BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

2014 Number 4

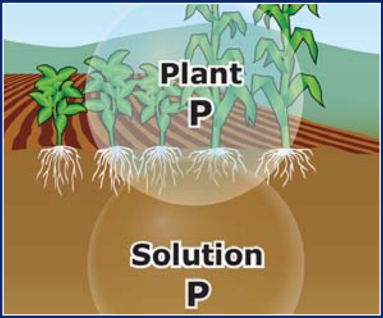
Nitrogen Use Efficiency in Corn: How has it Changed with Variety Improvement?

In This Issue...

Some Advice on Dealing with Crop Price Changes

Does Fertilizer Affect Soil Microorganisms?

The Simple Rule Guiding Plant-available Phosphorus



Also:

2014 IPNI Scholar Award Recipients

...and much more

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BETTER CROPS WITH PLANT FOOD

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Our cover: Combine harvesters and trucks harvesting corn in Ukraine.
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CONTENTS

Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* can be found at: >**www.ipni.net/bettercrops**<

IPNI Scholar Award Recipients Announced for 2014

The IPNI Scholar Award Program has once again expanded its reach by awarding Scholarships to 30 graduate students in 2014. Each Scholar receives a certificate, the equivalent of US$2,000, and they are welcomed as the latest additions to a prestigious group of young scientists who have demonstrated great dedication and promise within their respective careers.

"We have had another record response to our Scholar Award program this year," said Dr. Terry L. Roberts, IPNI President. "The global representation of universities and the wide array of fields of study that were represented in this year's submissions were impressive. The academic institutions these young people represent, and their professors and advisers, can be proud of their student's accomplishments. Our selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic and personal achievements."

Graduate students attending a degree-granting institution located in any country within an IPNI regional program are eligible. The award is available to graduate students in science programs relevant to plant nutrition science and the management of crop nutrients including: agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, environmental science, and others.

The following provides a summary (by region) of the winners for 2014.

AUSTRALIA/NEW ZEALAND

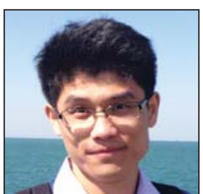

Courtney Peirce

Ms. Courtney Peirce, The University of Adelaide, Australia, is working toward her Ph.D. in Soil Science. Her dissertation title is "Foliar fertilization of wheat plants with phosphorus." This study is being conducted to investigate whether foliar P application can be used as an in-season top-up to tactically increase grain yields of wheat in seasons with favorable climatic conditions. This will help minimize risk for farmers in variable rainfall areas, who typically apply all their P fertilizer before sowing. For the future, Ms. Peirce aims to continue her research in crop and soil nutrition.

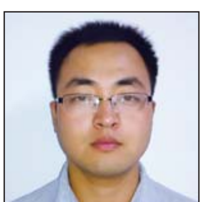

Karthika Krishnasamy

Ms. Karthika Krishnasamy, Murdoch University, Australia, is completing requirements for her Ph.D. in plant nutrition. Her dissertation title is "Wheat potassium nutrition in saline, and/or sodic soils of Western Australia." This study will look into the role of sodium (Na) in K nutrition of wheat grown in saline/sodic soils by understanding the mechanism behind the Na replacement of K. This research has particular relevance for rainfed cropping systems grown on saline and sodic soils because of the important role of K in stomatal control and in plant water relations. In the future, Ms. Krishnasamy aims to become an independent plant scientist to gain knowledge and become an expert in different aspects of plant nutrition.

CHINA


Ai Chao

Mr. Ai Chao, Chinese Academy of Agricultural Sciences, Beijing, China, is pursing his Ph.D. in plant nutrition. His dissertation is titled "Mechanisms of microbes-mediated carbon and nitrogen cycles in the rhizosphere soil under long-term fertilization practices." This research aims to examine how enzyme activity (involved in C, N, P, and S cycling) and microbial community structure differ between the rhizosphere and bulk soil in a farmland ecosystem, and how each of them respond to long-term (34-year) fertilization. This work will explore the microbial mechanism for C and N turnover in the rhizosphere soil under long-term fertilization practices, and will be practically significant in developing balanced fertilization strategies. For the future, Mr. Ai plans to become an agricultural scientist.


Pan Junfeng

Mr. Pan Junfeng, Anhui Agricultural University, Anhui, China, is working toward his M.Sc. in plant nutrition. His thesis is titled "Effect of fertilization on farmland weed seed banks," which aims to study the effect and regulatory mechanisms of fertilization on weed persistence. Initial results from this study suggest that balanced fertilization is beneficial in not only producing high yields and better quality of agricultural products but also in stabilizing the soil weed seed bank that will ensure a reasonable, efficient and stable agro-ecosystem. Being a son of a farmer, Mr. Pan is quite interested in becoming an agricultural researcher to extend to farmers professional agricultural knowledge and scientific techniques for a sustainable and profitable agriculture.


Hao Yanshu

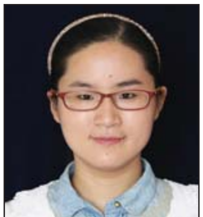
Ms. Hao Yanshu, Huazhong Agricultural University, Hubei, China, is working toward her Ph.D. in plant nutrition. Her dissertation title is "Mechanisms of potassium uptake and distribution of photosynthates in two different potassium efficiency cotton genotypes." This study would provide a theoretical foundation for rational application of K and evidence for screening high efficiency cotton genotypes. For the future, Ms. Hao's goal is to become an agricultural researcher specializing in environmental impact on plant nutrition.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; C = carbon; B = boron; Zn = zinc.

CHINA (continued)

Chen Yanling

Ms. Chen Yanling, China Agricultural University, Beijing, China, is pursuing a combined M.Sc.-Ph.D. in plant nutrition. Her research work is focused on determining the physiological mechanism underlying high yield and efficient N utilization in maize. The research aims to investigate temporal and spatial N and dry matter accumulation and remobilization in stalk and leaves, leaf area and photosynthesis in three maize hybrids in two soils and the effect of genotype x environment interactions effect on these parameters and to understand whether and/or how N fertilization rates can regulate the coordination of grain yield and grain N concentration in high-yielding maize hybrids with different senescence characters. Ms. Chen plans to focus her future research efforts on promoting scientific techniques to improve crop yield and quality while protecting environment.



Wang Xiao

Ms. Wang Xiao, Chinese Academy of Sciences, Hubei, China, is working toward her Ph.D. in plant nutrition. Her dissertation is titled "Research on the mechanisms of high K use efficiency of varied genotypic cottons and their rhizospheres." Due to the rapid depletion of soil K and increasing cost of K fertilizers, K-use efficient crop genotypes have become quite important for agricultural sustainability. This research aims to exploit the biological potential of high K-efficiency genotypes of cotton to resist adverse environmental conditions, achieve high yields, and increase water and K use efficiency. Ms. Wang intends to continue her research efforts and also educate students on plant nutrition.

EASTERN EUROPE AND CENTRAL ASIA

Alexandra Orekhovskaya

Ms. Alexandra Orekhovskaya, Belgorod State Agricultural Academy, Russia, is working toward her Ph.D. degree in agricultural chemistry. Her research work is focused on determining N regimes of typical chernozem soils and the productivity of winter wheat depending on agro technical aspects of crop production. The accumulation of N in the soil is a characteristic feature of soil formation, and the reserves of total N in a soil determine its potential fertility. The overall goal of this research is to determine the effect of different tillage practices, mineral and organic fertilizer rates on the content of mineral N in soil as well as yield and quality of grain. For the future, Ms. Orekhovskaya's career goal is to become an agricultural researcher and an educator.

Gulnaz Yusupova

Ms. Gulnaz Yusupova, Bashkir State Agrarian University, Russia, is pursuing her Ph.D. in agronomy. Her dissertation title is "Agroecological efficiency of application of different fertilization systems for spring rapeseed grown in a southern forest-steppe zone of the Republic of Bashkortostan." The goal of this study is to develop a science-based system of fertilization of spring rapeseed varieties on leached chernozem soils to provide long-term average seed yields of 2.0 to 2.5 t/ha with a crude protein content not less than 19% and also mitigating environmental nutrient pollution. In the future, Ms. Yusupova intends to pursue a career in agricultural research and teaching.

Alina Revtie

Ms. Alina Revtie, National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky", Ukraine, is enrolled in a Ph.D. program in soil science and agrophysics. Her dissertation is "Soil-environmental aspects of anhydrous ammonia application in crop production." Application of liquid N fertilizer, such as anhydrous ammonia, not only improves productivity but also has a number of economic and technological advantages over granular N fertilizer application. The objective of this study is to understand the effect of anhydrous ammonia on soil properties and environmental parameters to help in developing a regulatory process and procedure of application of liquid N fertilizers in Ukraine. Ms. Revtie desires to continue her research efforts as well as teach students.

LATIN AMERICA

Marcelo Ferrando

Mr. Marcelo Ferrando, Universidad de la República, Uruguay, is working toward his Ph.D. in agronomy. His dissertation is titled: "Potassium dynamics in agricultural soils: characterization of potassium reserves in soils." The study will investigate the dynamics of K in soils under conservation tillage and develop rational guidelines for fertilizer K recommendations by comparing the different methods of estimating soil exchangeable K and non-exchangeable K. This will be done through characterizing soil mineralogy by identifying predominant clays for soils under current production, grouping these soils based on predominant clays, and studying the relationship between the results of analysis, soil characteristics and crop yields. For the future, Mr. Ferrando wishes to pursue his research efforts evaluating the efficacy of different extractants for determining different nutrients in soil.

Geisa Lima Mesquita

Ms. Geisa Lima Mesquita, Instituto Agronômico, Brazil, is pursuing her Ph.D. examining the absorption and transport of B in citrus. This study is aimed at maximizing productivity of citrus and also understanding the physiological mechanisms occurring in response to B deficiency and toxicity. Ms. Mesquita's goals are to complete her doctoral studies and pursue further studies in plant nutrition.

LATIN AMERICA (continued)

Elialdo Alves de Souza

Mr. Elialdo Alves de Souza, São Paulo State University, Brazil, is completing requirements for his Ph.D. in agronomy. The focus of his research is on localized application of ammonia fertilizer to improve P utilization efficiency of corn. This research will study the impact of ammonia-N on P use, the biochemical conditions of the rhizosphere and corn production. The results of this work will allow the development of better management practices for P fertilization. Mr. Alves de Souza wishes to pursue postdoctoral research abroad and focus his career on agricultural research and education.

Juan Pablo Martinez

Mr. Juan Pablo Martinez, Universidad Nacional de Mar del Plata, Argentina, is working toward his Ph.D. in agricultural sciences. His research work is focused on sustainable soybean production systems in the Pampas region of Argentina. This study will focus on developing crop management and fertilization strategies to sustainably increase soybean productivity. Mr. Martinez wishes to pursue a career in agricultural research, teaching, and extension to generate and transfer to students and farmers the best technologies related to crop production, nutrition and soil conservation.

Elizabeth R. Iglesias

Mrs. Elizabeth Ramirez Iglesias, Universidad Central de Venezuela, Venezuela, is pursuing her Ph.D. in ecological sciences. Her research work is focused on synchronizing soil-plant-animal components in low P, acid soils in the savannah agroecosystems of Venezuela. This research analyzes the impact of agroecological alternatives (like P fertilization together with maize and legume associations) on soil properties, forage production and animal response (weight gain). The study indicates positive impact of these new practices, which are being implemented taking into consideration customary practices of producers in the area (like the introduction of cattle at the beginning of the dry season to eat corn stover after harvest, etc.). Mrs. Iglesias intends to pursue her postdoctoral education abroad.

MIDDLE EAST

Marwa M. Abd-Elbasset

Ms. Marwa Mahmoud Abd - Elbasset, National Research Center, Agricultural & Biological Div. and Ain Shams University, Egypt, is working toward her doctorate degree majoring in irrigation engineering. Her research work is focused on evaluating the effect of automatic scheduling of irrigation to improve water use efficiency and crop productivity under drip irrigation system vis-à-vis the traditional irrigation methods. This study aims to fine-tune the automatic control of scheduling irrigation and fertigation. Ms. Mahmoud Abd - Elbasset wishes to travel across the world to learn and extend to farmers new technologies related to improving water use efficiency and crop productivity.

NORTH AMERICA

Sarah Page

Ms. Sarah Page, University of Wisconsin, Madison, WI, USA, is working toward her M.Sc. in Agroecology and Horticulture. Her research looks at the potential for drip and deficit irrigation to increase irrigation water and nutrient use efficiency in potato without negatively affecting yield and quality when compared to industry standard practices. She is also exploring if N fertilizer rates can be decreased in conjunction with the use of drip irrigation. She hopes that her findings will help to identify alternative management systems for areas in which groundwater withdrawal and contamination is of particular concern. In the future, Ms. Page hopes to work with smallholder farmers to identify culturally appropriate and location-specific strategies to mitigate and adapt to climate change.

Alexis Adams

Ms. Alexis Adams, University of Saskatchewan, Saskatoon, SK, Canada, is pursuing her M.Sc. in soil science. Her thesis title is "Long-term effect of fertilizer microdosing on soil fertility in the west African Sahel." The study is focused to determine if fertilizer microdosing can be used as a best management practice in the Sahel region for long-term sustainable nutrient stewardship. Her research is in developing synchrotron science as a tool for food security research by studying the effect of nutrient and organic C sources on soil quality, along with analyzing yield data, soil chemical properties, and nutrient balances from long-term research sites in Niger and Burkina Faso. In the future, Ms. Adams intends to work alongside impoverished farmers in food-insecure countries, equipping them with techniques to overcome socioeconomic and plant nutrition related issues affecting their livelihood.

Sarah Light

Ms. Sarah Light, Oregon State University, Corvallis, OR, USA, is enrolled in a M.Sc. program in soil science. Her thesis is "Growing potatoes with less inputs through better nutrient management and disease control: Developing a fertilization model for more efficient K application and alternative treatments for Verticillium wilt." The research aims to develop a model where a normalized petiole reading can be predicted using K application source, time and rate. This should make N applications from petiole nitrate levels more efficient throughout the growing season. Ms. Light desires to work directly with farmers in some capacity, either doing agricultural research, or as a resource to farmers through the extension service, another federal government supported agency, or a private foundation.

NORTH AMERICA (continued)


Libby Rens

Ms. Libby Rens, University of Florida, Gainesville, FL, USA, is working toward her Ph.D. in horticultural sciences. Her dissertation title is "Optimization of nitrogen fertilizer use efficiency for commercial chipping potatoes in northeast Florida." The objective of this research is to develop strategies to increase N-fertilizer uptake efficiency of potatoes and to minimize N-fertilizer losses to the environment. This research will focus on development of best management practices to determine the right rate, right time and right placement of N-fertilizer for commercial chipping potatoes in Florida. Ms. Rens's career goal is to be an agriculture researcher specializing in innovation of methods to optimize agricultural procedures for the production of fruits, vegetables, or staple crops.


Anne Sawyer

Ms. Anne Sawyer, University of Minnesota, St. Paul, MN, USA, is pursuing her Ph.D. in soil science. Her research work is focused on "Switchgrass yield, nutrient uptake and rhizosphere microbial populations as a function of cultivar and phosphorus fertility on marginal soils in Minnesota." Her research focuses on developing regional best management practices for N and P fertility in switchgrass-for-biofuel production. This work will also help address the food-fuel-energy trilemma by characterizing biofuel feedstock growth on marginal lands, with the goal of retaining prime agricultural lands for food production. Ms. Sawyer's ideal career focus will allow for research into practical solutions for environmental problems related to agriculture and, most importantly, communication and engagement with the public.

NORTH AFRICA


Saad Drissi

Mr. Saad Drissi, Institut Agronomique et Veterinaire Hassan II, Morocco, started his Ph.D. program in 2013 majoring in Agronomy. His research work is focused on standardizing Zn fertilization in corn grown on coastal sandy soils in northwest Morocco. This study will help answer questions like the response of maize to Zn application and optimal levels of Zn fertilization in coastal sandy soils. Mr. Drissi intends to pursue his future research efforts with a foreign research institute specialized in plant nutrition and soil science.

SUB-SAHARAN AFRICA


Obianuju Emmanuel

Ms. Obianuju Emmanuel, Kwame Nkrumah University of Science and Technology, Ghana, is working toward her Ph.D. in soil fertility. Her dissertation title is "Response of cowpea to NPK fertilizer and rhizobia inoculant in the Guinea savanna zone of Ghana." This study is focused on improving the yield of cowpea using site-specific fertilizer recommendations and complementary use of fertilizer and rhizobia inoculation. The blanket fertilizer recommendation currently used in Ghana dates back to 1972 and doesn't consider the complexities of weather, soil and crop interacting to affect crop production. This study will help develop localized regional fertilizer recommendations for cowpea. For the future, Ms. Emmanuel wants to be actively involved in research, teaching and mentoring youth in the field of soil science.


Stephen Ichami Muhati

Mr. Stephen Ichami Muhati, Wageningen University, Netherlands, is pursing his Ph.D. in production ecology and resource conservation. His dissertation is titled "Refining fertilizer use recommendations for smallholder maize fields in African landscapes." The main objective of this study is to develop and test a novel methodology based on the diagnosis of soil nutrient constraints for better targeting fertilizer use recommendations to local conditions rather than the current blanket recommendations. In this study, maize was the test crop because it is a staple food in many sub-Saharan countries. Mr. Muhati seeks research opportunities that will help him better understand the spatial and temporal aspects of smallholder farming systems.


Yenus Kemal

Mr. Yenus Kemal, Bahirdar University, Ethiopia, is working toward his Ph.D. in agronomy. His dissertation title is "Improving sustainable productivity of chickpea through supplemental irrigation and integrated nutrient management options in Vertisols of western Ethiopia." The general objective of this proposed research is to improve chickpea yields sustainably through supplemental irrigation and integrated nutrient management strategies, which in turn will improve farmer profits. For the future, Mr. Kemal's goal is to scale up the best and permissible nutrient management options for higher crop yields in Ethiopia.

SOUTH ASIA


Dheeraj Kumar Tiwari

Mr. Dheeraj Kumar Tiwari, C.C.S. Haryana Agricultural University, India, is pursuing his Ph.D. in Agronomy since 2013. His dissertation is titled "Performance of maize hybrids under different planting methods and nitrogen levels." The focus of his research is on evaluating the effect of N levels on growth and yield of maize hybrids under different planting methods and N levels on economics, quality and physicochemical properties of soil. In the future, Mr. Tiwari wants to become a research scientist in an international organization.

