BETTER CROPS
WITH PLANT FOOD

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BETTER CROPS WITH PLANT FOOD

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Our cover: USDA-ARS technicians collecting greenhouse gas sample (front) from strip-till plots near Fort Collins, Colorado

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2012 Scholar Award Recipients Announced by IPNI

The 2012 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected.

"We are very pleased at the growing interest for our Scholar Award competition, which has once again attracted many high quality applicants from a diverse mix of agricultural research centers—this year located in Argentina, Australia, Brazil, China, India, Malaysia, Russia, South Africa, Sri Lanka, Uruguay, and the United States," said Dr. Terry L. Roberts, IPNI President. "Being selected from this group is a great accomplishment that each student should be proud of, as should their advisers, professors, and supporting institutions. Our selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic achievements."

The individual awards of USD 2,000 are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients. The following 24 graduate students (listed by region) were named to receive the IPNI Scholar Award in 2012.

AFRICA

Tesha Mardamootoo

Ms. Tesha Mardamootoo is completing her Ph.D. degree at the **University of the Free State, Bloemfontein, South Africa**. Her dissertation entitled "Developing an index for phosphorus loss from sugarcane soils in Mauritius" aims at integrating source and transport factors to produce a simple decision support tool (the P index) for agronomists, extension officers, or farmers to reliably predict the potential contribution of farm and management practices on eutrophication. The tool will help to identify where beneficial management practices should be targeted to reduce the incidence of accelerated eutrophication. For the future, Ms. Mardamootoo hopes to contribute to the scientific understanding necessary for a better synchrony between agricultural use of nutrients and environmental protection.

AUSTRALIA & NEW ZEALAND

Jian Jin

Mr. Jian Jin is pursing his Ph.D. in Agronomy at **La Trobe University in Melbourne, Australia**. His dissertation is titled "Effect of phosphorus supply on plant P acquisition under elevated CO_2," which aims to investigate the mechanisms of P and CO_2 interaction to devise appropriate strategies for P fertilization of farming systems in response to climate change and variability. With an improved understanding of the rhizosphere processes under elevated CO_2, management of soil quality and crop productivity in farming systems could be optimized and may become more predictable with climate change. Mr. Jin wishes to develop his research capabilities further by studying how legumes physiologically respond to nutrient-deficient soils, and the processes of plant-soil-microbe interactions.

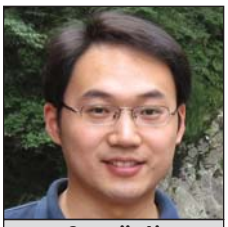
Humaira Sultana

Ms. Humaira Sultana is working toward her Ph.D. degree in Agronomy at **The University of Melbourne in Melbourne, Australia**. Her dissertation title is "Nitrogen fertilizer management–an integrated approach to enhanced efficiency fertilizers." The major objective of this study is to evaluate the management potential of fertilizer related strategies with emphasis on enhanced efficiency fertilizers (EEFs) and related products like urease inhibitors and nitrification inhibitors in both pasture and cropping systems. Since the response mechanism of EEFs is very complex and demands a comprehensive system-based approach, this research combined quantitative analysis, experiments, and modeling to address N related issues in Australian agricultural systems. For the future, Ms. Sultana's goal is to pursue a career in research working on the agronomic management of cropping systems.

CHINA

Weini Wang

Ms. Weini Wang is in a combined M.Sc. - Ph.D. program in plant nutrition at **Huazhong Agricultural University in Wuhan, China**. Her dissertation is titled "Regional evaluation of fertilization effects of nitrogen, phosphorus, potassium and estimating appropriate fertilizer application rates for rice production: A case study of Hubei province." Some objectives of her study include assessing variation in soil fertility among paddy fields, evaluating fertilizer use efficiency of rice, establishing predictors and classification systems of indigenous soil nutrient supply capacity in paddy fields, developing appropriate fertilizer recommendation methods, and estimating optimum fertilizer application rates for rice over large domains. For the future, Ms. Wang intends to continue research and extension efforts to improve crop yields and farmer profits.



