and well-drained soils are more likely to be S deficient. No-till fields may exhibit S deficiency at times when soil temperatures are low, limiting S mineralization from organic matter. Little information is available about S application effects on cotton yields and fiber quality of economic importance in Tennessee and other states in the Cotton Belt region.

A replicated field trial was conducted on a non-irrigated Dexter loam soil in Jackson, TN during 2008-2010 to evaluate the effects of S on cotton lint yields and fiber properties under no-tillage. Initial soil test S levels in the top 6 in. were rated low according to A & L Laboratories, Memphis, TN. Four S application rates (i.e. 0, 10, 20, and 30 lb S/A as potassium sulfate) were broadcast to designated plots before cotton planting each year. All plots received 80 lb N and 120 lb K_2O per acre each year. The cotton cultivar was 'PHY375WRF'. Soil S content was measured using the Mehlich 3 method. Leaf blade samples were taken from the highest fully expanded main-stem leaves, usually three or four nodes from the terminal at early-bloom. Leaf samples were dried at 60°C for 72 hours and ground through a 2-mm screen. Leaf samples were digested using nitric acid and hydrogen peroxide, and the digest was analyzed for total S on an ICP. Relative lint yields were calculated using the following method in order to minimize the influences of year (due to weather conditions, etc.) on lint yields. The highest numeric value of yield among all treatments within each year was assumed to equal 100% yield for that year. The percentage values relative to this maximum value were calculated for the other treatments within that year. The relative lint yield averages over 2008-2010 were calculated based on the relative yields of these three individual years.

Figure 1. Cotton plants fertilized without S (left) and 30 lb S per acre (right).

Sulfur Deficiency Symptoms in Cotton

Sulfur deficiency symptoms gradually appeared in the zero-S plots by about 40 days after planting each year. Plants without S fertilization showed classical S deficiency symptoms, such as pale green to yellow leaves in the upper part of plant, while 30 lb S/A treated plants grew normally **(Figure 1)**. These symptoms became less apparent as the crop grew larger and began to set fruit at about 70 days after planting.

Common abbreviations and notes: S = sulfur; N = nitrogen; K = potassium.

Table 1. Soil S content at mid-bloom as affected by S application rates.

S rate	2008	2009	2010	Average
lb/A		- - - - lb/A - - - -		
0	27b†	22a	36c	28c
10	26b	23a	39bc	29bc
20	27b	23a	40b	30b
30	31a	29a	45a	35a

†Values in each column followed by different letters are statistically different at p = 0.05.

In-Season Soil Test S Levels

In 2008, 30 lb S/A generated a higher soil test S level at mid bloom than the other three lower rates **(Table 1)**. In 2009, 30 lb S/A tended to increase soil S level, although the level was not statistically different from the other S rates. In 2010, 20 and 30 lb S/A resulted in higher soil S compared to zero S. The 3-year average soil test S level at mid-bloom was 25% higher with 30 lb S/A than zero S fertilization. Soil test S was higher in 2010 than in 2008 and 2009, reflecting the positive effects of higher temperatures during the 2010 summer on S release from soil organic matter.

Leaf S Concentrations

Leaf S concentrations at early-bloom were consistently affected by S applications in all 3 years (**Table 2**). The 20 and 30 lb S/A rates had higher leaf S levels than zero S each year. On average, leaf S concentrations were statistically different among the four S rates with 30 lb S/A having the highest leaf

Table 2. Leaf S concentrations at early-bloom as affected by S application rates.

S rate	2008	2009	2010	Average
lb/A	- - - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - -			
0	0.28b†	0.31b	0.23d	0.27d
10	0.31b	0.37b	0.31c	0.33c
20	0.35a	0.43ab	0.37b	0.38b
30	0.38a	0.45a	0.40a	0.41a

†Values in each column followed by different letters are statistically different at p = 0.05.

Table 3. Lint yields at harvest as affected by S application rates.

S rate	2008	2009	2010	Average
lb/A	- - - - - - - - - - - - - - - - - - lb/A - - - - - - - - - - - - - - - - - -			
0	2,083b†	1,280a	1,602a	1,655b
10	2,160ab	1,307a	1,728a	1,731ab
20	2,221a	1,413a	1,729a	1,788a
30	2,253a	1,388a	1,757a	1,799a

†Values in each column followed by different letters are statistically different at p = 0.05.

Table 4. Fiber micronaire at harvest as affected by S application rates.

S rate	2008	2009	2010	Average
lb/A				
0	4.32a†	3.53a	4.62b	4.16b
10	4.47a	3.65a	4.85a	4.32a
20	4.50a	3.65a	4.82a	4.32a
30	4.54a	3.70a	4.83a	4.36a

†Values in each column followed by different letters are statistically different at p = 0.05.