SOUTH ASIA (continued)

Ramesh Chandra Yadav

Mr. Ramesh Chandra Yadav, Indian Agricultural Research Institute, India, is working toward his Ph.D. in soil science. The focus of his research is on the development and testing of nano-based novel carriers of N for enhancing its use efficiency and reducing greenhouse gas emissions under elevated carbon dioxide and temperatures. It is expected that this study will lead to the development of nano-clay composites that can then be used as slow-release N fertilizers to improve N use efficiency and mitigate the effect of climate change on crop productivity. Mr. Yadav aims to establish a career in agricultural research and contribute to the well being of the farming community.

Krishnendu Ray

Mr. Krishnendu Ray, Bidhan Chandra Krishi Viswavidyalaya, India, is completing requirements for his Ph.D. in agronomy. His dissertation title is "Site-specific nutrient management for improving nutrient use efficiency in hybrid *rabi* maize cultivars in the lower Gangetic plains." This study will evaluate the impact of site-specific nutrient management on growth, yield and quality of maize by managing large spatial and temporal variability observed in smallholder farming systems. In the future, Mr. Ray wishes to extend his research further and quantify soil-plant-atmosphere interactions for better crop and soil management.

J.A.S. Chathurika

Ms. Jayathunga Arachchige Surani Chathurika, Postgraduate Institute of Agriculture, Sri Lanka, is working toward a Ph.D. in soil science. Her dissertation is titled "Improving soil fertility of low productive lands by beneficial management practices for maize." The main objective of her study is to identify beneficial management practices to improve soil fertility of marginal agricultural lands. This research will help to develop approaches to improve C sequestration using available resources, thereby improving the overall soil fertility to support higher crop yields on marginal agricultural lands in the long-run. For the future, Ms. Chathurika wishes to pursue a career in soil science research and extension.

SOUTHEAST ASIA

Suzie Haryanti Husain

Ms. Suzie Haryanti Husain from the Faculty of Plantation and Agrotechnology, Universiti Teknology Mara (UiTM), Malaysia is working toward her Ph.D. in Plantation Management majoring in Agronomy. Her research dissertation is titled "Uptake and distribution of boron in young and matured oil palm of different genotypes as affected by nitrogen fertilization." This research aims to look into the pattern of B uptake in the eight most popular oil palm varieties widely planted in Malaysia and will also assess the effect of applying different rates of N on B uptake and distribution in the crop. The study will help in the overall fertilizer management and improve not only the oil palm yield but also the nutrient use efficiency. Ms. Husain aims to pursue further education in agronomy keeping her focus on plant nutrition.

Regional committees of IPNI scientific staff select the recipients of the IPNI Scholar Award. The awards are presented directly to the students at a preferred location and no specific duties are required of them.

Funding for the scholar award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

More information is available from IPNI staff, individual universities, or from the IPNI website: www.ipni.net/awards. BC

Encourage Growers to Do the Numbers before Reacting to Crop Prices

By Mike Stewart and Paul Fixen

Changes in crop prices often generate questions about the economics of fertilization. Prices for many crops, particularly corn, have fallen considerably from the highs of the past few years. This shift has some asking questions such as, "should I reduce fertilizer rates in response to lower prices?" A detailed answer for a specific situation will depend on several factors, but a review of some fundamental principles can give us a foundation for addressing such questions.

There are four primary factors affecting profitability…crop price, production costs, yield level, and crop quality (as it affects price). Now, which of these factors does the grower have significant control over? Typically, producers are price takers and thus have little control over prices. However, they do have control over variable costs, which directly impact yield and quality. Thus, in this sense yield level is a controllable factor determining profit. Once a decision has been made to plant a certain crop then it becomes a simple matter of making the most of the opportunity. This requires planning a program designed to optimize efficiency and produce maximum returns per acre... in other words, to produce yields that maximize profit while exercising responsible environmental stewardship.

Greater profits come from higher yields (to a point) since costs are spread over more production units (bushels, bales, pounds, etc.) resulting in lower cost per unit of production. Efficient and profitable production involves lowering unit cost to a point of maximum net return. This MEY (maximum economic yield) concept was popular decades ago, and is as valid and legitimate today as it was then.

Crop and fertilizer prices have relatively little effect on optimum levels of fertilization. This is because in determining profitability yield level has an overshadowing effect on crop and fertilizer price. Economists at Kansas State University (KSU) have published an online Excel tool (KSU-NPI_CropBudgets.xls, at http://agmanager.info/crops/prodecon/decision/default.asp) that helps demonstrate the impact of crop and fertilizer prices on estimated economic optimum rates of both N and P application. For irrigated corn with yield goal set at 250 bu/A, N and P_2O_5 prices set at \$0.50/lb, and all other settings left at default, when crop price was varied from \$7.00 to \$3.50/bu the estimated optimum N rate went from 340 lb N to 308 lb N/A—a decline of 32 lb N with a halving of corn price. For P the rate dropped from 34 to 27 lb P_2O_5/A—a decline of only 7 lb. This example is meant solely for illustrating that while shifts in crop prices do have an impact on optimal rates of application, that impact may not be nearly as great as one would first expect. Therefore, the tendency to react to crop price declines by deeply cutting inputs should be closely scrutinized.

Viewing corn as a form of currency is a useful exercise to illustrate the impact of market swings. **Table 1** compares fertilizer prices in November 2012 to August 2014 as \$ per ton of product and \$ per pound of nutrient. **Table 2** uses these fertilizer costs plus corn prices to determine the amount of fertilizer a bushel of corn would buy and also what the cost, in bushels, was for 100 pounds of each of the nutrients. The analysis shows that that cost of 100 pounds of nutrient was 6 to 8 bushels in 2012, 9 to 12 bushels in 2013, and 11 to 15 bushels currently. It now takes more bushels to buy fertilizer than in the previous years, but not much more relative to the full value of today's high yielding crops. The analysis further shows that under current market conditions, N, P and K remain good investments when a yield response is expected.

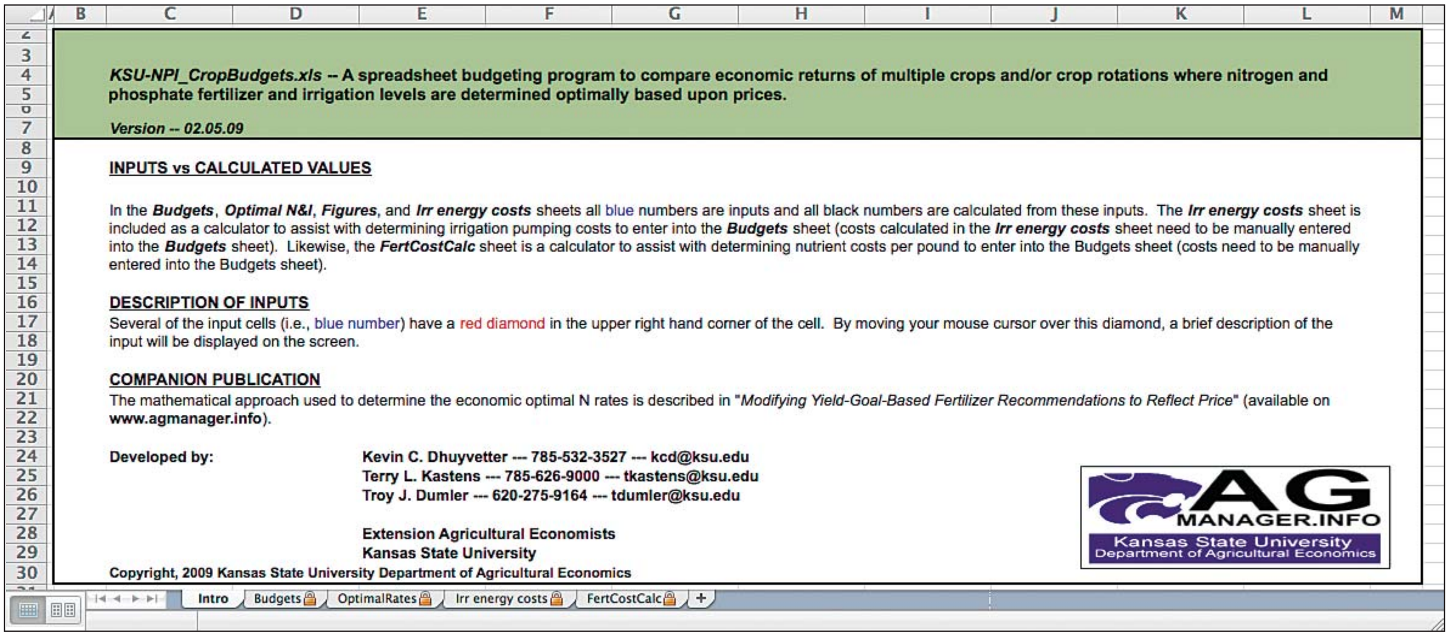
Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; DAP = diammonium phosphate; KCl = potassium chloride.

iStock/Getty Images

Table 1. Comparison of fertilizer prices in November 2012 to August 2014.

	Fertilizer cost (11/2012, 11/2013, 8/2014)					
	2012	2013	2014	2012	2013	2014
Source	- - - - - - - \$/ton* - - - - - - -			- - - - \$/lb nutrient** - - - -		
Urea, N	570	450	535	0.62	0.49	0.58
DAP, P_2O_5	631	516	580	0.44	0.37	0.40
KCl, K_2O	605	476	474	0.50	0.40	0.40

*Midwest retail – The NPK Insider (12/3/2013, 8/15/2014).
**N in DAP valued as urea.



Spreadsheet budgeting tool developed by Kansas State University for comparing economic returns of multiple crops and crop rotations.

Table 2. Corn as a form of currency keeps prices in perspective.

	A bu buys:			Cost of 100 lbs		
	2012	2013	2014	2012	2013	2014
Source	----------- lb -----------			---------- bu ----------		
N	12	9	7	8	12	15
P_2O_5	17	11	9	6	9	11
K_2O	15	11	9	7	9	11

Based on Midwest retail for urea, DAP and KCl; November 2012, 2013 and August 15, 2014 (The NPK Insider). Corn $7.50/bu (2012); $4.25/bu (2013); $3.75/bu (2014).

So an important science-based reaction to potential financial pressures due to crop prices is the strengthening of yield response and nutrient need prediction through use of up-to-date soil testing and the latest N need prediction tools that are calibrated and proven for the cropping system in question. The goal is to maximize return on the last dollar spent on fertilizer inputs.

Adequate and balanced fertility may also produce non-yield profit affecting benefits. For example, in a KSU irrigated corn study (Dhuyvetter and Schlegel, 1994) P fertilizer hastened maturity, lowered grain moisture at harvest, and resulted in greater profit due to lower drying cost. This work showed that P fertilizer reduced drying costs by an average of $0.10/bu.

Farmers and their advisers are more than ever operating in a fluid global environment. Adaptation to abrupt and sometimes massive change is necessary for survival, but always remember that even in the face of change certain principles endure. One of these is the MEY principle discussed above, another is the principle of 4R Nutrient Stewardship. This article has discussed the effect of crop price on estimated optimum fertilizer rate. But none of the 4Rs (fertilizer rate, source, time, and place) stands alone; all are interconnected, each affecting the other. A MEY program requires not only the right rate, but also source, time and place factors that collectively assure efficient and effective nutrient use.

So encourage growers to take a breath, "do the numbers", and apply sound agronomic and economic principles before reacting to recent market swings. BC

Dr. Stewart is a Director of the IPNI North American Program, located in San Antonio, TX; e-mail: mstewart@ipni.net. Dr. Fixen is IPNI Senior Vice President and Director of Research, located in Brookings, SD; e-mail: pfixen@ipni.net.

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Dhuyvetter, K.C. and A.J. Schlegel, 1994. Better Crops with Plant Food 78(2):10-11.

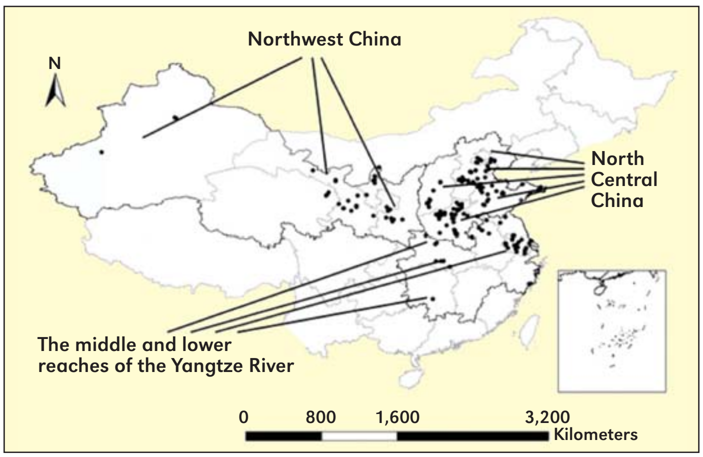
Estimating Nutrient Uptake Requirements for Wheat

By Limin Chuan, Ping He, Mirasol F. Pampolino, Jiyun Jin, Shutian Li, Cynthia Grant, Wei Zhou, and Adrian M. Johnston

Over a decade's worth of data collected for winter and spring wheat in China revealed that most crop N uptake could be classed as luxury (excessive) consumption. Data for P showed a mix of both excessive and deficient crop uptake, while some K uptake data indicated a deficiency situation. These results collectively reflect the current status of fertilizer application practices in China—considerably less than site-specific. Field validation trials showed that the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model could be a practical tool for making balanced fertilizer recommendations in China.

The total wheat production in China has remained fairly stagnant in the last decade or so, with some decrease reported due to the changes in wheat planting area. One of the reasons for stagnating wheat yields is that the current fertilizer management approaches do not usually apply nutrients in balance (i.e., to match the crop demand) resulting in wasted fertilizer resources and low nutrient use efficiency.

To improve the efficiency of fertilizer inputs, a computer software program, Nutrient Expert® (NE) was developed by IPNI as a decision support tool to make fertilizer recommendations (Pampolino et al., 2012). The NE system is based on improved SSNM guidelines and the QUEFTS model that consider a balanced input of all essential plant nutrients.



Geographical distribution of studied locations in north central China (NC), the middle and lower reaches of the Yangtze River (MLYR), and northwest China (NW). The black solid lines are the boundaries of each region.

Strategies for SSNM that assess crop nutrient requirements, indigenous nutrient supply and recovery efficiency (RE) of applied fertilizer could be used to increase crop yields and nutrient use efficiency. However, there are many uncertainties about N, P and K requirements of crops because the internal efficiency (IE) varies greatly depending on variety, nutrient supply, crop management, and climate. This makes it difficult to extrapolate results to small farm fields.

The QUEFTS model was selected to resolve this problem since the model takes into account the interactions of N, P and K (Janssen et al., 1990). The model provides a generic empirical relationship between grain yield and nutrient accumulation in plants and also uses two linear boundaries to describe the range between maximum and minimum nutrient accumulation situations (Witt et al., 1999). The model has proven to be a practical SSNM tool in major crops (Setiyono et al., 2010).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; SSNM = site-specific nutrient management; OPT = optimal practice treatment; IPNI = International Plant Nutrition Institute.

Nutrient use efficiency indicators used in this article

Recovery Efficiency (RE) = increase in nutrient uptake in above-ground biomass per unit of nutrient applied

Internal Efficiency (IE) = grain yield per unit of nutrient accumulated in above-ground plant dry matter

Reciprocal Internal Efficiency (RIE) = kg nutrient uptake in above-ground plant dry matter per t grain produced

The objective of this study was to estimate the optimal requirements of N, P and K in wheat for a specific target yield using the QUEFTS model. For this, data was collected from 2000 to 2011 covering a wide range of wheat yields, soil types and climates. Datasets for grain yield, N, P and K uptake in above-ground plant dry matter, harvest index (HI, kg grain per kg total above-ground dry matter) and fertilizer application were compiled from literature published from China between 2000 and 2011, and unpublished datasets from research trials conducted by the IPNI China Program.

Yield optimizing (OPT) trials for wheat in Hebei (32 plots), Henan (50 plots), Shandong (30 plots), and Shanxi provinces (10 plots) in north central China were also conducted by IPNI cooperators from 2010 to 2011 to validate the QUEFTS model. Fertilizer N recommended by NE was estimated from the yield response to applied N fertilizer and agronomic efficiency of N, while fertilizer P and K were determined from the target yield and yield response combined with optimal reciprocal internal efficiency (RIE) and nutrient balance sufficient to replace P and K removed from harvested product. Urea was applied in two or three splits, depending on soil fertility or expected yield response to N, while P and K fertilizers were both broadcast and incorporated as a basal application before seeding. The rates of fertilizer application are listed in **Table 1**.

Table 1. Rates of fertilizer application in optimal practice treatment (OPT).

	Fertilizer application, kg/ha		
Province	N	P	K
Hebei	135 (130-150)[a]	23 (22-24)	50 (40-58)
Henan	150 (140-170)	32 (29-34)	62 (50-66)
Shandong	140	34	58 (50-66)
Shanxi	137 (125-140)	29	65 (50-66)

[a]Data in parentheses indicates the range of fertilizer application. Irrigation and other cultural practices were applied using the best local management practices.