Guangjie Li

Mr. Guangjie Li is pursuing his Ph.D. in Molecular Genetics of Plant Nutrition at the **Institute of Soil Science, Chinese Academy of Science in Nanjing, China**. His dissertation title is "Study on the mechanisms of plant's adaptation to high ammonium and low potassium stress by using genetic mutation technique." A native of Jinan, Shandong province, Mr. Guangjie's research is focused on evaluating mechanisms to optimize K absorption efficiency of the plant so as to improve the plant's ability to adapt to high NH_4 conditions resulting from a continuous overuse of N fertilizer on farms. In the future, Mr. Guangjie hopes to be in a faculty position at a leading university and continue research and extension work on plant nutrition.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium, Co = cobalt; Cu = copper; Fe = iron; Mn = manganese; Se = selenium; Zn = zinc; NH_4 = ammonium; CO_2 = carbon dioxide.


Zhanjun Liu

Mr. Zhanjun Liu is working toward a Ph.D. in plant nutrition at the **Graduate School of the Chinese Academy of Agricultural Sciences in Beijing, China**. His research work is on the characteristics and assessment of soil quality of low-yielding paddy soils in South China. The work is aimed at finding out the limiting factors and improving rice yields by determining the scale and distribution of paddy farms, analyzing soil samples for their physical, chemical, and biological properties, and building a database for future use in South China. Mr. Liu's career goal is to become an agricultural scientist to increase crop yields, improve farmer profits, and improve agricultural sustainability.


Yunfeng Peng

Mr. Yunfeng Peng is working on a Ph.D. at **China Agricultural University in Beijing, China**. His dissertation is titled "Effect of nitrogen supplies on root and mineral nitrogen distribution in soil profile and carbon/nitrogen interactions between source and sink of field-grown maize." The main objectives of this study are: (a) comparing root distribution of N efficient and inefficient maize inbred lines in a soil with sufficient N supplies, (b) examining plant N uptake, temporal and spatial distributions of maize roots, and mineral N concentration in the soil profile during whole maize growth period, and (c) investigating allocation and remobilization of carbohydrates and N between leaf and developing ear under field conditions. Mr. Peng's career goal is to become an agricultural scientist to study crop growth responses to nutrient stress and develop new crop management practices to increase crop yields and enhance fertilizer use efficiency.

EASTERN EUROPE & CENTRAL ASIA


Anastasia Dolgodvorova

Ms. Anastasia Dolgodvorova is working towards her M.Sc. degree in Soil Science and Agricultural Chemistry at the **Moscow State University, Moscow, Russia**. It will be completed in 2013. Her research work is titled "Biofortification of cereal grains with selenium." She is studying the effect of foliar application of Se on its accumulation in spring wheat and spring barley plants and interactions with other nutrients in both field and pot experiments. The experimental data obtained in her studies are helpful in recommending the optimal rate of Se to be applied to both cereal crops. For the future, Ms. Dolgodvorova intends to continue her research efforts to improve plant nutrition with micronutrients and especially with Se.


Alina Arginbaeva

Ms. Alina Arginbaeva is working toward her M.Sc. degree in Agricultural Ecology at the **Bashkir State Agrarian University, Ufa, Russia**. It will be completed in 2013. Her research work is titled "Effect of soil tillage methods and fertilizer use on soil fertility of leached chernozem in the Southern forest-steppe of the Republic of Bashkortostan." She is studying the effect of no-till systems and other conservation tillage methods on organic matter and nutrient status in the soil, including available P and K, in the long-term field experiment conducted by the University. The important target of her work is to develop recommendations for both mineral and organic fertilizer use to spring wheat under conservation tillage systems for obtaining high grain yield with high quality. Ms. Arginbaeva plans to start her Ph.D. program on conservation tillage methods at the same university that will allow adjusting such systems to the regional conditions.


Elena Yakovleva

Ms. Elena Yakovleva completed her M.Sc. degree in Agricultural Chemistry and Soil Science at the **Kuban State Agrarian University, Krasnodar, Russia** in July 2012. Her thesis title is "Optimization of mineral nutrition of winter wheat grown on leached chernozem in the Northwestern Caucasus through the use of innovative chelate complexes of micronutrients." The major objective of this study is to evaluate the effect of foliar application of chelate complexes of micronutrients (Mn, Cu, Zn, and Co) and physiologically active organic acids on winter wheat grain yield and its quality. The high efficiency of these new micro-fertilizers was demonstrated in a short-term field experiment. The important results of the study are the recommendations on both rates and time of fertilizer application for obtaining high grain yield with high gluten and protein content. For the future, Ms. Yakovleva's goal is to continue research work on crop nutrition with micronutrients starting a Ph.D. program at the same University.