S level. Sulfur concentrations ranging from 0.25 to 0.80% in the youngest mature leaf blade are considered sufficient for cotton at early bloom in the southern United States (SAAESD, 2009). According to this criterion, leaf S concentration was not sufficient under zero S in 2010; while all other leaf S concentrations were sufficient regardless of S application rate and year in this trial.

Lint Yields

In 2008, application of 20 or 30 lb S/A increased lint yields by 7 to 8% compared to zero S **(Table 3)**. In 2009, lint yield response to S applications was nearly significant (p = 0.054). Lint yields tended to increase in 2010, although differences were not statistically significant among S applications rates. It appears that high temperatures during the summer of 2010 may have decreased the cotton response to S application. Averaged over the three seasons, applying 20 or 30 lb S/A increased lint yields by 8 to 9% over zero S. The response bar graph of relative lint yields on 3-year averages to S application rates visually shows a quadratic plateau relationship between lint yields and S application rates **(Figure 2)**.

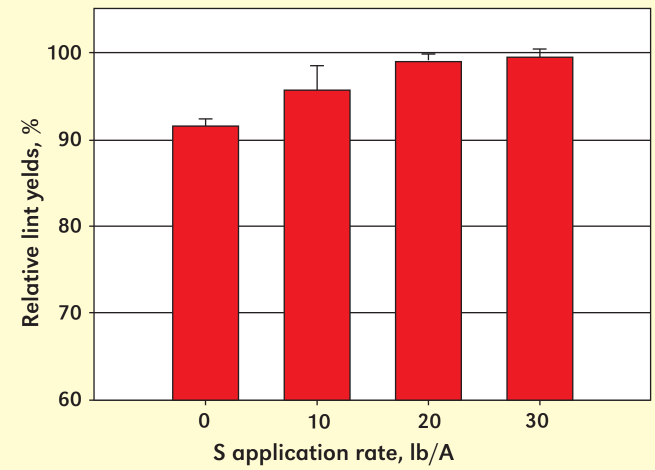

Figure 2. Responses of relative lint yields to S application rates on 3-year averages (2008-2010) at Jackson, TN. The error bars show the standard deviations for relative lint yield averages.

Fiber Quality

Fiber micronaire responded to S applications in 1 out of 3 years **(Table 4)**. The S applications produced 4 to 5% increases in micronaire compared to zero S in 2010. When the 3-year results were combined, application of 10, 20, or 30 lb S/A increased micronaire by 4 to 5% relative to zero S. However, other fiber quality properties including length, uniformity, strength, and elongation were not affected by S applications (data not shown).

Summary

Applying about 20 lb S/A can increase lint yields and fiber micronaire of cotton on no-till fields with low S levels in Tennessee and similar environments. More attention needs to be paid to potential S requirements of no-till cotton in Tennessee and other cotton producing states where S deficiencies may become more common due to increased use of low-S fertilizers, adoption of high yielding cultivars, more intensive cropping systems, and lower atmospheric S deposits.

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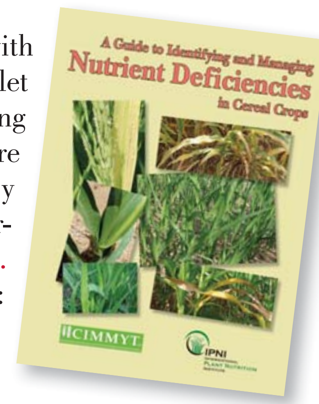
Crop Nutrient Deficiency Photo Contest Entries Due by December 13

December 13, 2011, is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. An individual can submit an entry for each of the four categories: nitrogen (N), phosphorus (P), potassium (K), and other nutrient deficiencies (i.e. secondary nutrients and micronutrients).

Preference is given to original photos with as much supporting/verification data as possible. Cash prizes are offered to First Place (USD 150) and Second Place (USD 75) in each of the four categories, plus a Grand Prize of USD 200 will be awarded to the photo selected as best over all categories. Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest

For further details and instructions, please visit the contest website.

A Guide to Identifying and Managing Nutrient Deficiencies in Cereal Crops



A new field guide 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 booklet (8 1/2 x 11 in. size, wire-o bound) designed to describe the appearance and underlying causes of nutrient deficiencies in maize, wheat, rice, sorghum, pearl millet, and barley. Tips are also included 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.

Details on obtaining a copy of this booklet can be found at the IPNI on-line store at: http://info.ipni.net/nutridefcereal

Recent Release: Crop Nutrient Deficiency Image Collection

IPNI has assembled a new image collection comprised of more than 400 examples of nutrient deficiency symptoms in common crops. Images have been collected from various field settings around the world …some originating from our annual contest described above.

The images are organized in groups including primary nutrients, secondary nutrients, and micronutrients. Text and diagrammatic descriptions of nutrient deficiency are also available as supporting information.