Estimating Nutrient Uptake and Removal with QUEFTS

The QUEFTS model was able to simulate balanced nutrient uptake requirements for N, P and K assuming conditions where the yield was not limited by any nutrients and the crop produc-

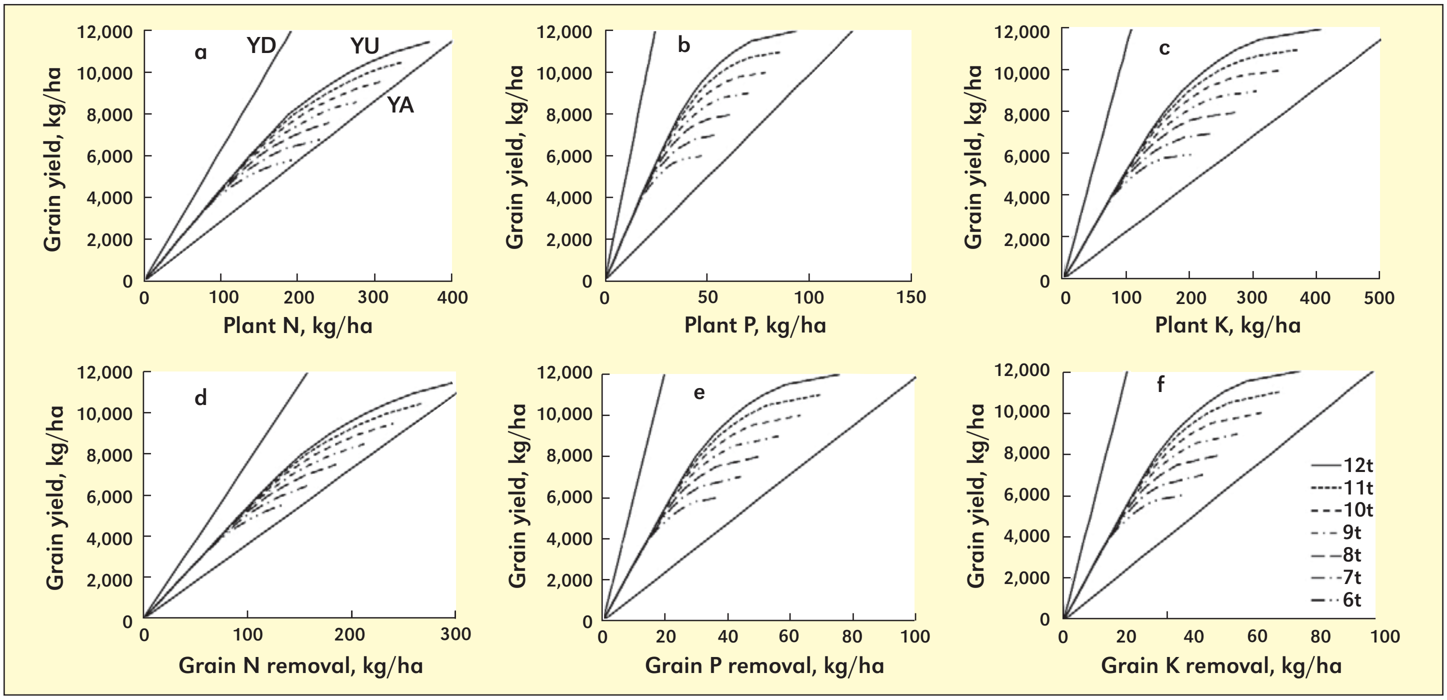


Figure 1. Balanced nutrient requirement (a to c) and grain nutrient removal (d to f) for N, P and K under different yield potentials simulated by the QUEFTS model. YD = maximum nutrient dilution; YA = maximum nutrient accumulation; YU = balanced nutrient uptake.

tion was managed using best practices. QUEFTS predicted that the balanced nutrient accumulation required to produce 1,000 kg grain was 22.8 kg N, 4.4 kg P, and 19.0 kg K, respectively, when the yield reached about 60 to 70% of the potential yield, with an N:P:K ratio of 5.2:1.0:4.3. The corresponding optimal IE values were 43.9 kg grain/kg N, 227.0 kg grain/kg P and 52.7 kg grain/kg K. Interestingly, regardless of the yield potential, the N:P:K ratio in the plant that was required to produce 1,000 kg grain was always the same within the linear part of the response curve (**Figure 1a to c**).

Results showed that the balanced grain nutrient removal curve was very similar to the balanced nutrient requirement for the total aboveground plant under yield potentials ranging between 6 to 12 t/ha (**Figure 1d to f**). Regardless of the yield potential, in the linear part of the curve, the balanced N, P and K removals by 1,000 kg grain were 18.3, 3.6 and 3.5 kg, respectively, and the N:P:K ratio in the grain was 5.1:1.0:1.0. Compared to the balanced nutrient uptake in the total aboveground plant, approximately 80, 82 and 18% of N, P and K, respectively, accumulated in the grain and were removed from

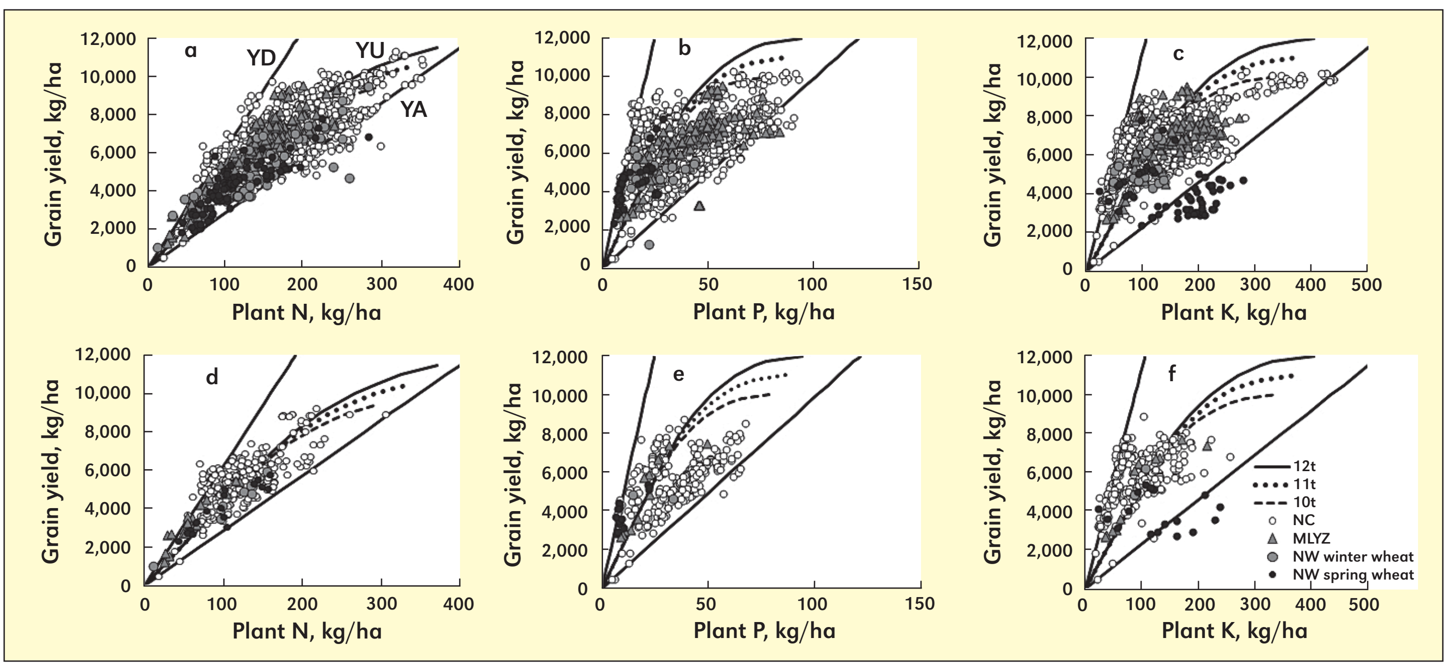


Figure 2. Observed relationships between grain yield and N, P and K uptake in the NC, MLYR and NW regions of China. Figures 2a to c are based from all experimental datasets, while Figures 2d to f are based from available CK (unfertilized plots) and N, P or K omission plot studies. YD = maximum nutrient dilution; YA = maximum nutrient accumulation; YU = balanced nutrient uptake.

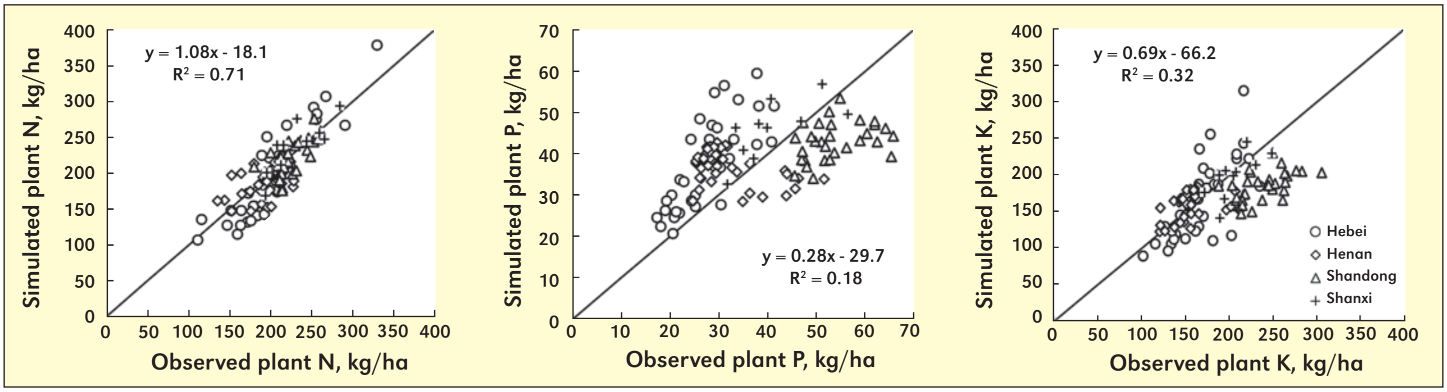


Figure 3. Relationship between observed and simulated NPK uptake in the above-ground plant dry matter for wheat.

the field. These values should provide practical algorithms for fertilizer recommendations that can sustain soil fertility.

Regional Relationships between Wheat Yield and Nutrient Uptake

The datasets in **Figure 2** are from field experiments conducted from 2000 to 2011 dealing with N, P and K treatments in different wheat production areas of China. Datasets above the balanced nutrient uptake line and close to the upper boundary indicate a deficient supply. In contrast, datasets below the balanced nutrient uptake line and close to the lower boundary indicate excessive supply such that yield is limited by growth factors other than the nutrient concerned.

Figure 2a reveals that most of north central China had luxury N uptake in wheat. In the northwest, N uptake was also excessive both in winter and spring wheat. In the MLYR region, N uptake could not be dominantly classed as either excessive or deficient, which suggests that N application in this region may be more rational.

Phosphorus accumulation data for winter wheat in north central China showed both examples of deficiency and excess, indicating that P fertilizer application has not been balanced (**Figure 2b**). Some P uptake in the MLYR region showed excessive supply, and in the northwest, most spring wheat data indicated an inadequate supply of P. Phosphorus is mainly applied as calcium superphosphate or calcium magnesium phosphate, or is added with N or K fertilizer. For example, compound fertilizers with a $N:P_2O_5:K_2O$ ratio of 15:15:15 that are used frequently in China would all include more P nutrient than is required for an optimum ratio.

For K, the majority of data showed deficiency in north central China with only a few data sets indicating an excess K supply. In the northwest, spring wheat showed a greater tendency for excessive uptake compared to the more balanced K uptake observed in winter wheat (**Figure 2c**). The difference might be due to the environment where spring wheat was grown. Northwestern soils tend to be higher in K, which could result in luxury uptake.

Verification via Omission Plot Study

In comparison, observations for yield versus nutrient uptake extracted from omission plot studies are shown in **Figure 2d to f**. Many observations were concentrated near the upper boundary line of high IE values reflecting maximum yield dilution (minimum nutrient accumulation) or severe nutrient deficiency. Some N but more P accumulation datasets, hover close to the lower boundary line, which suggests considerable available N and P in the soil from an unbalanced nutrient supply. These observations confirm a situation of long-term imbalanced fertilization practice within traditional wheat cropping systems (Chuan et al., 2013).

As validation of the QUEFTS model, observed N, P and K uptake for the above-ground plant dry matter were scattered more or less equally around the 1:1 line. Measured values for N agreed well with values for simulated nutrient uptake while this relationship for P and K was not as well defined (**Figure 3**). Liu et al. (2006) observed similar results in his experiments. Given such results, it is apparent that QUEFTS can be safely used to calibrate the predicted nutrient uptake and improve fertilizer recommendations.

Summary

Our results generally reflect the status of wheat fertilizer application practices in China and serve as a tool to help recommend balanced fertilization. Results from the field validation of the QUEFTS model in four different provinces of China showed that it could be used to support the NE system in wheat to recommend balanced fertilizer practices for farmers. BC

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This article is a summary of the 2013 article published by Chuan, L., P. He, J. Jin, S. Li, C. Grant, X. Xu, S. Qiu, S. Zhao, and W. Zhou. 2013. Field Crops Res. 146:96-104.

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Does Long-term Use of Mineral Fertilizers Affect the Soil Microbial Biomass?

By Daniel Geisseler and Kate M. Scow

Analysis of 64 long-term crop fertilization trials from around the world found that application of mineral N fertilizer was associated with an average 15% increase in microbial biomass and 13% increase in soil organic carbon compared to an unfertilized control. The effect of fertilization on the microbial biomass is strongly pH dependent. Increases in microbial biomass were largest in studies with at least 20 years of fertilization.

Mineral fertilizer use, especially N, has contributed to substantial increases in crop yields. However, reports from natural ecosystems, such as grassland and forests, suggest that long-term mineral N inputs might have a negative effect on soil microbial biomass.

We analyzed the response of soil microorganisms to mineral fertilizer inputs in 107 datasets from 64 long-term field trials, ranging from 5 to 130 years (37 years average) from across the world (**Figure 1**). Though we focused on N fertilizer, in most long-term trials both P and K are also applied. Therefore, the observed effects cannot be attributed solely to N inputs. All datasets included were from trials with annual crops (except lowland rice cropping systems in paddy soils), initiated at least five years prior to soil sampling, and contained an unfertilized control for comparison.

Most samples were collected from between 0 to 8 in. and received an average of 120 lb N/A each year, most commonly as a urea or ammonium-based fertilizer. The effect of N fertilization on the microbial biomass was determined using a meta-analysis, a statistical method that allows combining results from different studies to identify patterns across studies.

Soil Organic Carbon (C_{org})

The addition of mineral fertilizers significantly increased C_{org} content, by an average of 12.8%, compared to the unfertilized control (**Figure 2**). This was not surprising as increases in C_{org} are often associated with higher yields of crops and a higher return of crop residue to soil, resulting in a rise in the organic matter content. In soils where the pH dropped below 5 due to repeated ammonium or urea fertilizer applications, crop yields declined and in some cases, yields dropped below the unfertilized control. Soil acidification is a natural consequence of nitrification, the conversion of ammonium to nitrate. Nitrate fertilizer, which is already oxidized, had little effect on soil pH.

Soil organic matter is a complex mixture of organic materials that makes up a small but vital part of all soils. Soil organic matter consists of decomposing plants and soil animals, soil microbial biomass, and stable organic compounds. Soil organic matter is determined by measuring the loss of weight after burning, or after chemical oxidation with strong reagents.

Soil organic carbon is the carbon occurring in soil organic matter, but omits inorganic carbon materials, such as calcium carbonate. Soil organic carbon can be determined by measuring the carbon dioxide gas released by combustion.

Microbial biomass of soil is the part of the organic matter present in living microorganisms, such as bacteria, archaea and fungi. Only a portion of the total living microbial biomass consists of carbon.

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

Figure 1. The long-term agricultural field trials included in our meta-analysis were from every continent and 18 countries.

Long-term field trials, such as the Century Experiment at the Russell Ranch Sustainable Agricultural Facility at the University of California, Davis, are crucial to studying long-term effects of management practices on crop production, soil health and the environment (Photo by Bob Rousseau).

Microbial Biomass Carbon (C_{mic})

Fertilization significantly increased C_{mic}—by an average of 15%. The positive effect of N fertilization on C_{mic} differs from similar analyses done on data from studies in predominantly natural ecosystems. Several factors may contribute to this difference. Nitrogen additions to natural ecosystem often lead to changes in plant species composition and diversity, which in turn may affect the soil microbial community. Furthermore, if N fertilizer input decreases soil pH, aluminum (Al) may be more soluble and nutrient cations may be leached. In the studies included in our analysis, soil pH only decreased by an average of 0.26 units. This relatively small change observed is likely due to the fact that lime is regularly added to buffer soil pH in many trials.

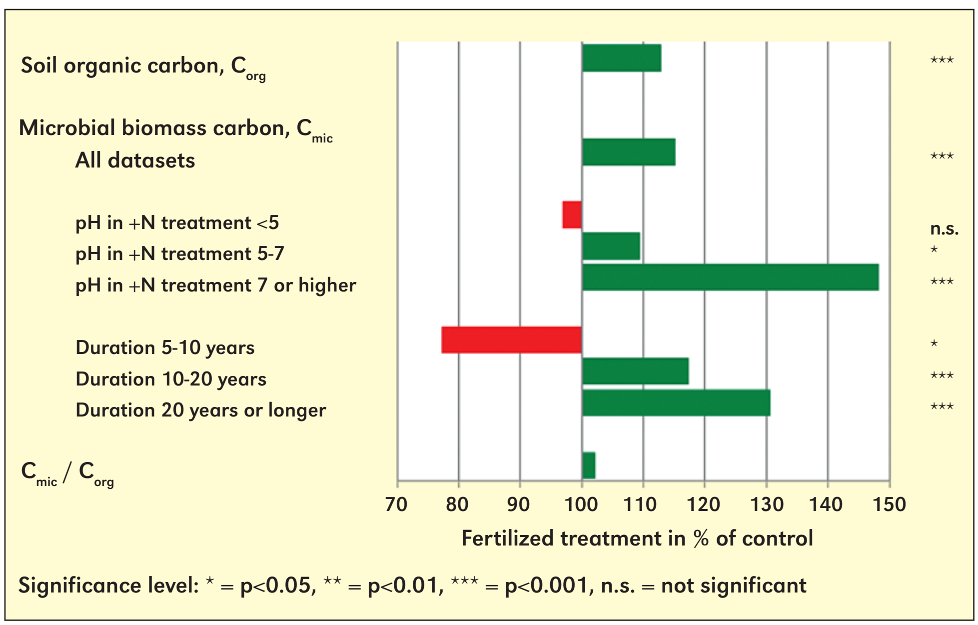

Figure 2. Effect of fertilization on soil organic carbon (C_{org}) and microbial biomass carbon (C_{mic}).

The effect of fertilization on C_{mic} was strongly pH dependent. While fertilization slightly reduced C_{mic} in soils with a pH below 5, it had a strong positive effect at higher soil pH values (**Figure 2**). When the soil pH was at least 7, the fertilization-related increase in C_{mic} averaged 48%. Studies carried out in a number of ecosystems have shown that pH exerts a strong influence on the biomass and composition of soil microbial communities. Therefore, our results agree with those from other ecosystems.

The duration of the trial also affected the response of C_{mic} to fertilization, with increases in C_{mic} noticeably higher in studies older than 20 years (**Figure 2**).

Microbial biomass C was positively correlated with C_{org} concentrations as has been previously observed. The C_{mic}/C_{org} ratio was little affected by fertilization across all datasets (**Fig-**

ure 3), suggesting that the higher C_{org} content in the fertilized treatments is a major factor contributing to the overall increase in C_{mic}. An exception may be with the use of anhydrous ammonia. Only two of the 107 datasets used anhydrous ammonia, but it resulted in a very low C_{mic}/C_{org} ratio, and C_{mic} decreased with increasing N additions (**Figure 3**). Furthermore, one trial included three N application rates of either anhydrous ammonia or urea. At all N rates, C_{mic} was considerably lower in the anhydrous ammonia than urea treatment.

Microbial community composition

The composition of the microbial community is far more sensitive to long-term inputs of mineral fertilizer than C_{mic}. The microbial community response to mineral fertilizer is strongly influenced by environmental and management factors. Differences in the microbial community were more pronounced between years and different sampling times during the same season than between the unfertilized control and the fertilized treatment.