NORTH AMERICA


Matt Yost

Mr. Matt Yost is working toward his Ph.D. in applied plant sciences at **University of Minnesota in St. Paul, USA**. His research work has consisted of nearly 44 on-farm research experiments where he has investigated the effects of tillage, alfalfa regrowth, manure, K fertility, and residue management on the N fertilizer requirement of corn following alfalfa. He also is conducting a meta-analysis of alfalfa-corn literature and a statewide survey in order to improve the prediction and adoption of alfalfa N credits to corn. For the future, Mr. Yost's goal is to become an agricultural scientist to continue agricultural research, transfer results to users, mentor students, and possibly teach courses.


Tom Bottoms

Mr. Tom Bottoms is pursuing his Ph.D. in horticulture and agronomy at **University of California in Davis, USA**. His dissertation title is "Nitrogen management and remediation for environmental protection in Central Cost lettuce and strawberry production." This research is focused on monitoring current irrigation and fertilization practices in coastal lettuce and strawberry fields across a wide range of production environments to identify practices associated with significant N loss to the environment. Another component of this study is to document crop growth, N uptake, and N cycling patterns in both crops, and use this information as well the results from monitoring surveys to develop efficient crop management templates. Mr. Bottoms has an impressive resume of academic achievements and awards. In the future, Mr. Bottoms intends to serve Swaziland farmers for a couple of years and then work for the agricultural industry to meet grower needs in the US.


Ross Bender

Mr. Ross Bender has just enrolled in a Ph.D. program in crop sciences at **University of Illinois in Urbana-Champaign, USA**. His M.Sc. thesis title was "Nutrient uptake and partitioning in high-yielding corn." The central objective of this study was to quantify nutrient uptake, removal, and partitioning in elite commercial germplasm grown under modern management practices. Other objectives were to evaluate the impact of hybrid background, transgenic insect protection, agronomic management, and location and/or weather differences on these nutrient use parameters. For the future, Mr. Bender wishes to complete his Ph.D. degree for use in fertilizer and/or seed industries and then farm on his family farm.


Ryan Van Roekel

Mr. Ryan Van Roekel is working toward his Ph.D. in agronomy at **University of Arkansas in Fayetteville, USA**. His research is focused on achieving maximum yield of soybean. The primary goal is to work on a farm in southwest Missouri that holds the world's current soybean yield record, establish crop growth physiological characteristics of these crops, and provide a scientific basis for understanding how and if these yield levels are attainable. Close examination of these record-yielding management practices will provide avenues and opportunities to increase soybean yields worldwide through novel management of water, solar radiation, and nutrient resources. Mr. Van Roekel's future goal is to pursue a meaningful research career within the corn or soybean industry.


Yumiko Kanke

Ms. Yumiko Kanke is pursuing her Ph.D. degree in Agronomy and Statistics at **Louisiana State University, Baton Rouge, USA**. Her dissertation is titled "Establishment of remote sensing technology for optimum nitrogen management in rice and sugarcane." Her research work focuses on using spatial and temporal variability through remote sending techniques in modifying the current method of recommending N rates. She is also looking to identify spectral vegetation indices other than normalized difference vegetation index (NDVI) and parameters to characterize sugarcane biomass more effectively with respect to N health status. For the future, Ms. Kanke wants to specialize in sensing technologies and work to improve farm profits.

SOUTH AMERICA


Guillermo A. Divito

Mr. Guillermo A. Divito is pursuing his Ph.D. in Agricultural Sciences at the **Agronomy College of Balcarce, University of Mar del Plata, Argentina**. His dissertation is titled: "Indices of sulfur sufficiency in soybean: physiology basis and fitness." The main aims are to characterize the crop physiology bases that exert control on S demand—mainly those related to crop varieties and sowing date—and to propose and evaluate different plant analysis to determine S sufficiency indices. These indicators of crop S status address the need to improve S fertilizer recommendations, principally when soil test is not an entirely reliable tool yet. For the future, Mr. Divito intends to continue research and extension work on plant nutrition and soil fertility to help optimize fertilizer use.