The IPNI Crop Nutrient Deficiency Image Collection is available either in CD format 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.

Circulation Department, IPNI
3500 Parkway Lane, Suite 550
Norcross, GA 30092-2844
Phone: 770.825.8082 E-mail: circulation@ipni.net

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
0.0159	kg/ha	bu/A, corn (grain)	62.7
0.0149	kg/ha	bu/A, wheat or soybeans	67.2

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

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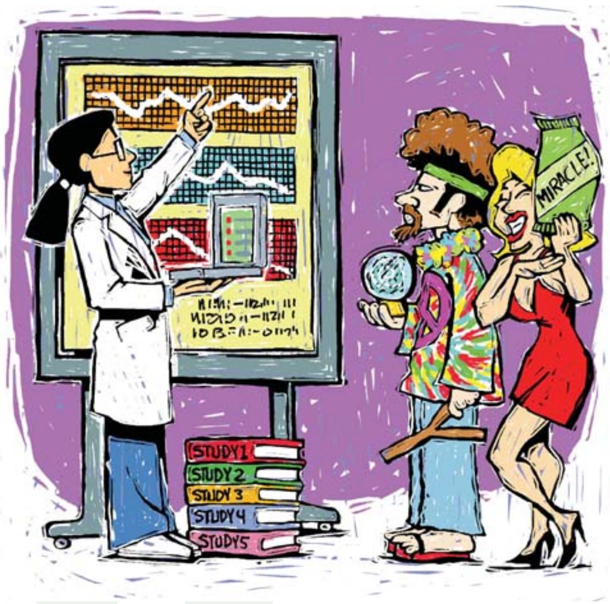
I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

PS Form 3526-R, September 2007 (Page 2 of 3)

"How Do You Know That?" – The Need for Scientific Evidence

In most countries, crop protection chemicals are evaluated for environmental safety and efficacy, and new crop varieties are tested in standardized comparisons. This gives growers and advisors confidence about the inputs they use or recommend.



Fertilizers are evaluated for their environmental safety and their potential hazard in manufacture, distribution, and handling. While important for the industry, there is rarely any requirement to present scientifically valid data on product efficacy—or simply—does it work?

Sir John Bennet Lawes and Sir Joseph Henry Gilbert developed superphosphate and wanted to test the efficacy of this "new" product along with a suite of other mineral—as opposed to organic nutrient sources. To do so, they established the Broadbalk long-term fertilizer experiment at Rothamstead. That was in 1843, and that particular experiment has allowed science to track the impacts of mineral fertilizers over time.

Over the years, organizations such as the Tennessee Valley Authority through its National (and now International) Fertilizer Development Centre have developed new fertilizer products such as ammonium nitrate and triple superphosphate that would produce high quality and reliable nutrient sources to produce food. This work has been critical in expanding the tool box of products for growers.

These developments are based on a clear understanding of soil science and crop agronomy, with testing regimes put in-place to evaluate these products. In the past two decades, there have been many "alternative" fertilizer products coming onto the market. These may be in response to new markets such as the organics industry, or by those searching for strategies to unlock nutrients bound in the soil. Some are also the inevitable "snake oil".

When checking on the claims of a product, the first and most important thing is the evidence the supplier has about the crop response. This evidence should be done in a scientifically credible way using methods that are explainable and reproducible.

Appropriate controls – every fertilizer experiment should have a nil treatment (no added fertilizer) and a standard practice. Without these checks, there is no indication if the new product actually did anything, or if it was better than current practice. Comparisons should be done at least on a nutrient-to-nutrient basis where similar amounts of the nutrient are applied so the comparative efficacy is clear.

Replicated – the treatments are repeated so that the information collected can be statistically compared. Without that, the effects of the treatments cannot be distinguished from luck.

Randomization – the treatments should be randomized in such a way that one is not necessarily in the same place in each replication. Often treatments will be blocked together so that paddock trends can be accounted for in the analysis.

Repeated – one trial in one year at one site does not give proof of a response. Has the trial been done on relevant soil types, in appropriate regions, and on the same test crop?

Compared statistically – a replicated trial will have an average (or mean) and a measure of error for that mean. The error term gives a range of "normal" values so that the ranges of different treatments can be compared. Means are significantly different when these ranges do not overlap at a particular probability.

Scientists start with the premise that there is no difference among treatments, and design experiments to test this. Endorsements and product testimonials are no substitute for good experimental design and robust statistical analyses.

Objective fertilizer choice demands that good science be used to support decisions by growers and advisors. When presented with product claims, Dr. Jim Virgona of Charles Sturt University in Australia reminds us to ask "How do you know that?" It is up to those who are marketing to provide scientific evidence to keep our farming systems sustainable and productive.

Robert Norton
IPNI Director, Australia and New Zealand

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