Conclusions

Our meta-analysis revealed that long-term N fertilization of agricultural soil results in increased C_{mic} content, most likely due to associated increases in C_{org} resulting from higher crop productivity. Increases in C_{mic} in fertilized soils under annual crops contrasts with observations in natural ecosystems, where N inputs may decrease C_{mic}.

Applications of ammonium and urea fertilizer, when not buffered, gradually lower soil pH. When soil pH drops below 5, C_{mic} is generally decreased. However, when pH is maintained near neutral, the input of N fertilizer does not seem have long-term negative effects on C_{mic} in annual cropping systems. However, long-term repeated mineral N applications can alter microbial community composition in many cases even when pH changes are small, but no clear patterns were evident. Future research using advanced tools is needed to advance our understanding of the relationships between microbial communities and addition of plant nutrients. BC

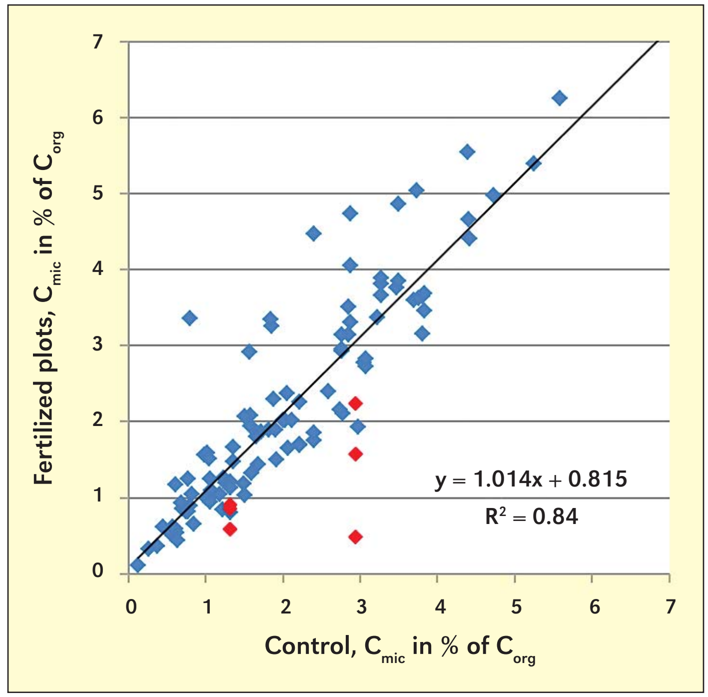

Figure 3. Microbial biomass carbon (C_{mic}) in % of total soil organic carbon (C_{org}) in unfertilized soils plotted against C_{mic} in % of C_{org} in soils receiving mineral N fertilizer. The red symbols are treatments from two trials with anhydrous ammonia additions. All data points were included in the regression analysis.

This article is an abridged version of the journal article, Geisseler, D., and K.M. Scow. 2014. Soil Biol. Biochem. 75:54-63.

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Crop Nutrient Deficiency Photo Contest Entries Due December 11

The deadline for submitting entries to the annual IPNI contest for photos showing nutrient deficiencies is fast approaching.

This year, in addition to the four nutrient categories (N, P, K and Other Nutrients) we have added a new "Feature Crop" category focused on Hay and Forage Crops.

Our prizes are as follows:

- US$300 First Prize and US$200 Second Prize for Best Feature Crop Photo.
- US$150 First Prize and US$100 Second Prize within each of the N, P, K and Other Nutrient categories.
- In addition, all winners will receive the most recent copy of our USB Image Collection. For details on the collection please see http://ipni.info/NUTRIENTIMAGECOLLECTION

Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest. Specific supporting information is required (in English) for all entries, including:

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

Winners will be announced in January of 2015. Winners will be notified and results will be posted at www.ipni.net. BC

Nutrient Management Improvements in Forestry Species

By Alfredo Alvarado, Jesús Fernández-Moya, José M. Segura, Edwin E. Vaides, Manuel Camacho, María J. Avellán, and Carlos E. Ávila

Proper soil management and forest nutrition are key to maintaining the productivity of planted or natural forests. This article reviews related concepts and developments for Central American forests and focuses on relevant topics for forest managers including land evaluation, nutrient cycling, diagnosis of nutrient deficiencies, and limitations of general recommendations for liming and fertilizing.

Proper land evaluation is the first step towards a successful forest plantation. Poor forest growth is very often the result of planting in sites that were improperly assessed (Segura et al., 2013). Early success within a new plantation site is most easily achieved by conducting a site assessment step well before making any land purchase. New land evaluation tools are being developed for forest managers that involve statistical and modeling approaches. These models can predict species suitability based on soil and climate at a specific location. For example, our research is combining digital soil maps with modeling techniques to predict the suitability for teak (*Tectona grandis*) plantations based on remote sensing (Landsat images) and digital elevation models.

Analyzing nutrient accumulation dynamics for *Terminalia amazonia* (J.F. Gmel.) Excell in South Pacific, Costa Rica.

For small landowners who cannot afford to invest in new land, they have to make the best decisions based on the land they already own. In many cases their land has low soil fertility and problems related to soil acidity. Establishing species with high nutrient requirements like teak (**Figure 1**) or melina (*Gmelina arborea*) on marginal land is a common mistake. The alternative of using native species such as white olive or amarillón (*Terminalia amazonia*) and mahogany (*Swietenia macrophylla*) with less nutrient demands, could be more profitable (Griess and Knoke, 2011). Consideration of both the soil conditions at the site and species demands is critically important.

Nutrient cycling in forestry plantations is a topic that is often discussed in literature. In reality, even though forest managers and researchers typically agree on the need to assess the balance between the quantity of nutrients taken up by a growing forest and that which is removed from the site during timber extraction, there is a common lack of concern about this issue among plantations (Fölster and Khanna, 1997).

Agronomists have traditionally analyzed when, where, and at what rates nutrients are accumulated by annual crops, and extracted as harvested products. Such studies of nutrient accumulation dynamics of a forest species can be used to estimate: (i) nutrient removal caused by thinning or harvesting; (ii) nutrient requirement of the species during a rotation; (iii) amount of nutrients left at a site after harvesting; and (iv) minimum nutrient inputs (fertilizers) that a system needs to be sustainably managed (Alvarado and Raigosa, 2012).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum; B = boron; Cu = copper; Fe = iron; Mn = manganese; Na = sodium; Zn = zinc; ECEC = effective cation exchange capacity.

Even with all site and species information available, managers often need more dynamic and *in situ* tools for nutrient status evaluation. Foliar concentrations are considered key parameters for evaluating the nutritional status of a forest stand. Values considered as adequate for several species, as a combination of the results of several research projects, are provided in **Table 1**. This table acts as a simple guide, designed as a management reference for a range of forest species, regimes and ages. Managers can compare their foliar tissue analysis results with this reference guide. If the empirical value is within the range given then nutrition is considered adequate. However, if a nutrient concentration is below or above the range then professional advice should be sought or a more detailed study of the specific site and soil conditions should be recommended.

As soil critical levels are also commonly used as a conceptual framework in plant nutrition, similar work in Central America has focused on, for example, establishing soil nutrient critical levels for teak plantations—the main species for the

Table 1. Approximate average and range (in parentheses) for foliar nutrient concentrations in forest plantations of six species for Central America.

Species†	Age, years	N	Ca	K	Mg	P	S
		% Dry weight					
Alnus acuminata (Alder, Aliso)	1-19	3.66 (3.57-3.75)	0.29 (0.27-0.31)	0.46 (0.44-0.48)	0.20 (0.19-0.20)	0.20 (0.19-0.24)	0.20 (0.20-0.21)
Gmelina arborea (Melina)	1-12	2.85 (2.78-2.92)	1.3 (1.23-1.38)	0.96 (0.90-1.03)	0.34 (0.33-0.36)	0.21 (0.-20-0.22)	0.15 (0.14-0.15)
Cedrela odorata (Cedar acajou)	1-19	2.74 (2.48-3.01)	0.92 (0.59-1.24)	1.06 (0.83-1.30)	0.15 (0.12-0.18)	0.18 (0.16-0.20)	0.22 (0.19-0.24)
Vochysia guatemalensis (White mahogany)	1-20	2.26 (2.14-2.38)	0.13 (0.11-0.15)	1.09 (0.95-1.22)	0.35 (0.31-0.38)	0.86 (0.65-1.08)	0.22 (0.20-0.24)
Tectona grandis (Teak)	1-19	1.97 (1.83-2.15)	1.34 (1.13-1.54)	0.88 (0.73-1.02)	0.29 (0.22-0.34)	0.16 (0.12-0.20)	0.12 (0.11-0.13)
Terminalia amazonia (White olive)	1-23	1.68 (1.54-1.83)	1.23 (1.02-1.43)	0.75 (0.68-0.83)	0.22 (0.19-0.24)	0.16 (0.12-0.20)	0.11 (0.10-0.12)
Species	**Age, years**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Al**
		mg/kg					
Alnus acuminata (Alder, Aliso)	1-19	79 (73-85)	22 (21-23)	37 (35-39)	59 (40-77)	15 (14-16)	4 (3-4)
Gmelina arborea (Melina)	1-12	72 (61-83)	78 (65-91)	10 (9-10)	53 (49-57)	41 (38-44)	40 (32-48)
Cedrela odorata (Cedar acajou)	1-19	90 (79-101)	24 (17-31)	25 (17-34)	8 (6-9)	24 (15-33)	59 (43-76)
Vochysia guatemalensis (White mahogany)	1-20	97 (68-125)	6 (5-7)	20 (16-23)	113 (84-142)	29 (24-34)	22,907 (21,278-24,536)
Tectona grandis (Teak)	1-19	130 (85-175)	43 (39-46)	11 (10-12)	32 (24-39)	20 (18-21)	na
Terminalia amazonia (White olive)	1-23	76 (51-101)	275 (163-387)	9 (8-11)	26 (19-34)	33 (27-39)	na

† References: Avellán (2012); Camacho (2014); Ramirez (2014), and Fernández-Moya et al. 2013.
Note 1: Some of the values for *T. amazonica*, and *A. acuminata* are part of documents in preparation.
Note 2: Most of these reports have also information on nutrient dynamics, but see also Portuguez (2012) with specifics on teak dynamics. Our group has also information soon to be published, on the nutrient dynamics for *G. arborea*.

forestry sector (**Table 2**).

The results of many fertilization and liming trials in Latin America are generally inconsistent (Alvarado and Raigosa, 2012). The response of forests to fertilizer is known to vary according to a wide range of factors, and can be highly site-specific. Hence, more research is needed to understand the underlying differences between various fertilization trials in order to be able to predict any nutrient response prior to its application. Despite this lack of consistency, fertilizer application is still generally common in Central America, especially in large-scale forest plantations where it typically occurs only at planting.

Soil heterogeneity is a key factor determining fertilization success, especially in large forest plantations, even though a single recommendation is used across large areas. Establishing stand-specific nutrient management plans would be very complicated in many forests at present.

Table 2. Critical values for selected soil fertility variables for teak plantations in Central America.

	Critical values			
	Literature generic values (Bertsch, 1998)	Literature specific values (Alvarado and Fallas, 2004)	Literature specific values (Fernández-Moya et al., In review)	Experience of the authors
pH	5.5			
Ca, cmol(+)/L	4			10
Mg, cmol(+)/L	1			3
K, cmol(+)/L	0.2			
Acidity, cmol(+)/L	0.5			
Ca saturation, %		68		
Mg saturation, %				
K saturation, %			3.09	
Al saturation, %		3		
Na saturation, %			1.1	
P, mg/L	10			5

Ca saturation [Ca Sat=Ca/ECEC]; Mg saturation [Mg Sat=Mg/ECEC]; K saturation [K Sat=K/ECEC]; Acidity saturation [A Sat=Acidity/ECEC]; Na saturation [Na Sat=Na/ECEC]; ECEC = Acidity+Ca+Mg+K].
Analysis for pH in water, and all cations, Al, and acidity was a modified Olsen procedure (Díaz-Romeu and Hunter, 1978).

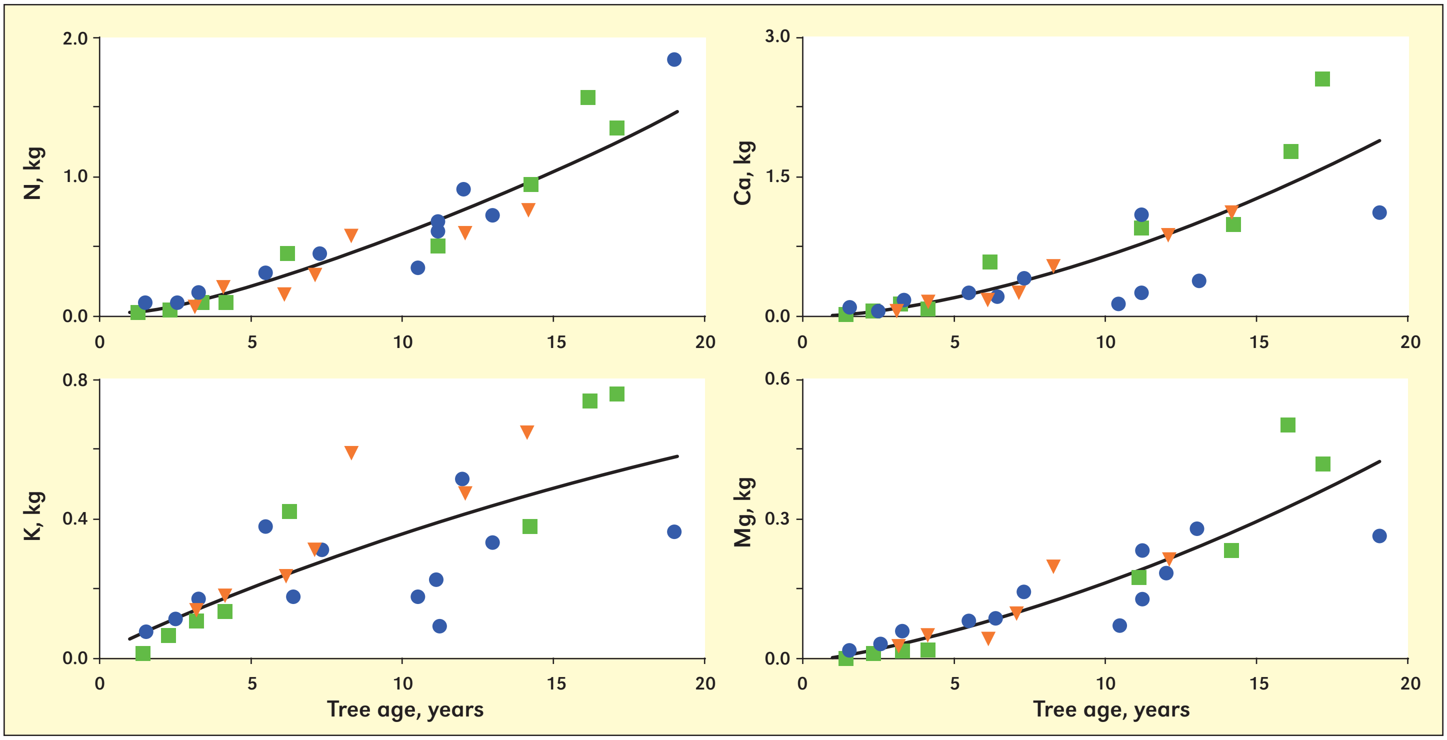

Figure 1. Tree bole and bark nutrient (N, Ca, K, and Mg) accumulation (kg/tree) related to tree age (years) in teak plantations (*Tectona grandis* L.f.). Points represent sampled trees at three different locations: Guanacaste, Costa Rica (■); Northern Region, Costa Rica (●); Panama (▼). Lines represent fitted models (Fernández-Moya et al., 2014 b).

In many large-scale and intensively managed forests, stands can be grouped by similarities in soil fertility through which managers can define management blocks. Fernández-Moya et al. (2014a) showed how multivariate analysis techniques could effectively contribute to the manager's decision on how to create these management units.

Finally, even though foliar and soil analyses can identify certain nutritional deficiencies, fertilization will not always have a positive effect if the factors that affect the success of fertilization are not taken into account. Plantation density is a key factor and a mandatory step in the design of fertilization programs should consider the thinning scheduling in order to identify synergies between different treatments. The usual low dosage of N-P-K fertilizers may not be adequate either, as higher dosages or perhaps other products may be more appropriate in many plantations. Hence, fertilizers containing more nutrients (e.g., Mg, Zn, B) or products that increase the availability of elements that are immobilized in the soil (e.g., biofertilizer or mycorrhizae) may be better choices in some cases. We have collected mycorrhizae throughout teak plantations in Costa Rica and proposed the inoculation of seedlings as a way to improve P uptake and enhance productivity, particularly in acid soils (Alvarado et al., 2004).

Summary

Forest plantation success depends on the use of several right decisions. With the sound support of land use evaluation tools and knowledge on the tree nutrient demand, we can select the best combination of species for each site. After planting we have diagnostic tools for tissue and soil that can help us decide on the nutrients we may need, or investing on further studies to implement site-specific management, instead of generalized fertilization regimes. We provide here the basic numbers for adequate diagnosis on six important forest tropical crops in Central America. BC

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Nitrogen Use Efficiency for Old versus Modern Corn Hybrids

By Ignacio A. Ciampitti and Tony J. Vyn

An analysis of all known research (100 studies from around the world) that reported corn yields, N rates, plant densities, and whole-plant N uptake was performed to compare "Old" (1940 to 1990) versus "New" (1991 to 2011) corn hybrids for their yield relationship to whole-plant N uptake, and their associated N use efficiency (NUE). This summary confirmed that NUE gains in "New" hybrids were primarily achieved by increased grain yields per unit of N stored in the plant at maturity. The accompanying reduction in grain N concentrations over time suggests that future NUE progress in corn should not overlook nutritional quality of the resulting grains.

Corn grain yields have climbed progressively over the last century due to collective changes in genetics and management practices. Annual crop yield information is robust in most corn-producing countries, but there is virtually no documentation available on the progression in nutrient use efficiency over the last six decades of corn improvement. The primary objective of this investigation was to summarize previously published scientific information to advance the understanding of the relationship of corn yield to whole-plant N uptake and associated NUE changes apparent in "Old Era" (1940 to 1990) versus "New Era" (1991 to 2011) corn hybrids.