María Florencia Varela

Ms. María Florencia Varela is working towards her Ph.D. in Agricultural Sciences at the **Agronomy College of the University of Buenos Aires, Argentina**. Her dissertation is titled: "Impact of cover crops on phosphorus dynamics and soil physical properties in the Western Pampas of Argentina." This study aims to evaluate nutrient recycling, mainly P, from residues of different cover crops under soybean-cover crop rotations. Her research provides information about both the release dynamics, as well as the chemical forms in which nutrients are released from crop residues, that are key topics to improve the knowledge about this nutrient source and their use efficiency in a sustainable way. For the future, Ms. Varela hopes to continue linked to soil science and soil fertility teaching and research.


Luciana Paula Di Salvo

Ms. Luciana Paula Di Salvo is completing requirements for her Ph.D. in Microbiology at the **Agronomy College of the University of Buenos Aires**. Her dissertation is titled: "Effect of inoculation with Azospirillum spp. on rhizosphere microbial populations and plant growth in wheat and maize on field conditions." This study focuses on the inoculation with plant growth promotion rhizobacteria (PGPR) and its interaction with fertilizer management (particularly N and P). This research will promote a better understanding of microbial processes related to nutrient dynamics, which is still necessary to achieve better results on strategic crops for human feed. For the future, Ms. Di Salvo's goal is to pursue a career as a scientist working on microbiology, especially on aspects related to crop nutrition.


Agustín Núñez

Mr. Agustín Núñez is pursuing his M.Sc. degree on Agricultural Sciences at the **Agronomy College of the University of the Republic, Montevideo, Uruguay**. His thesis is titled: "Potassium dynamics in agricultural soils." His research work has focused on describing K dynamics in soils of Uruguay, where there are very few studies about this nutrient and its behavior under agricultural systems. To improve the state of knowledge about soil K in his region, he is evaluating plant growth parameters in ryegrass and changes in different soil K pools. He is attempting to analyze soil indices able to provide information about the interaction between soil K reserves and K availability for grain crops. Mr. Núñez wishes to specialize in soil fertility and precision agriculture and his main goal is to become an agricultural scientist.


Rodrigo Coqui da Silva

Mr. Rodrigo Coqui da Silva is pursuing his Ph.D. in Soil and Plant Nutrition at **"Luiz de Queiroz" College of Agriculture, University of São Paulo, Piracicaba, Brazil**. His dissertation is titled "Agronomic effectiveness of phosphate fertilizers varying in water and citrate solubility as influenced by soil pH, P-fixing capacity, and available P." His main goals are to study the use and management of marginal-grade phosphate rock as an acidulated P fertilizer source in the most cost-effective way. Mr. Silva has been a visiting scholar at Kansas State University where he worked on highly developed techniques of evaluating both traditional and potential P fertilizer sources. After his Ph.D. Mr. Silva intends to be involved in research and education, helping to solve practical problems regarding fertilizer use, management, and technology.

SOUTH ASIA


Pardeep Kumar

Mr. Pardeep Kumar is pursuing his Ph.D. in Agronomy at **Punjab Agricultural University in Ludhiana, India**. The focus of his present research is on agronomic biofortification and enhancement of productivity of bread wheat varieties, where he is studying the impact of nutrient management on growth, productivity, and quality of common bread wheat varieties popular in the region, and also the agronomic biofortification of wheat grains by managing N, Zn, Fe, Mn, and Cu at critical phenological stages of wheat through soil and/ or foliar fertilization strategies. In the future, Mr. Kumar wants to continue his research efforts in crop nutrition and do a postdoctoral fellowship in USA.


Ekta Joshi

Ms. Ekta Joshi is working toward a doctorate degree in Agronomy at **Indian Agricultural Research Institute in New Delhi, India**. Her dissertation is titled "Nutrient omission studies in maize-wheat cropping system." The main objectives of her study are to (a) determine indigenous nutrient supplying capacity of soil, (b) develop soil-test based recommendations for N, P, K, and Zn for different yield targets of wheat and maize, (c) determine the effect of omitted nutrients on soil quality and soil microbial population, (d) work out a site-specific nutrient management strategy for the maize-wheat system, (e) develop an apparent soil nutrient balance sheet, and (f) assess the direct, residual, and cumulative effect of omitted nutrients on productivity and profitability of maize and wheat crops and as maize-wheat system. Ms. Joshi hopes to become an agricultural scientist working on soil fertility and soil biology.


Angelene Mariaselvam

Ms. Angelene Mariaselvam is completing requirements for her master of philosophy degree at **University of Peradeniya in Peradeniya, Sri Lanka**. Her thesis title is "Improving a low productive Ultisol soil through fertility enhancement and carbon stocks improvement." This study has two main objectives including the selection of a suitable organic amendment to improve soil carbon stock and developing a beneficial nutrient management practice specific to the area. The work is expected to pave the way for future research on specific nutrient management practices to improve marginal agricultural lands.