Our data were collected from studies conducted (a) from 1940 until 2011 to assure a wide range of genotypes from different eras, (b) in all continents capable of corn production, and (c) across wide-ranging N rates (from 0 to 500 lb fertilizer N/A) and plant densities (from 4,500 to 44,000 plants/A). Only "experimental treatment means" were used. In addition, the term "N uptake" utilized in this paper is limited to above-ground whole-plant N uptake, so N accumulated in the root system is not included. Other corn traits included were NUE and its components. The following equation was used for the NUE (sometimes called agronomic efficiency for N) calculation:

$$\text{NUE} = \Delta\text{Yield}/\Delta\text{N applied} \quad (1)$$

where ΔYield is the yield (bu/A) of a treatment receiving N minus the yield (bu/A) of the 0N treatment, and ΔN applied (lb N/A) is the fertilizer N applied. A component of the NUE term is the N internal efficiency (NIE), defined as:

$$\text{NIE} = \text{Yield}/\text{Plant N uptake} \quad (2)$$

where NIE is calculated on a per unit area basis (bu/lb N uptake).

Another N efficiency parameter evaluated was the N fertilizer recovery efficiency (NRE):

$$\text{NRE} = \Delta\text{Plant N uptake}/\Delta\text{N applied} \quad (3)$$

where ΔPlant N uptake is the change in whole-plant N uptake due to N fertilization (lb N/A). Maximum and minimum boundaries were established to constrain possible NRE values ($0 < \text{NRE} < 1$), so that the NRE calculation is more biologically meaningful (Ciampitti et al., 2012).

Grain Yield and Plant N Uptake: New vs. Old Corn Genotypes

Superior grain yield and whole-plant N uptake were documented for the New compared to the Old Era corn hybrids (**Table 1**). Nitrogen internal efficiency followed a quadratic model (**Figure 1**), and higher average yield-levels were evident for newer (240 bu/A) vs. older (200 bu/A) hybrids as plant N uptake increased.

Following adjustments for plant density in each trial (**Table 1**), it was clear that NIE was greater for newer versus older

Abbreviations and notes: N = nitrogen.

Table 1. Summary of variables compared for old and new era corn hybrids.

Variable	Old Era	New Era
Mean N rate, lb N/A	126	125
Plant density, plants/A	22,800	28,800
Plant N uptake, lb N/A	136	143
Grain yield, bu/A	115	144
N use efficiency (NUE), bu increase/lb N	0.58	0.66
N internal efficiency (NIE), bu/lb N uptake	0.89	1.00
Grain harvest Index[1] (HI), %	48	50
N harvest Index[2] (NHI), %	63	64
Grain N, %	1.33	1.20
Stover N, %	0.77	0.69
% of total plant N coming from new N uptake after R1	31%	36%
% of grain N that came from new N uptake after R1	52%	56%

[1]Grain harvest index is the percent of the total above-ground dry matter that is in the grain.
[2]N harvest index is the percent of total above-ground N accumulation that is in the grain.
Source: Ciampitti and Vyn, 2012

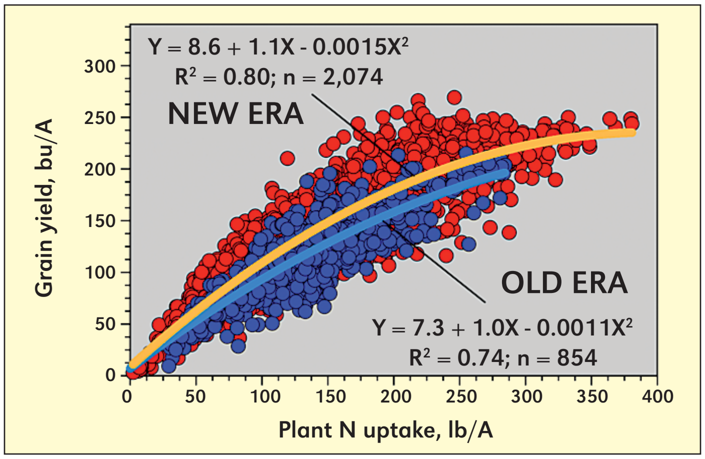

Figure 1. Corn grain yield versus plant N uptake at maturity in studies conducted from 1940 to 2011. Blue circles correspond to Old Era observations from 1940 to 1990 (n = 854), and the red circles refer to the New Era from 1991 to 2011 (n = 2074).

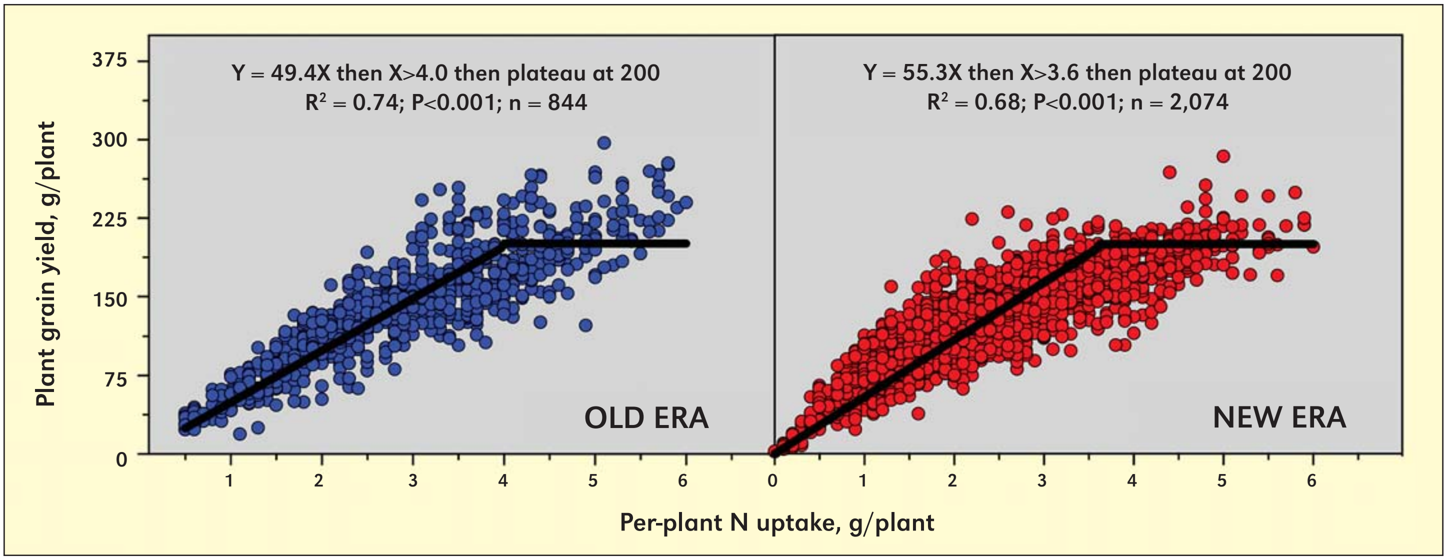

Figure 2. Relationships between grain yield and whole-plant N content at the per-plant-scale for older (Old Era, blue color: observations from 1940 to 1990) versus newer corn genotypes (New Era, red color: research carried out between 1991 and 2011).

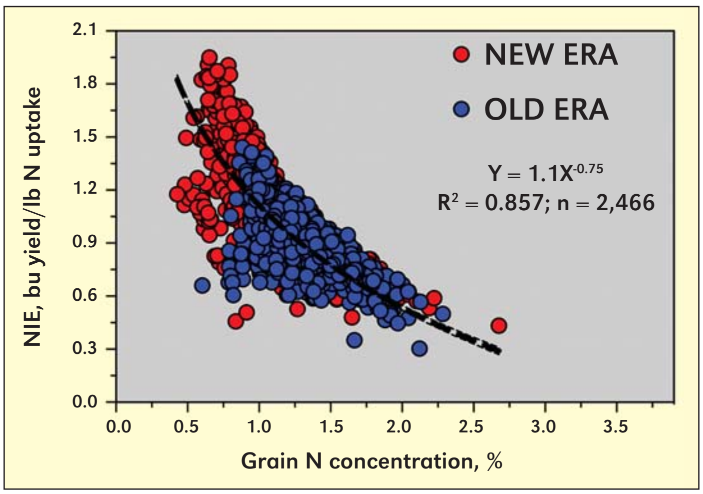

Figure 3. Relationship between nitrogen internal efficiency (NIE), calculated on a per unit area basis, and grain N concentration determined at maturity stage for Old (blue color, studies from 1940 to 1990) and New (red color, from 1991 to 2011) Eras.

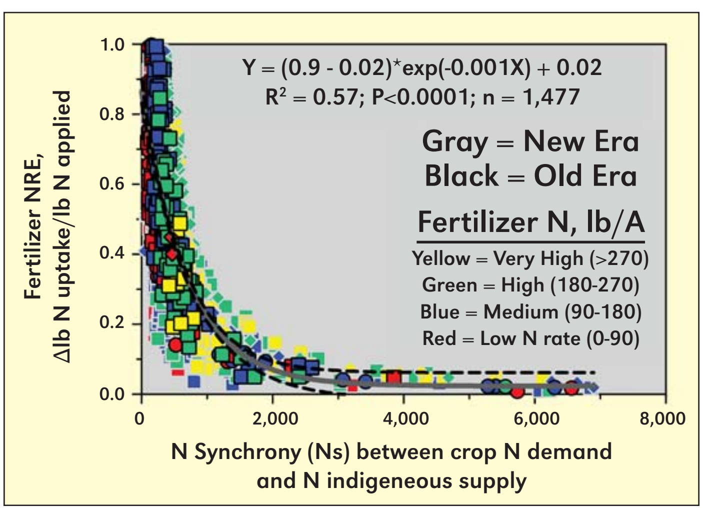

Figure 4. Relationship between N synchrony and fertilizer N recovery efficiency (NRE). New Era = experiments from 1991 to 2011; Old Era = studies from 1940 to 1990.

genotypes (**Figure 2**). In addition, maximum N uptake per plant at maturity (6 g N/plant) had not changed between Eras despite increased plant densities in newer genotypes.

Nitrogen Use Efficiency Components: NIE and NRE

The NIE change previously documented is primarily accounted for by changes in the grain N concentration (%N; **Figure 3**). Grain %N declined about 10% from older to newer genotypes (with similar reductions in whole-plant %N). Both Duvick (1997) and Scott et al. (2006) documented a similar diminishing pattern in grain protein for corn hybrids representing different eras.

Both older and newer corn genotypes had similar NRE with an overall average of 0.46. The synchrony between soil N supply and crop N demand (hereinafter termed "N synchrony") is the key component determining the fertilizer NRE term (Cassman et al., 2002):

$$\text{N Synchrony } (N_S) = \text{N applied} / (1 - \text{N uptake at 0N / N uptake with N applied})$$

Smaller values of N_S indicate greater synchrony.

The association between the N_S and the NRE showed that greater N synchrony can be obtained in a NRE range from 0.4 to 1.0, corresponding primarily to low and medium N rate levels from 0 to 180 lb/A (**Figure 4**). When fertilizer N was applied in excess (>270 lb/A; yellow points), the mean NRE was dramatically reduced (usually between 0.3 to 0.1). Reduction in NRE increases both environmental risk of N loss and lower farmer profitability.

Yield and N Uptake Responses to Fertilizer N Rates: New vs. Old Era Hybrids

For an integrated evaluation of the yield and plant N uptake responses at diverse fertilizer N rate levels, data from studies were arbitrarily divided into seven N fertilizer rate ranges based on successive 45 lb/A N-rate increments (starting from 45 lb/A).

A summary analysis presented in **Figure 5** highlights that i) when no N was applied, the grain yield advantage of newer versus older corn genotypes (ΔGY_{0N}) was ~ 13 bu/A; ii) the yield gap enlarged as the fertilizer N rate increased; iii) with highest N rates (>215 lb/A), the yield advantage (ΔGY_N) increased to 32 bu/A; and iv) at the plant-scale, N uptake was very similar for both Eras under (at) the full range of N fertilizer rates. This analysis permitted us to conclude that per-plant N uptake has not changed since 1940; nonetheless, per unit area, greater stress tolerance to N deficiency and N responsiveness to fertilizer N rate was observed in modern corn hybrids.

Conclusion

Improvements in NUE in past decades were primarily achieved by increasing NIE at the expense of lower grain N concentrations. Future NUE improvements should attempt to achieve simultaneous gains in NRE and grain yields without further sacrifices in grain N concentrations. From the management perspective, further optimization of best management practices (the "4 Rights": Source, Rate, Timing, and Placement) need additional research to improve global food security while minimizing N "footprints" in corn production systems around the world. BC

This article is an excerpt from a research review synthesis-paper, which first appeared in the July/August 2012 issue of Field Crops Research Journal (Ciampitti and Vyn, 2012).

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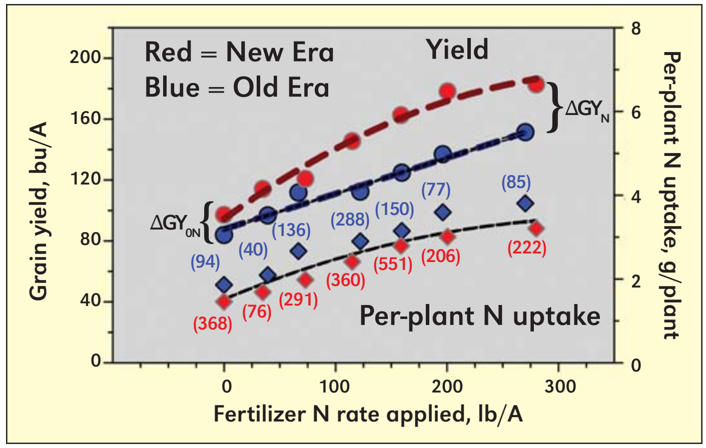

Figure 5. Corn yield and per plant N uptake (at maturity) versus overall fertilizer N rate applied. Red and Blue symbols refer to New and Old Era, respectively. Diamond symbols refer to plant N uptake and the circles refer to grain yield. Values refer to the total number of data points for each N rate and Era combination. GY_{0N} denotes the difference in grain yield between Old and New Era hybrids when no N was applied. Similarly, ΔGY_N indicates differences in N-fertilized yield.

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Research Notes

Agriculture: Sustainable Crop and Animal Production to Help Mitigate Nitrous Oxide Emissions

Nitrous oxide (N_2O), a potent greenhouse gas, is emitted from many natural and human activities; including from the soil following nitrogen (N) application. This article discusses several options to reduce N_2O emissions from agricultural fertilizer N use at the field scale.

Improved Efficiency Reduces N_2O Losses

Improving the crop recovery of N fertilizer helps reduce residual soil N that is susceptible to conversion to N_2O or losses through nitrate leaching. Research has confirmed that proper fertilizer management practices can provide reduced N_2O losses, which are generally small until the optimum fertilizer N rate is significantly exceeded.

Enhanced Efficiency Fertilizers

Several coated N fertilizers may significantly reduce N_2O emissions, while some N fertilizer treated with additives (e.g., nitrification inhibitors) have more consistently reduced N_2O emissions when compared with standard N fertilizers, in a variety of soil conditions.

Crop Sensors

Use of optical crop N sensors allows farmers to better match fertilization with crop N needs, and often results in improved fertilizer N efficiency and farmer profitability. One recent study on corn reported that sensor use could save farmers 10 to 50 kg of N/ha. A citrus fertilization study showed that optical sensors resulted in 40% less fertilizer N use, >60% less nitrate leaching, and improved profitability compared with traditional N practices.

Winter Cover Crops

Winter cover crops help protect soil from erosion, build soil organic matter, and capture residual soil nitrate. In some soils, cover crops stimulate N_2O emissions, due to the release of soluble carbon and N from decaying cover crop residues. In other situations, cover crops prevent N losses and lower N_2O emissions. There are many specific site factors that determine the effectiveness of cover cropping practices.

Summary

The quandary of producing 50% more food by 2050 while protecting environmental quality and minimizing N_2O emissions rests with both demand-side measures (such as dietary choices and reducing food waste), and implementing improved farmer 4R fertilizer practices. These important goals can be met through proper education, research, and supportive policies. BC

Adapted from: Snyder, C.S., E.A. Davidson, P. Smith, and R.T. Venterea. 2014. Agriculture: sustainable crop and animal production to help mitigate nitrous oxide emissions. Curr. Opin. Environ. Sustain. 9–10:46–54. (OPEN ACCESS) http://dx.doi.org/10.1016/j.cosust.2014.07.005

The Efficient Use of Phosphorus in Agriculture

By Johnny Johnston, Paul Fixen and Paul Poulton

Data from vastly different soils located on two continents, and from both controlled experiments in England and derived state-wide aggregated data in the U.S., were merged to evaluate P use efficiency. The data suggest that there is an underlying "simple rule" for the behaviour of plant-available soil P in these soils, which can be related to a four-pools concept of inorganic soil P.

Phosphorus is an essential, irreplaceable element in all living organisms, and the global resource of readily-minable phosphate rock (PR) is limited. After processing, more than 80% of the PR mined annually is used in food production. Thus, extending the life span of this global resource will depend on using P more efficiently in agriculture; especially since P use will increase as the world's expanding population has to be fed. The inefficient use of P in agriculture has a direct cost to farmers.

Behavior of Soil and Fertilizer P

As a contribution to improving P use efficiency in agriculture, Syers et al. (2008) reviewed the current understanding of the behaviour of soil and fertilizer P and showed that the long-held view that P was irreversibly fixed in most soils was not supportable. These authors proposed that plant-available, inorganic P in soil could be considered to be in four pools related to the availability for uptake by roots and its extractability by reagents used in soil analysis (**Figure 1**). The first two pools are the soil solution P (pool 1, a very small amount) and the readily plant-available P (pool 2). These two pools are only a small proportion of the total P in soil, but the amount can be determined by acceptable, widely used methods for routine soil analysis.

The availability and extractability of P in the four pools is largely determined by the nature and strength of the bonding between the inorganic P and the soil constituents on which it is held. The important feature shown in **Figure 1** is the reversible transfer of P among the first three pools as discussed in detail with examples by Syers et al. (2008). Developed from this concept, there is a critical level of plant-available P in pools 1 and 2 below which optimum crop yield is not achieved and above which there is no need to apply P (i.e., such P is used inefficiently).

Abbreviations and notes: P = phosphorus.

Efficiency of Fertilizer P Use

The direct determination of the amount of P taken up from an added fertilizer can only be done using ^{32}P-labelled fertilizer, which is expensive and has a short half-life. Consequently, the recovery of added P has been more commonly determined by the difference method:

$$(U_p - U_o)/F_p$$

where U_p and U_o are the P taken up by a crop from soils with (U_p) and without (U_o) added P and F_p is the amount of P applied, expressed as a percentage.

Often referred to as percent use efficiency, reported values are often 10 to 15% and rarely exceed 25%. Such small values are used to imply that applied P is used inefficiently.

If only a small amount of P in a crop has come directly from P applied as fertilizer or manure then the remainder must have come from soil P reserves, which might be naturally occurring or as accumulated P residues from past applications of fertilizer or manure. Syers et al. (2008) suggested that replacing the P taken up from the soil P reserve was equally as efficient a way of using freshly applied P as was that taken up directly from fertilizer by the crop. The concept is based on the observation that for many soils when P inputs are at a level similar to the amount of P removed in crop harvest, the sum of pools 1 and 2 in **Figure 1** remains constant. Thus, the P removal-to-input ratio, sometimes referred to as partial nutrient balance, is a useful metric of P efficiency, especially when combined with data on plant-available soil P.

Efficiency of Fertilizer P Use on Soils at the Critical Level of Plant-available P

The efficiency of P inputs can often exceed 80%, calculated as a P removal-to-input ratio, when P is applied to maintain the critical level of soil P. In an experiment on a silty clay loam at Rothamsted, Great Britain, a "maintenance" P application (20 kg P/ha each autumn for four years) was tested on soils

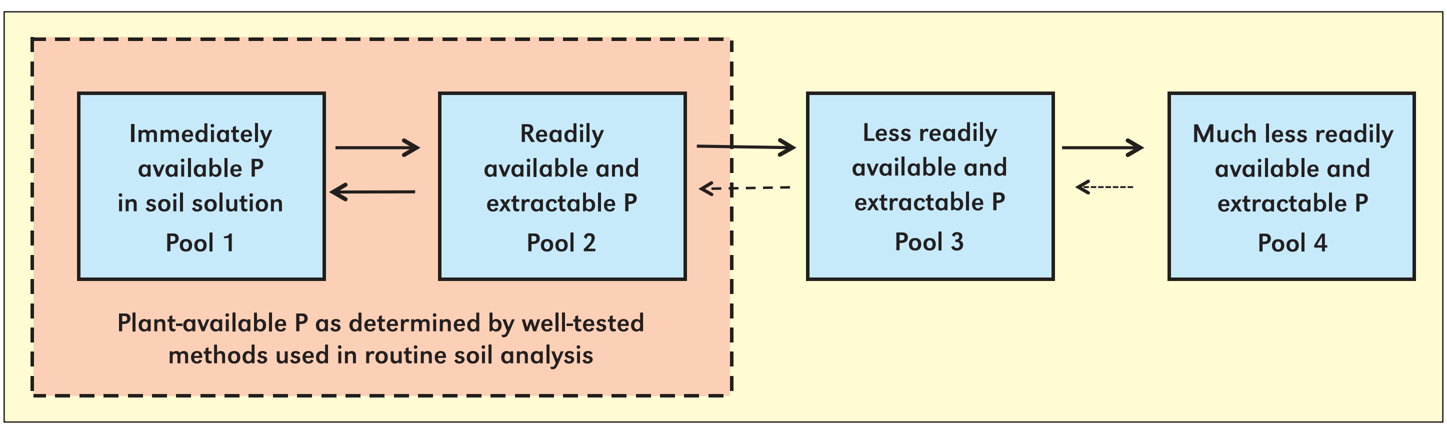

Figure 1. Conceptual diagram for the forms of inorganic P in soils categorized in terms of plant availability and extractability.

growing winter wheat and with plant-available P (extractable with Olsen's reagent; Olsen P) ranging from 9 to 31 mg/kg. The average annual grain yield and the total P removed in grain plus straw increased as Olsen P increased; thus the P balance declined. Where yields were near maximum, and P offtake more nearly matched the amount of P applied, then P-use efficiency exceeded 90% when calculated as a removal-to-input ratio (**Table 1**). Similar experiments showing maintenance of the critical level of plant-available P by replacing that removed in the harvested crop were reported by McCollum (1991) and Halvorson and Black (1985).

Table 1. Maintaining Olsen P by replacing the amount of P removed in four winter wheat crops*, Exhaustion Land, Rothamsted, 2005-2008.

	Olsen P, mg/kg, in 2004***				
	9	14	20	23	31
Average annual grain yield, t/ha	7.6	8.3	8.1	8.5	8.5
Total P applied, kg/ha**	80	80	80	80	80
Total P removed, kg/ha	56	68	66	77	75
Phosphorus balance, kg P/ha	24	12	14	3	5
Olsen P, mg/kg, in 2008***	8	13	18	24	31
P removal-to-input ratio, %	70	85	82	96	94

* Winter wheat grown continuously.
** Phosphorus, 20 kg P/ha applied in autumn.
*** Olsen P in soil sampled in autumn.

Relating P Removal-to-Input Ratios to Changes in Plant-available P in Soil

The ratio of P removed by crop harvest compared to P applied as fertilizer, or recovered from manure, should be related to changes in plant-available P in soil. A ratio of 1 implies that output and input are in balance with probably little change in plant-available soil P. A ratio greater than 1 implies that output exceeds input and soil reserves are being depleted; when soils are at, or below, the critical value this increases the risk of not achieving optimum yield. A ratio of less than 1 (i.e., output is less than input) in most soils should allow soil P to build up. Once the critical level is reached, or slightly exceeded, input should generally be reduced to a maintenance amount.

The International Plant Nutrition Institute (IPNI) uses its Nutrient Use Geographic Information System (NuGIS) (http://www.ipni.net/nugis) to get data on nutrient balances and relate them to changes in the plant-available soil P (Fixen et al., 2010, updated by Fixen, personal communication). For example, the IPNI data for the U.S. Northern Great Plains (**Table 2**) show that where the P removal-to-input ratio for each state approximates to 1 there is little change in the median Bray-1 levels for the 340,000 soil samples submitted to soil testing laboratories from these states for the three sampling years available. The conclusion from the data in **Table 1** (Rothamsted) and **Table 2** (U.S.) is that where the P removal-to-input ratio is about 1,

Table 2. Phosphorus removal-to-input ratio and Bray-1 equivalent levels in three States in the U.S.

	P removal-to-input* ratio			Median Bray-1, mg/kg		
State	2002	2007	Average	2001	2005	2010
Montana	0.97	1.04	1.01	12	14	14
North Dakota	1.07	0.94	1.01	10	11	11
South Dakota	1.02	0.91	0.97	11	14	13

* Input = Fertilizer P applied plus recoverable manure P.
Data derived using IPNI NuGIS data, 1/12/2012, see text.

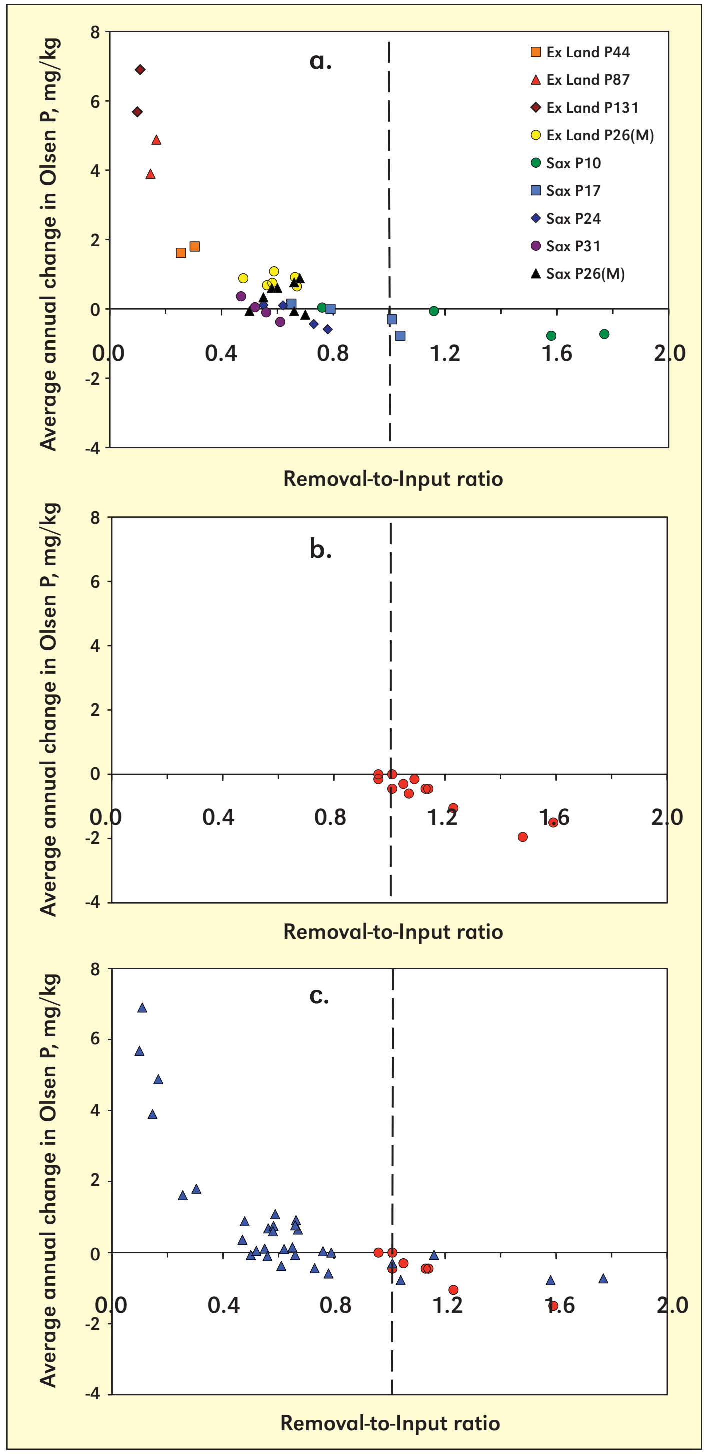

Figure 2. Relationship between the removal-to-input ratio (P removed by the crop divided by fertilizer P inputs) and the change in plant-available P for (a) two long-term experiments in the U.K. [P44 etc. denotes average annual application of fertilizer P; (M) denotes a maintenance dressing]; (b) 12 states in the U.S. (P Fixen, Pers. Comm.); (c) all U.S. ●, and U.K. ▲, data.

and there is little or no change in the level of plant-available soil P then the efficiency of P use is very high as discussed initially by Syers et al. (2008).

Removal-to-input ratios, which are mainly less than 1, and changes in Olsen P in two long-term field experiments at Rothamsted are shown in **Figure 2a**. There is a strong curvilinear relationship that can be fitted with a polynomial function with an r^2 of 0.84.

Figure 2b shows the relationship between P removal-to-input ratios and change in plant-available P for 12 U.S. Corn-Belt States derived using NuGIS. In this case an estimate of "recoverable manure P" is included in the total P input; for this figure, Bray-1 data were converted to Olsen P values by multiplying by 0.75. Although there are uncertainties about the accuracy of individual observations because of the assumptions that have to be made, each point in **Figure 2b** is the average of many individual values, which suggests that it is an acceptable approximation of what is occurring for each state. The data can be fitted with a straight-line function with an r^2 of 0.85. Most of the ratios are greater than 1 (i.e., there was a negative P balance and soil P reserves are being depleted).

Visual inspection of **Figures 2a** and **2b** suggests that there is a degree of commonality, and it is of considerable interest that when both sets of data were put on the same basis they could be combined to produce **Figure 2c**. We have chosen not to show a line through the data points because they can be considered in two ways. First, a log function can be fitted to all the data with an r^2 of 0.84, or second, a lower straight line can be fitted to the soils with small annual inputs of P with an r^2 of 0.63 and another straight line to the six soils to which large amounts of P were added with an r^2 of 0.84. Irrespective of the approach used, this combined graph is for data from vastly different soils and two continents, and from both controlled experiments in England and derived "State-wide" aggregated data in the U.S. That the combined data can be described using a single simple function makes a powerful and convincing statement. It suggests that for the agricultural soils from which these data were obtained, there is an underlying "simple rule" for the behaviour of plant-available soil P, which can be related to the four-pools concept of inorganic soil P proposed by Syers et al. (2008) and discussed in detail by Johnston et al. (2014). BC

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Simulating Potential Growth and Yield of Oil Palm with PALMSIM

By Munir P. Hoffmann, Alba Castaneda Vera, Mark T. van Wijk, Ken E. Giller, Thomas Oberthür, Christopher Donough, Anthony M. Whitbread, and Miles J. Fisher

The growing demand for palm oil can be met by reducing the gap between potential yield and actual yield. Simulation models can quantify potential yield, and therefore indicate the scope for intensification. A relatively simple physiological approach was used to develop PALMSIM, which is a model that simulates, on a monthly time step, the potential growth of oil palm as determined by solar radiation in high rainfall environments. The model was used to map potential yield for Indonesia and Malaysia. This map could be used to identify degraded areas that have high yield potential for oil palm.

Indonesia (6) and Malaysia (4) have 10 million ha under oil palm and between them produce 81% of global production. The average yield for fresh fruit bunches (FFB) in Indonesia is 17 t/ha and in Malaysia is 22 t/ha. The area under oil palm has increased rapidly over the last 20 years, doubling in Indonesia from 2003 to 2011. Demand for palm oil continues to grow, but it could be met by intensifying production in existing plantations.

Some producers have reported average oil yields of 6 t/ha from 27 t/ha FFB over areas up to 150,000 ha, with yields of single blocks (30 to 50 ha) over 40 t/ha. These data are site and year specific, and offer little insight for intensification on a wider basis. Simulation models are a viable way to assess what potential and attainable yields might be (van Ittersum et al., 2013). But the simulation models that are currently available require detailed data to parameterize the model and run the simulations, which limits their usefulness to apply to a wide range of sites. The PALMSIM model simulates the potential growth of oil palm as determined by solar radiation on a monthly time step. PALMSIM was evaluated against measured yields under optimum water and nutrient management across Indonesia and Malaysia to test its usefulness as a land-use planning tool.

Structure of PALMSIM

The model estimates solar radiation for a particular site based on latitude, slope, azimuth, and an index for monthly cloudiness. The general structure of the model is shown in **Figure 1**. It uses the leaf area index, calculated from frond

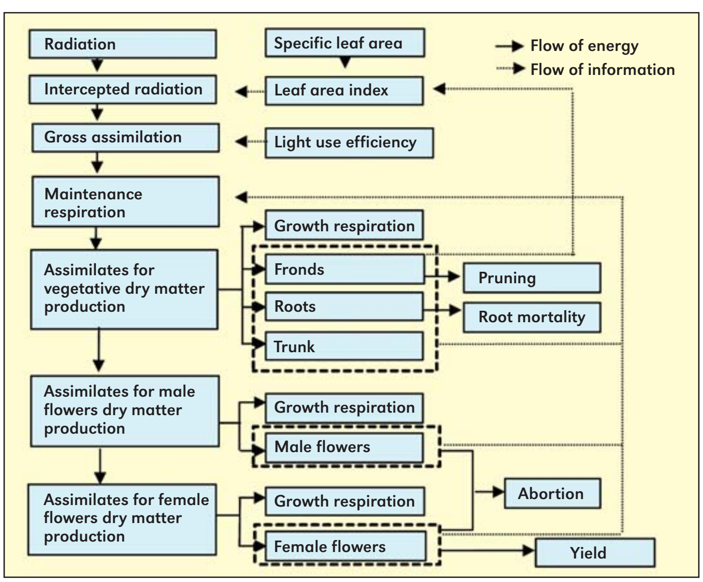

Figure 1. Schematic overview of PALMSIM. Dashed boxes represent standing biomass.

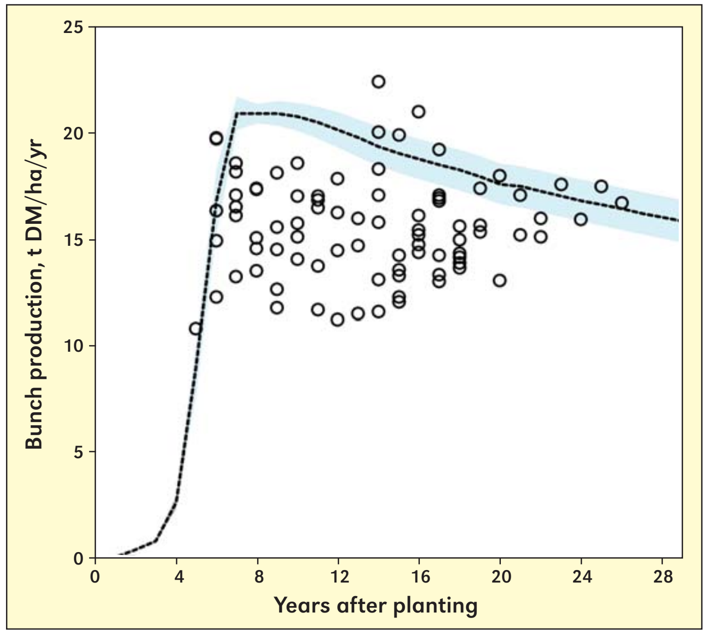

Figure 2. Simulated potential dry bunch weight averaged across all sites (curve) with standard deviation (grey spread) and observed dry bunch weight across sites from fertilizer plots.

mass using a fixed specific leaf area, to estimate the light extinction coefficient and applies a radiation use efficiency factor to the monthly integral of intercepted radiation. Assimilation is discounted by maintenance respiration and is then allocated for growth of fronds (70%), roots (18%), and trunk (12%) then reduced by factors to account for growth respiration. The mass of fronds is reduced by pruning, the amount depending on stand age, and the mass of roots by senescence; trunk mass is not discounted.

An inflorescence is initialized with each new frond, which after 15 months of age differentiates as male or female, the latter declining from 90% in year 4 to 60% in year 15 and onwards. The flowers develop over 18 months when pollination occurs followed by fruit growth for six months and harvest. Abortion of the inflorescence after pollination is assumed to be 10% per month. Bunch production is a function of calculated gross assimilation, that is, it is source limited.

Model Evaluation

PALMSIM was evaluated by comparing simulated yields with data from 15 trials at 13 sites in Malaysia and Indonesia, grown with optimum fertilizer and management and not water limited. Frond yield was available from 46 observations on 9 trials, and fresh bunch and oil yield from 89 observations on 15 trials. Fresh bunches were assumed to be 53% dry matter. Mean monthly cloudiness data from 2001 to 2010 was

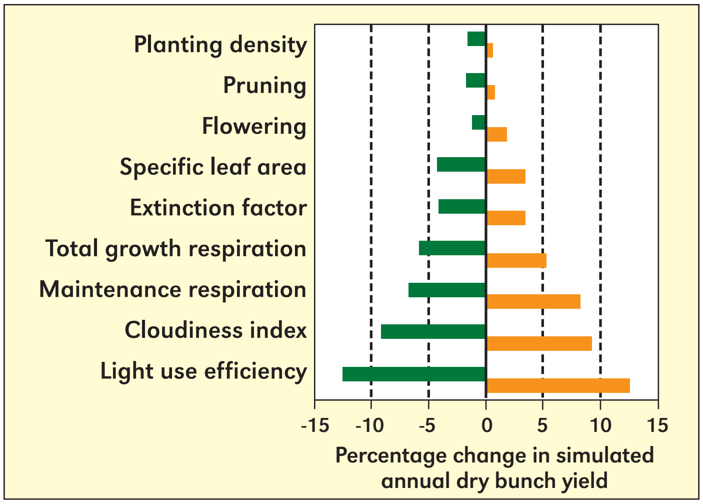

Figure 3. Results of the sensitivity analysis for simulated potential annual dry bunch yield in Sabah. The percentage change in potential yield after increasing or decreasing the value of the parameter along the y-axis with 10% is shown.

extracted from the NASA website. We used root mean square error (RMSE) to assess goodness of fit of the model. A sensitivity analysis was done by adding and subtracting 10% to the default values for 19 physiological, 2 management, and 1 climate parameters.