SOUTHEAST ASIA


Choon Cheak Sim

Mr. Choon Cheak Sim is working toward his Ph.D. in Plant Nutrition and Soil Science at **Universiti Putra Malaysia in Serdang, Malaysia**. His research is focused on identifying K-efficient oil palm genotypes and studying the physiological mechanisms of K uptake and utilization efficiencies in oil palm genotypes. Information gained from the study will eventually lead to lower dependency on potash fertilizer for palm oil production. Mr. Sim's career goal is to apply his plant nutrition and soil fertility knowledge for sustainable crop production and optimal use of resources.

Funding for the scholar award program is provided through support of IPNI member companies, primary producers of N, P, K, and other fertilizers. The recipients of the IPNI Scholar Award are selected by regional committees of IPNI scientific staff. The awards are presented directly to the students at a preferred location and no specific duties are required of them. Graduate students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. More information is available from IPNI staff, from individual universities, or from the IPNI website: www.ipni.net/awards. BC

Nitrogen Source and Placement Affect Soil Nitrous Oxide Emissions from Irrigated Corn in Colorado

By Ardell D. Halvorson and Stephen J. Del Grosso

Research shows that N fertilizer source affects growing season soil N_2O emissions from irrigated corn systems in Colorado. Use of controlled-release and stabilized N sources reduced N_2O emissions under NT and ST corn production systems up to 66% when compared to commonly used urea and up to 43% compared to UAN. Urease and nitrification inhibitor additions to urea and UAN resulted in significant reductions in N_2O emissions, as did polymer-coated urea. Surface broadcast application of N sources resulted in lower N_2O emissions than surface band applications. Choice of N source and placement can be valid management alternatives for reducing N_2O emissions to the environment in semi-arid areas.

Nitrogen fertilization is essential for optimizing crop yields and economic returns in irrigated cropping systems in the Central Great Plains area of the USA. However, N application generally increases the emissions of the potent greenhouse gas, N_2O, from these systems. Nitrous oxide is produced through nitrification and denitrification processes in the soil. Agriculture contributes approximately 67% of the total anthropogenic N_2O emissions in the USA. Information on how N fertilizer source might affect soil N_2O emissions from semi-arid, irrigated cropping systems is limited. Halvorson et al. (2008, 2009, 2010a, 2010b) showed N rate, N source, tillage, and crop rotation influence N_2O emissions from semi-arid, irrigated cropping systems in northern Colorado.

This article presents a summary of the effects of N source on soil N_2O emissions from studies conducted from 2009 to 2011 within NT and ST irrigated corn systems located near Fort Collins, Colorado on a Fort Collins clay loam soil. Nitrogen rates were 0 and 202 kg N/ha (0 and 180 lb N/A). Nitrogen sources compared to the commonly used granular urea (46% N) and liquid UAN (32% N) included a controlled-release polymer-coated urea (ESN®), stabilized urea and UAN products containing nitrification and urease inhibitors (SuperU and UAN+AgrotainPlus®), and UAN containing a slow release N source (Nfusion®). A subsurface band ESN treatment (ESNssb) was also included. Each N source, except ESNssb, was surface band applied at corn emergence and watered into the soil the next day with a linear move sprinkler irrigation system. Nitrous oxide fluxes were measured two to three times per week during the growing seasons using vented static chambers and a gas chromatograph analyzer (see photos). Details on methodology can be found in Halvorson et al. (2011) and Halvorson and Del Grosso (2012).

Nitrogen Source Effects on N_2O Emissions

Nitrous oxide fluxes increased within days following the application of all N sources except for ESN, which had a delayed release of N_2O. An example of the cumulative change in N_2O flux for several N sources with time during the 2010-growing season for NT is shown in **Figure 1**. Urea and UAN reached 80% of their growing season N_2O emissions 24 and 23 days after N application, respectively. UAN+AgrotainPlus and SuperU reached 80% of their growing season emissions 40 and 46 days, respectively, after N application. Nitrous oxide emissions from ESN and ESNssb followed a different pattern from the other N sources, remaining low until mid-June when N_2O-N fluxes started to increase. The ESNssb and ESN treatments reached 80% of their growing season emissions 65 and 70 days after N application, respectively.