The PALMSIM model was run for 30 years on a 0.1° grid between 7° N to 6° S latitude and 96° to 129° E longitude, using NASA's mean monthly cloudiness data and digital elevation model, which mapped the simulated FFB yields.

Results

Total palm biomass increased until year 11 and remained constant thereafter. The biomass was initially dominated by fronds, but as the palms matured the trunk became dominant, as might be expected. Production of biomass remained constant after year 11 at 20 t/ha/yr, although fruit production fell as the palms aged. The mean measured yields of 18.5 t/ha/yr compared with 19.3 t/ha/yr for the simulations on palms 7 to 20 years after planting (**Figure 2**). The RMSE for the maximum observed yields and the corresponding predicted values for 12 sites was 1.7 t/ha/yr (8.75%).

The sensitivity analysis (**Figure 3**) showed that the most critical factor was light use efficiency with a 10% change reducing or increasing yield by 12%. Modifying the external driver of cloudiness index changed yield by 9%, while changing respiration changed yield by a little over 5%. Changing specific leaf area and the extinction coefficient gave about 3% change in predicted yield. Modifying flower development had little effect on predicted yield, while changing the agronomic factors of pruning and planting density had almost no effect.

Simulated yields were highest on the coastal plains of eastern and southeastern Sumatra and South Kalimantan Indonesia and Malaysia (**Figure 4**) with FFB yields of 36 to 48 t/ha/yr. Simulated yields were only 9 to 15 t/ha/yr in the mountainous areas of north-eastern Borneo, northern Sumatra and the central peninsular of Malaysia. The differences were largely due to differences in cloudiness.

Conclusions

PALMSIM is a relatively robust simple model that simulates well the potential growth and yield of oil palm across Malaysia and Indonesia. Combining it with maps of soil and land degradation could support the selection of potential new sites for plantations of oil palm. Further development of the PALMSIM model should include the effects of water stress on biomass production and yield of FFB. BC

This paper is a summary of the author's paper published in Agricultural Systems 131 (2014) 1–10.

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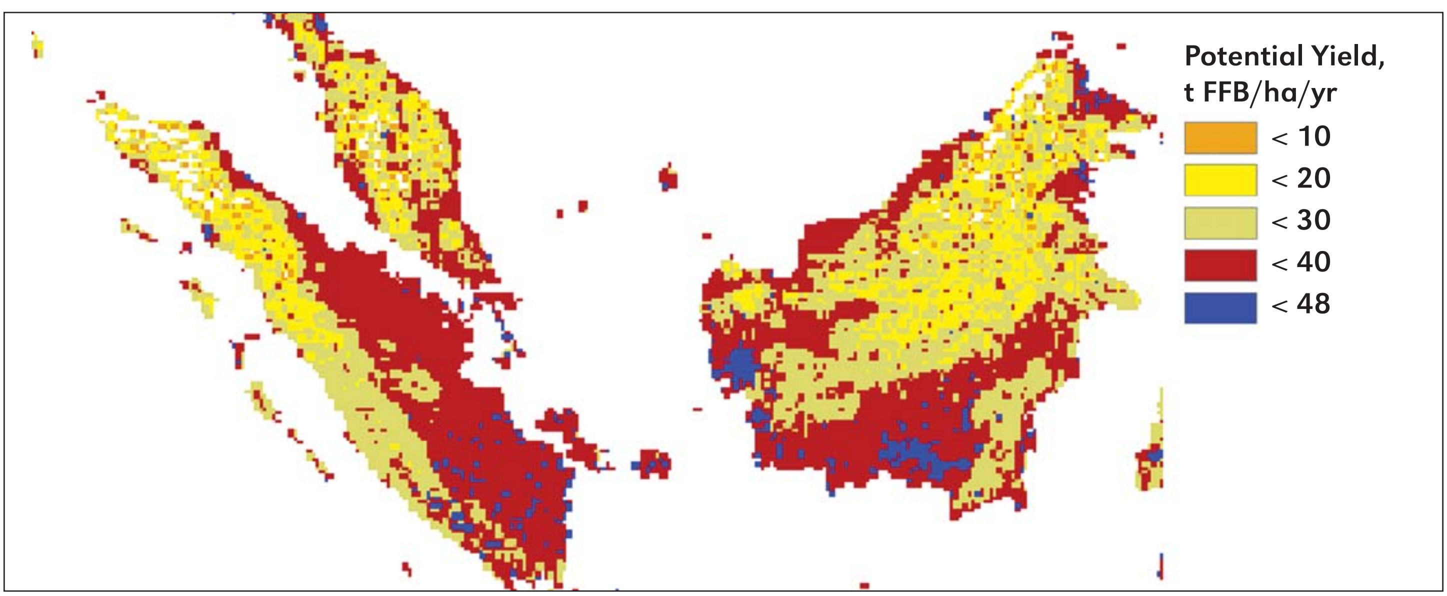


Figure 4. Potential yield (t FFB/ha/yr) map of the main oil palm regions in Indonesia and Malaysia based on simulation runs of the PALMSIM model. Simulation runs take into account incoming solar radiation, but ignore other limitations.

Nutrient Expert Improves Maize Yields while Balancing Fertilizer Use

By Vishal B. Shahi, Sudarshan K. Dutta, Kaushik Majumdar, T. Satyanarayana, and Adrian Johnston

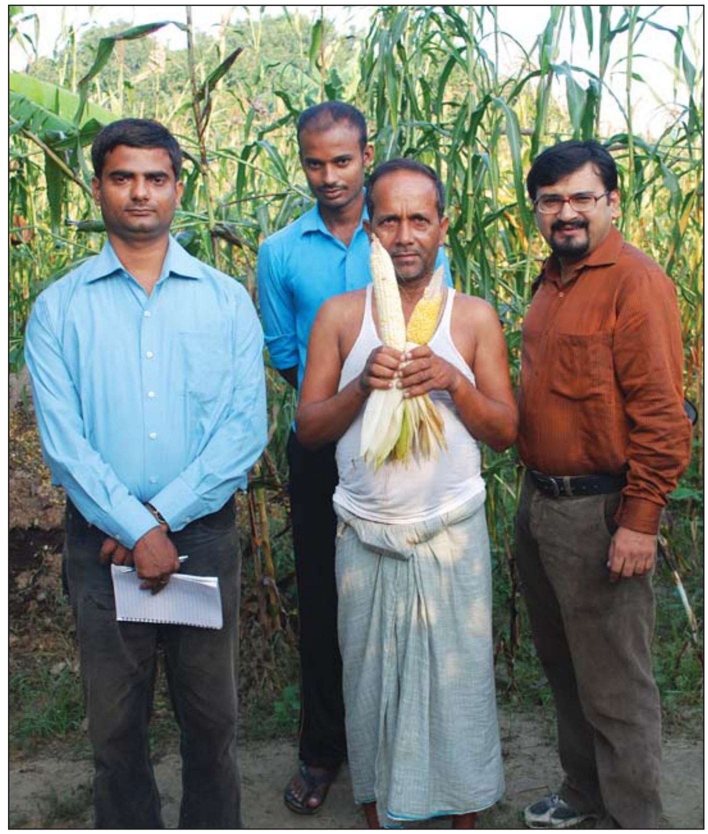
Nutrient Expert® (NE) is a simple and rapid tool for generating field-specific fertilizer recommendations. Results from 17 on-farm sites in five districts of Bihar showed that NE significantly increased maize yields and economic returns compared to the generalized State Recommendation (SR) and Farmers' Fertilization Practice (FFP). NE's impact on fertilizer use in maize shifted N and K application upwards while also lowering P application rates.

Bihar is one of the predominant maize-growing states in India as it produces about 9% of the country's total. But average maize yields in the state are much lower than their potential. One of the reasons for low maize yields is the lack of appropriate and balanced nutrient management strategies, especially for the recently introduced maize hybrids. Existing fertilizer recommendations in the state are also homogeneous in nature—prescribing a single rate of fertilizer for large areas without giving consideration to the variability in soil fertility that exists across farmers' fields. This has led to unsustainable use of fertilizer and the associated economic and environmental concerns. Fertilizer is a critical input in maize production, and its rational use is expected to improve productivity and economics of production while reducing the environmental footprint.

The principles of SSNM for maize have been integrated into a user-friendly decision support tool called Nutrient Expert® (Pampolino et al., 2012). The tool was developed for the South Asia Program of the International Plant Nutrition Institute (IPNI) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT) to facilitate large-scale implementation of SSNM in farmers' fields. The software configuration is described in detail by Xu et al. (2014). The tool starts by asking a few simple questions to determine attainable yield and yield responses to fertilizer. It can work with or without soil testing, and can provide field-specific nutrient recommendation to millions of smallholder farmers who might not have access to soil testing, especially for multiple cropping systems. The tool integrates 4R Nutrient Stewardship principles (i.e., ensuring the right source is applied at the right rate, right time, and right place) into a fertilizer recommendation and suggests different levels of application rates based on varying target yields as well as growing environments. More importantly, it considers the environmental, economic and agronomic benefits simultaneously.

The performance of Nutrient Expert (NE) was evaluated in Bihar State by comparing its results against the SR and FFP. These on-farm experiments examined grain yield, economic returns, and NPK fertilizer use in 17 farmers' fields across five districts (Samastipur, Patna, Begusarai, Jamui, and Purnia) with winter maize during 2011 to 2012. The individual treatment plot size was 100 m^2 or higher. The SR treatment included uniform application of 120-60-40 kg N-P_2O_5-K_2O/ha. Farmers chose hybrid maize varieties with yield potentials above 5 t/ha. The seed rate for all treatments was chosen to maintain a planting density of 65,000 to 85,000 plants/ha. Similar water management and plant protection measures were adopted for all treatments at each site. At harvest, the sampling area (located within the middle part of the plot) was selected randomly in each treatment plot to determine grain yield. Grain yields from all treatment plots were calculated at 15.5% moisture content.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; SSNM = site-specific nutrient management; 1₹ = US$61. Project #IPNI-2010-IND-509



Bihar farmer (center) demonstrates dramatic improvement in maize yield resulting from Nutrient Expert recommendation. Dr. Shahi is pictured on the farmer's right and Dr. Dutta is standing on the farmer's left.

The Impact of NE on Maize

Results suggested that both grain yield and the total biomass yield in NE-based fertilizer recommendation plots were significantly higher compared to SR and FFP treatments (**Figure 1**). The average grain yields were 8, 7.4 and 6.9 t/ha in NE, SR and FFP plots, respectively, which indicated a 10 to 15% increase in maize grain yield when using NE. Xu et al. (2014) achieved similar results in more than 400 on-farm trials conducted throughout China.

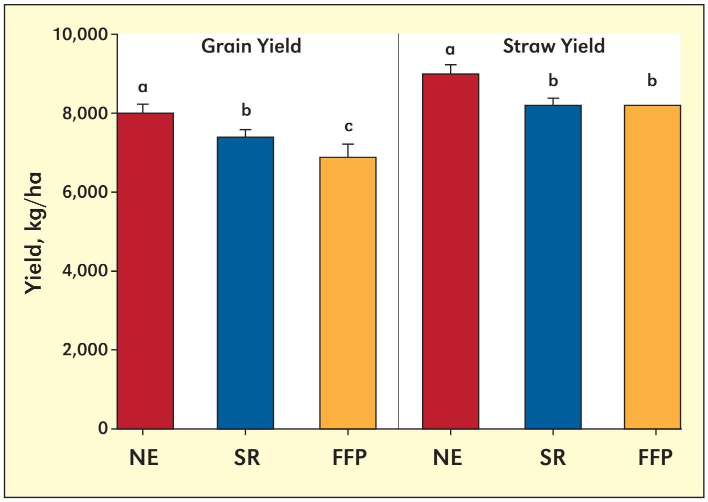


Figure 1. Average (n =17) grain and straw yields of maize in Nutrient Expert (NE), State Fertilizer Recommendation (SR) and Farmer Fertilization Practice (FFP) treatment plots. Yield component numbers with different letters are significantly different at $p \leq 0.001$.

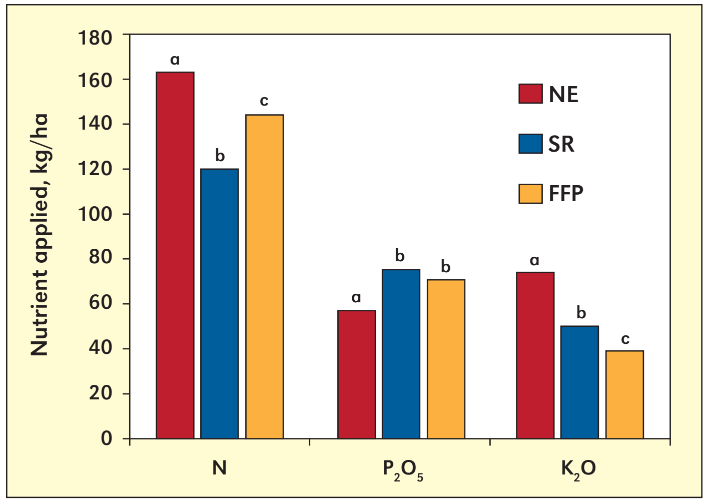


Figure 2. Average (n =17) N, P_2O_5 and K_2O applied in Nutrient Expert (NE), State Fertilizer Recommendation (SR) and Farmer Fertilization Practice (FFP) treatment plots. Numbers within each nutrient with different letters are significantly different at $p \leq 0.05$.

Table 1. Average economic return to farmers' resulting from fertilization.

Nutrient Expert	State recommendation	Farmer's practice
Gross return on investment, ₹		
14a	13b	13b
Net return on investment, ₹		
13a	12b	12b

2011/12 Costs/Prices: Urea = ₹12/kg N, SSP = ₹45/kg P_2O_5, KCl = ₹27/kg K_2O, Price of maize grain: ₹11/kg.
Numbers within rows with different letters are significantly different at $p \leq 0.07$.

Similar to grain yield increases, NE plots showed significant increase in gross returns over fertilizer cost compared to SR and FFP treatment plots (**Table 1**). Also, there was either no change or no significant increase in farmers' fertilization cost in NE plots compared to SR and FFP plots.

The average recommended N and K_2O were significantly higher with NE, while the average recommended P_2O_5 was significantly lower, compared to SR and FFP (**Figure 2**). Fertilizer N application in FFP ranged from 105 to 188 kg/ha, with an average of 144 kg/ha across different trial sites. Similarly, P_2O_5 application rates in FFP ranged from 39 to 147 kg/ha, with an average of 71 kg/ha, while K_2O application rates varied from 0 to 107 kg/ha, with an average value of 39 kg/ha. The NE-based fertilizer recommendation suggested an N application range between 130 and 190 kg/ha, P_2O_5 application between 44 and 64 kg/ha and K_2O application between 55 and 105 kg/ha, with average values being 163-57-74 kg N-P_2O_5-K_2O/ha. The ranges of nutrient application rates narrowed with NE compared to FFP, which suggested that NE was able to better manage the variability in growing environments in Bihar and can therefore be a reliable tool for site-specific fertilizer application.

Summary

Nutrient Expert enables farmers to dynamically adjust fertilizer application rates based on crop requirement, growing environment, and target yield in their fields, which resulted in better maize yields and economic returns in Bihar, while also balancing fertilizer use compared to FFP and SR. We expect that the user-friendliness of NE and its robust estimation of site-specific nutrient recommendation will be attractive to Bihar extension specialists working with its 1.5 million farmers and their intensively cultivated maize areas. BC

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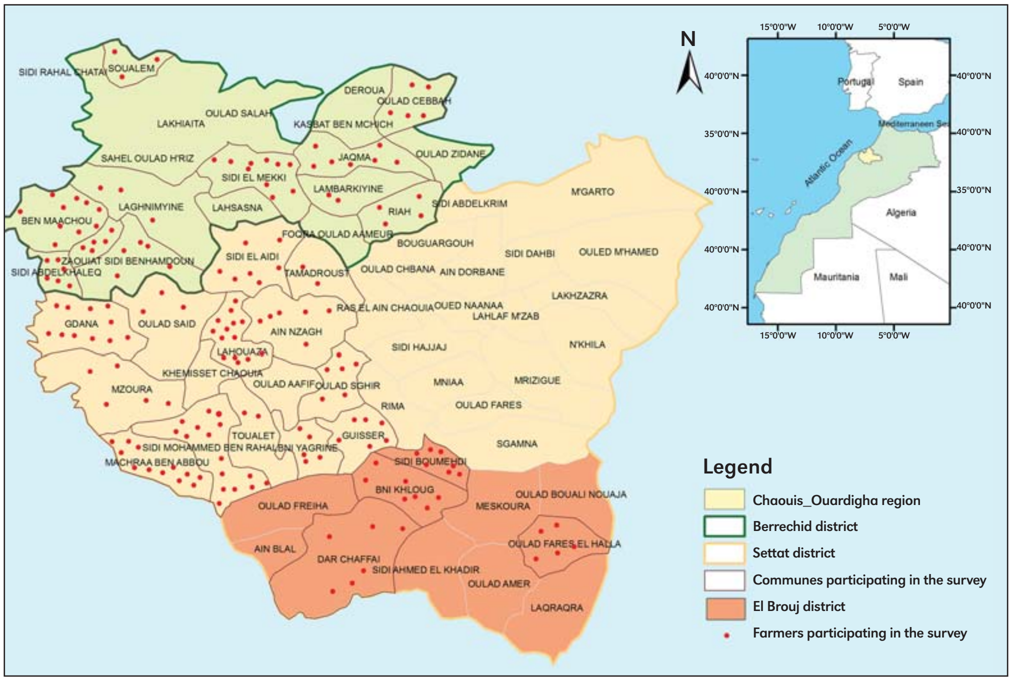
Fertilizer Use Patterns in the Semi-arid, Cereal Producing Region of Chaouia

By Zhor Abail, Oumaima Iben Halima, Hakim Boulal, and Mohamed El Gharous

Fertilizer use in Morocco must increase to ensure that soil nutrients are being replenished and to help reverse the current trends of low crop productivity and land degradation. The role of the agricultural extension centers in making fertilization-related advice needs to be improved drastically to help in promoting best management practices.