Total cumulative growing season N_2O-N fluxes during the corn growing season are shown in **Figure 2** for ST for all N sources evaluated, plus a blank treatment (no N ap-

Common abbreviations and notes: N = nitrogen; N_2O = nitrous oxide; UAN = urea ammonium nitrate; NT = no-till; ST = strip till.

Dr. Ardell Halvorson (foreground) analyzing gas samples from field plots on a gas chromatograph (photo by S. Ausmus, USDA-ARS photographer).

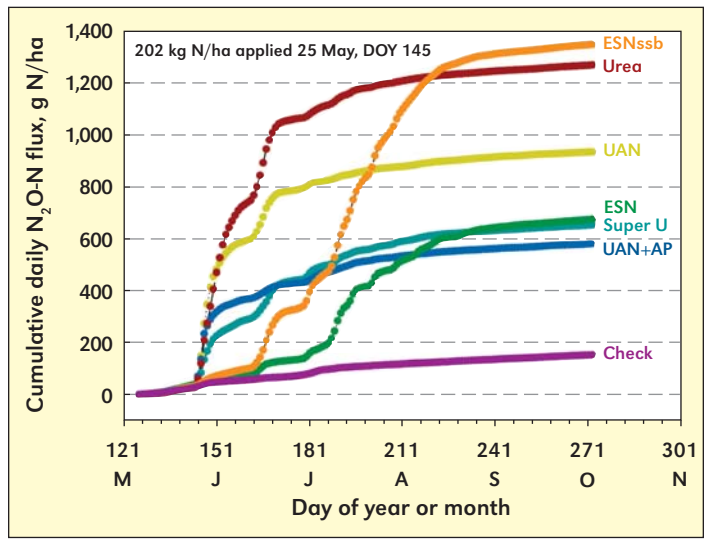


Figure 1. Cumulative growing season soil nitrous oxide (N_2O) emissions with time as a function of N fertilizer source applied on day-of-year (DOY) 145 near Fort Collins, Colorado (Halvorson and Del Grosso, 2012).

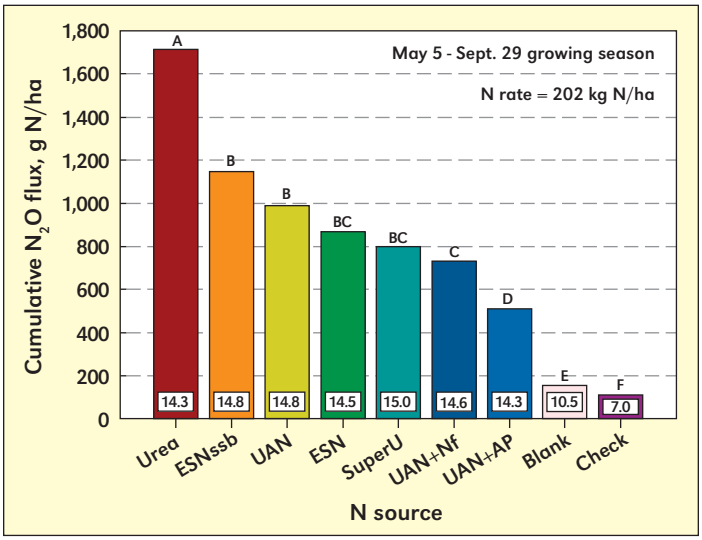


Figure 2. Average (2009 and 2010) growing season soil nitrous oxide (N_2O) emissions as a function of N source in a strip-till, irrigated continuous-corn cropping system near Fort Collins, Colorado (Halvorson et al., 2011). Each N source was surface banded near the corn row at emergence, except ESNssb was subsurface banded. UAN+Nf is UAN plus Nfusion and UAN+AP is UAN plus AgrotainPlus. Average grain yields (t/ha) are shown in a white box within each bar. (1 t/ha = 15.9 bu/A).