Morocco is among the Mediterranean countries where agriculture plays an important role. Agriculture contributes about 15% to the gross national product and employs almost half of the active population. The arable land represents 21% of the total area of Morocco. Over 85% of the arable land is located in rainfed areas, where wheat and barley are the primary crops grown. The best management practices adapted to low rainfall area including variety selection, fertilization, and weed and pest management have contributed to mitigate the negative effects of drought.



Locations of the surveyed farmers in Chaouia region at the districts of Berrechid, Settat and El Brouj, Morocco.

While soil fertility research conducted in Morocco has played a major role in the improvement of knowledge about the fertility status of Moroccan soils, and has provided a rational basis for fertilizer use in the field, the impact at the farm level is still far from satisfactory in terms of fertilizer application and yield increases. Several on-farm trials conducted in the semi-arid areas of North Africa showed that the use of fertilizers is highly profitable for wheat production (Soltanpour et al., 1987) and significantly improved grain yields (Shroyer et al., 1990; Cossani et al., 2011). This diagnostic study was conducted with the objective of providing an overview of fertilizer use in one of the most important cereal production areas of Morocco.

The study was conducted in the summer of 2013 in Chaouia region, which is located in the central part of Morocco. In general, the soils of Chaouia are characterized by high contents of Ca and calcium carbonates and are rich in clay. The soils have poor physical and structural properties and are low in organic matter. The main cultivated crops are barley and wheat with a cropping system of one crop per year, or two crops in three years. Crop rotations are either continuous cereals or cereals (wheat or barley) in rotation with fallow, food legumes, forage, or spring crops such as chickpea. Wheat–fallow is, however, the dominant cropping system. Most farmers integrate livestock into their cropping system, which becomes quite important as the quality of soils and annual rainfall decrease. Beyond the social and economic considerations, the cropping system is dictated by average annual rainfall, soil quality and water storage capacity.

For the survey, a sample of 179 farmers was randomly selected from the districts of Berrechid, Settat and El Brouj. These districts provide a range of crop production potential (Berrechid - high, Settat - intermediate, and El Brouj - low). Berrechid district is characterized by the dominance of wheat, productive soils (vertisols, vertic calcixerolls) and a good annual rainfall between 350 to 400 mm. Settat district is characterized by the dominance of wheat and an average rainfall of about 350 mm. El Brouj district is characterized by the dominance of barley, marginal soils, and an average rainfall of less than 300 mm.

The selection of farmers was done in collaboration with regional extension centers within each district. This sample size was designed in order to achieve a representative sample for the Chaouia region and to represent major farming systems and sizes. Thus, 46 farmers were interviewed in Berrechid, 81 farmers in Settat and 27 farmers in El Brouj.

On average 90% of the agricultural lands that belong to surveyed farmers were rainfed, which generally represents the characteristics of the Chaouia region. The most common farmers are smallholders (land area <10 ha) representing 66% of the total surveyed and with an average land area of 5.6 ha (**Table 1**). The main cropping pattern is cereals (wheat and/or barley) grown as a monocrop or in rotation. According to the survey, cereals/cereals/food legumes and cereals/fallow rotations are the dominant cropping systems. The historically

Abbreviations and notes: Ca = calcium; DAP = diammonium phosphate.

Table 1. Distribution of surveyed farmers under different farm size at three districts.

Farm size, ha	Berrechid	Settat	El Brouj	Total %
< 10	63	67	67	66
10-20	22	19	20	20
20-50	11	11	10	10
> 50	4	4	4	4

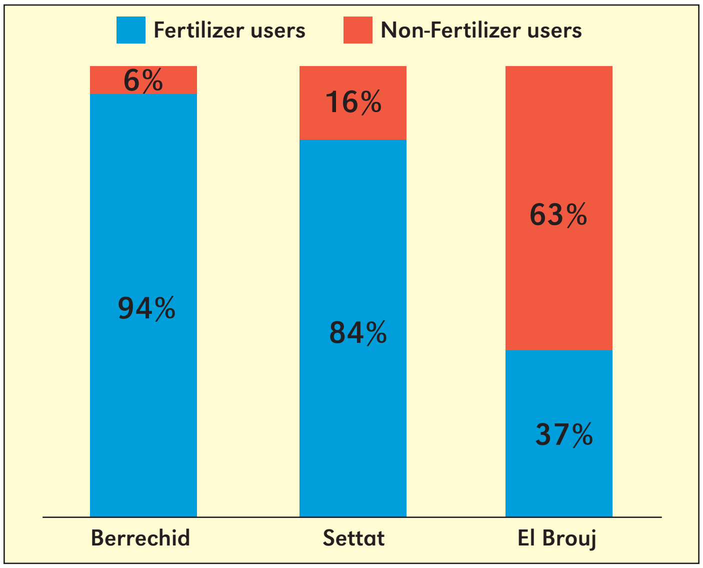


Figure 1. Proportion of fertilizer users and non-users in Berrechid, Settat and El Brouj districts.

important cereals/food legume rotation, which is now only practiced by 6% of surveyed farmers, was reported by farmers to be less popular due to high costs of manual labor required for weeding and harvest operations. Wheat is the predominant crop within Settat and Berrechid, while barley was more dominant in El Brouj.

Fertilizer Use by Farmer Types

Results of the survey showed that 79% of respondents had used fertilizers on at least one crop. There were, however, some variations between districts. A high percentage of fertilizer users (94%) are located in the favorable region (Berrechid), while in the less favorable region (El Brouj), the percentage of fertilizer users was less than 40% (**Figure 1**). Decreased fertilizer use is often associated with the economic risks of high probability of drought.

The choice of fertilizers and their rate of application by farmers were based on four main factors (i.e., previous experience, advice from dealers, advice of neighbors, and advice from the extension services). About 65% of farmers in Berrechid and El Brouj reported that their management of fertilizers was based on their past experience, while 65% farmers in Settat reported that their neighbors had the most significant influence. The role of agricultural extension centers in fertilizer advice was mentioned by less than 25% of farmers. Despite the fact that soil tests are subsidized by about 50%, only 25% of the respondents reported using soil testing once, and just over 50% of farms used soil testing for the first time during the 2012-13 cropping season. Only 5% of farms reported frequent use of soil testing (i.e., at least once every two years) all of which

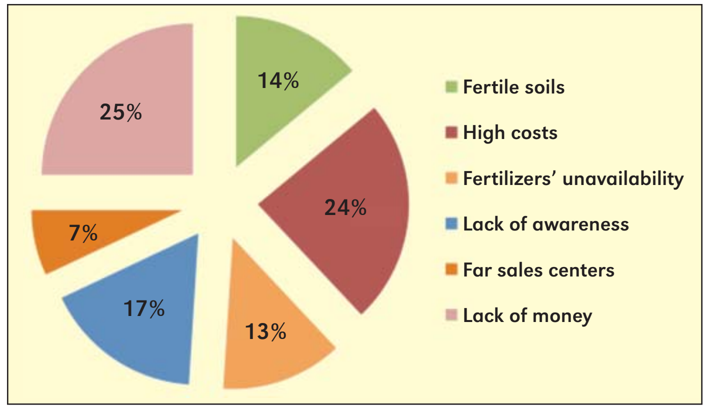


Figure 2. Main constraints expressed by non-fertilizer users (% of farmers) in Chaouia region.

were mainly large farms (> 20 ha).

In the survey, three groups of non-fertilizer users were identified (**Figure 2**). The first group, which represents 49% of non-users, reported that the high cost of fertilizers and lack of money were their main constraints. The second group, who represented 20% of non-users, revealed limited to no availability of fertilizers and a remoteness from fertilizer sale centers as their main constraints. The third group reported a complete lack of awareness on the use and benefits of fertilizers. Farmers in this second and the third group expressed willingness to use fertilizers based on easy access to a dealer and improved awareness on fertilizer use. High prices of fertilizers, as cited by many farmers, are also a challenge to increasing crop production on smallholder farms.

Fertilizer Use By Crops

The survey found that farmers using fertilizers were confident in receiving a return on their investment. However, about 75% of wheat growers, and only 36% of barley growers, use fertilizers. Only 35% of wheat growers used fertilizers in El Brouj region compared to 86% in Settat, and 100% in El Berrechid (**Figure 3**). Fertilizer use in barley was comparably low with 23 to 69% of growers across the Chaouia choosing the apply any fertilizer.

In wheat and barley, a high percentage of farmers use N and P fertilizers at planting time, and topdress N at later stages. The most favorable rainfall district of Berrechid receives 50 to 200 kg/ha of fertilizer applied at planting to wheat and barley, with 89% of wheat growers using 100 to 200 kg/ha applied mainly as DAP (**Table 2**). This decreases to 72% in the Settat region. In El Brouj, only 10% of wheat growers use fertilizer at planting between 50 to 100 kg/ha. DAP is also widely used in wheat at planting time in all three districts. The availability of DAP and its low price in Moroccan market increases its use by wheat growers. In barley, where the proportion of non-fertilizer users is higher, farmers use less than 100 kg/ha of fertilizers.

At topdressing, more than 50% of wheat growers use less than 100 kg/ha of fertilizers (**Table 3**). A large proportion of farmers (45%) were using higher amounts of fertilizer at topdressing in Berrechid, while in El Brouj only 30% use rates between 50 to 150 kg/ha. Barley growers use lower rates of fertilizer at topdressing, with more than 90% of them using less than 100 kg/ha of fertilizers. For both wheat and barley, ammonium nitrate is the predominant topdress fertilizer followed by urea. In a few situations, ammonium sulfate can also be used.

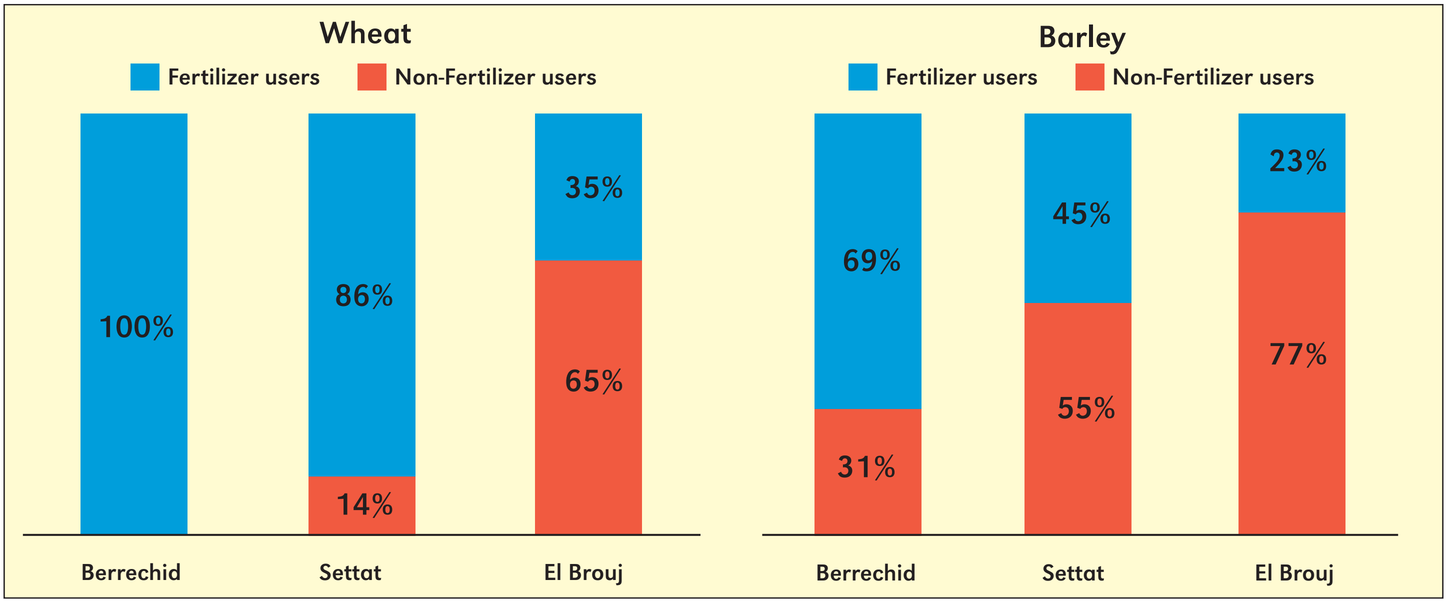


Figure 3. Proportion of fertilizer users and non users among the wheat and barley' growers in Berrechid, Settat and El Brouj districts.

Summary

About 79% of farmers presently use fertilizers in the Chaouia region of Morocco. However, fertilizer use decreases when rainfall decreases or when barley is the main cultivated crop. Even if farmers are willing to use fertilizers to increase crop production, their experience in fertilizer management is largely based on their self-experiences. The role of the agricultural extension centers in making fertilization-related advice needs to be improved drastically to help in promoting fertilizer best management practices in the semi-arid region of Morocco. Also, the overall fertilizer use in Morocco must increase in order to ensure that soil nutrients are being replenished and to help reverse the current trends of low crop productivity and land degradation.

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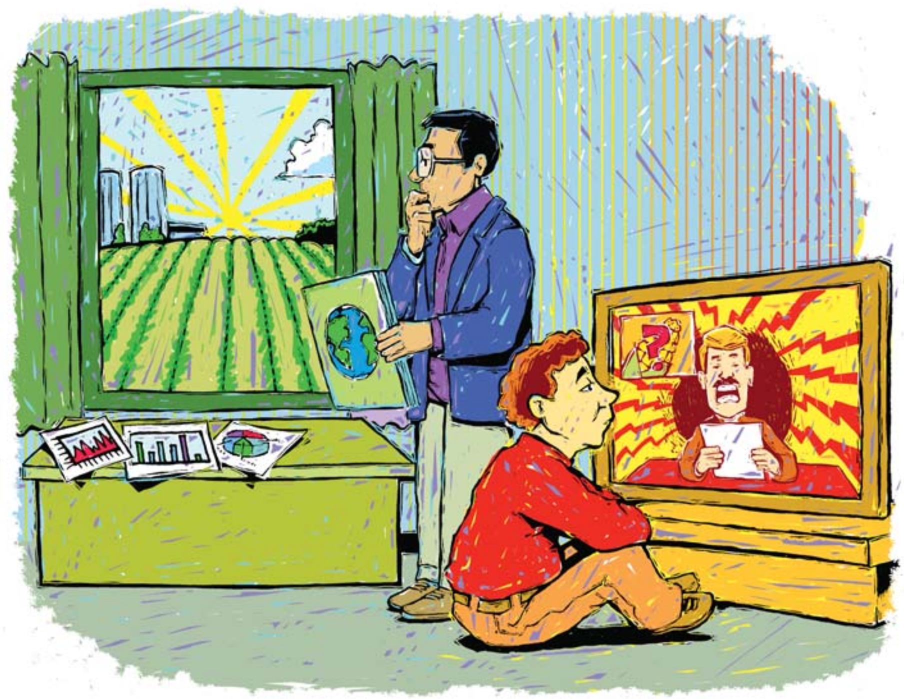
Table 2. Percentage of fertilizer users based on fertilizer rates and sources used in wheat and barley at planting time in Berrechid, Settat and El Brouj districts.

	---------- Wheat ----------			---------- Barley ----------		
Rate, kg/ha	Berrechid	Settat	El Brouj	Berrechid	Settat	El Brouj
0	9%	20%	89%	40%	60%	95%
50	2%	8%	6%	4%	10%	5%
100	35%	23%	4%	28%	17%	-
150	28%	35%	-	12%	10%	-
200	26%	14%	-	16%	3%	-
	---------- Wheat ----------			---------- Barley ----------		
Source	Berrechid	Settat	El Brouj	Berrechid	Settat	El Brouj
DAP	51%	80%	50%	55%	82%	
Am. Sulfate	11%	12%	25%	19%	5%	100%
14-28-14	29%	7%	-	26%	5%	-
17-16-12	8%	-	-	-	-	-
Others	1%	1%	25%	-	8	-

Table 3. Percentage of fertilizer users based on fertilizer rates and sources used to topdress wheat and barley in Berrechid, Settat and El Brouj districts.

	---------- Wheat ----------			---------- Barley ----------		
Rate, kg/ha	Berrechid	Settat	El Brouj	Berrechid	Settat	El Brouj
0	20%	31%	70%	43%	78%	83%
50 to 100	35%	43%	17%	50%	18%	17%
100 to 150	37%	24%	13%	7%	4%	-
150 to 200	8%	2%	-	-	-	-
	---------- Wheat ----------			---------- Barley ----------		
Source	Berrechid	Settat	El Brouj	Berrechid	Settat	El Brouj
Am. Nitrate	64%	72%	57%	63%	62%	75%
Am. Sulfate	10%	8%	-	25%	-	-
Urea	26%	20%	43%	12%	38%	25%

Perception versus Reality



Perception is the way we think about or understand something. It is derived from our senses—sight, sound, taste, touch, and smell. It is objective. Perspective is how we interpret the things we perceive. It is derived from our emotions, beliefs, attitudes, values, and experiences. It is subjective and influenced by others. If we trust someone, like a role model, or if someone is famous we often take what he or she says at face value.

As an agricultural scientist I struggle with those whose perspective is more influenced by other's opinions than by facts, especially when it comes to the critical role fertilizer plays in global food security. We know that about half the world's food production is possible because of the use of commercial fertilizers, and about half the people who have lived on this earth owe their existence to the use of nitrogen fixed by the Haber-Bosch process. Data, research, and reviews of the published scientific literature tell us this.

My reviewing of scientific papers on fertilizers and crop production, my first-hand observing crop response to fertilization, my seeing crop yields double and triple in the developing world with the application of nitrogen, phosphorus and potassium, my hearing smallholder farmers express their gratitude for access to fertilizer, and numerous other experiences leads to my perception about fertilizers. My background and experience makes me view fertilizers positively. Scientific evidence also tells me that fertilizers used inefficiently or ineffectively can cause problems in our environment. But the evidence also tells me that the good outweighs the bad and the problems are manageable with proper nutrient management.

Why is it that most people's perspectives on fertilizer are negative? I believe they don't see the good they do … only the bad. It's because most people are either unaware or misinformed, or disconnected from the realities of global food production. They have a false perception based on misleading or inaccurate information. Their perception is their reality and that is difficult to change. But, it can be done.

As people get to know and understand the true value of fertilizers, as they understand what our industry is doing with 4R Nutrient Stewardship, and as we gain the public's trust we can change their perspectives. We are going to add another 2.3 billion people to this world in the next 35 years and we are going to have to produce at least 60% more food to feed them. That can't be done without fertilizer and it won't be easy without the public's confidence in our ability to manage fertilizers responsibly.

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