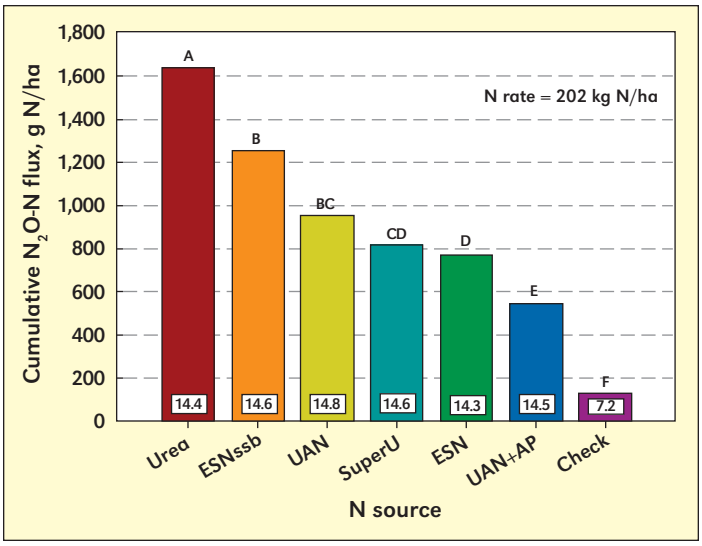


Figure 3. Growing season soil nitrous oxide (N_2O) emissions as a function of N source averaged over strip-till and no-till irrigated corn studies near Fort Collins, Colorado in 2009 and 2010 (Halvorson et al., 2011; Halvorson and Del Grosso, 2012). Average grain yields (t/ha) are shown in a white box within each bar. (1 t/ha = 15.9 bu/A).

plied) located in the same plot area as the N sources and a check treatment (no N applied for 10 years) located in a separate plot. The 2-year average ST growing season N_2O-N emissions from the controlled-release N fertilizers and UAN were significantly lower than dry granular urea. The ESNssb treatment had significantly higher N_2O emissions than the UAN+Nfusion, UAN+AgrotainPlus, blank, and check treatments. The UAN+AgrotainPlus and UAN+Nfusion treatments had lower N_2O emissions than UAN. The check treatment had the lowest level of growing season N_2O-N emissions,

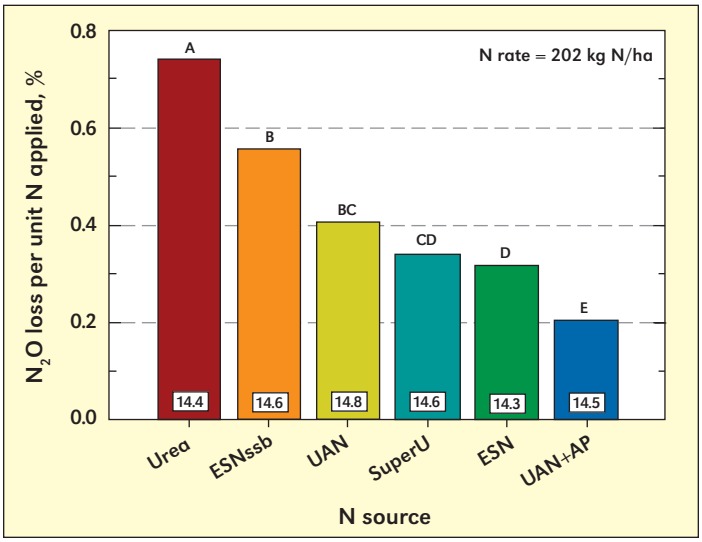


Figure 4. Growing season soil nitrous oxide (N_2O) loss per unit of N applied as a function of N fertilizer source averaged over strip-till and no-till irrigated corn production systems in 2009 and 2010 near Fort Collins, Colorado (Halvorson and Del Grosso, 2012). Average grain yields (t/ha) are shown in a white box within each bar.

with the blank being similar to the check. Compared to dry granular urea, UAN+AgrotainPlus reduced N_2O-N emissions 70% in the ST system, UAN+Nfusion 57%, SuperU 53%, ESN 49%, UAN 42%, and ESNssb 33%. Compared to liquid UAN, UAN+AgrotainPlus reduced N_2O-N emissions 49%, UAN+Nfusion 26%, SuperU 19%, and ESN 12%. Nitrification was thought to be the main pathway of N_2O loss in our studies.

Similar differences in growing season N_2O emissions were observed among N sources in the NT system, which did not include UAN+Nfusion, as those observed in the ST system. Combining the ST and NT data sets showed that there was no tillage x N treatment interaction, with the N_2O emissions from the ST and NT systems being similar (Halvorson and Del Grosso, 2012). Therefore, we combined the NT and ST N_2O data sets to obtain an overall average growing season N_2O emissions for the common N sources from both tillage systems to provide 4 site-years of observations (**Figure 3**). All N sources had growing season N_2O-N emissions lower than urea. Surface banded ESN and UAN+AgrotainPlus had lower emissions than UAN. Compared to dry granular urea, averaged across tillage systems and years, UAN+AgrotainPlus reduced N_2O-N emissions 66%, SuperU 50%, ESN 53%, UAN 42%, and ESNssb 23%. Compared to liquid UAN, UAN+AgrotainPlus reduced N_2O-N emissions 43%, ESN 19%, and SuperU 14%. Growing season N_2O-N losses were consistently <0.4% of N applied for the controlled-release N sources and UAN, except ESNssb (0.55%), with urea having a loss of 0.74% (**Figure 4**). The N_2O-N loss per unit of N applied was highest for urea and lowest for UAN+AgrotainPlus. The growing season N_2O-N emissions from the application of a unit of the controlled-release N fertilizer in this study were considerably lower (<0.5%) than the default 1% from Tier I methodology of IPCC (2006) used to estimate yearly N_2O-N emissions resulting from N fertilizer application.

N_2O Emissions as a Function of Grain Yield

Grain yields did not vary with N source (**Figure 2** and

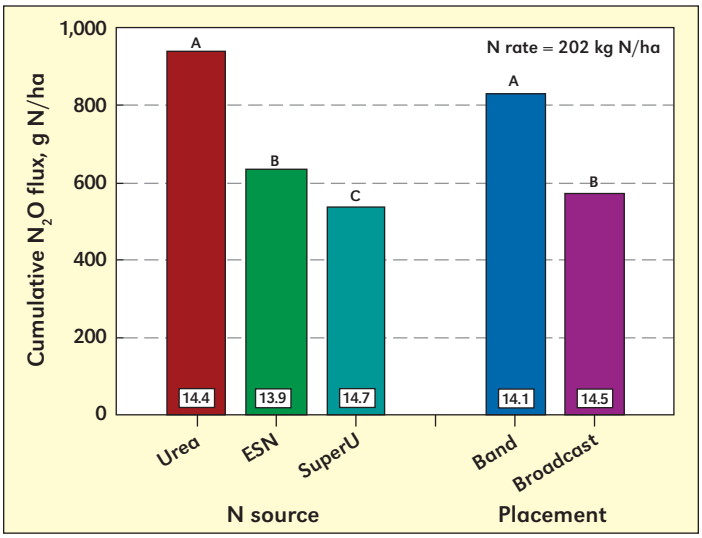


Figure 5. Nitrogen source and placement effects on soil nitrous oxide (N_2O) emissions when averaged over strip-till and no-till systems (3 site-years). Average grain yields (t/ha) are shown in a white box within each bar. (1 t/ha = 15.9 bu/A).

3) in our studies. Expressing N_2O emissions as a function of grain yield and N uptake showed greater agronomic N use efficiency for ESN, SuperU, and UAN+AgrotainPlus than for urea and ESNssb. On an agronomic basis, the N_2O emissions per unit of grain yield were highest for urea (115 g N_2O-N/t grain) and lowest for UAN+AgrotainPlus (38 g N_2O-N/t grain). The ESNssb (87 g N_2O-N/t grain) treatment had greater N_2O emissions per t grain than ESN (55 g N_2O-N/t grain), SuperU (56 g N_2O-N/t grain), UAN+AgrotainPlus, and the check (19 g N_2O-N/t grain) treatments. UAN+AgrotainPlus had lower N_2O emissions per t grain than UAN, ESN, and SuperU. The check treatment had the lowest level of N_2O emissions per t grain, but is not an economically sustainable management practice. These data show that the controlled-release fertilizers investigated have significant potential to reduce N_2O-N emissions per unit of grain production within irrigated corn production systems in the Central Great Plains.

Band versus Broadcast N and N_2O Emissions

Three N sources, urea, SuperU, and ESN were surface band and broadcast applied to ST (2010 and 2011) and NT (2011) corn plots to evaluate the effects of N placement on N_2O emissions under irrigated, corn production. Band applied N had a higher (45%) N_2O emission than broadcast N averaged over 3 site-years (**Figure 5**) (A. Halvorson and S. Del Grosso, unpublished data). Understanding the reasons why N_2O emissions were higher with banded than with broadcast N application will require that N placement effects on N_2O emissions be evaluated further under other soil, cropping system, and climatic conditions to obtain a broader perspective on the effects of N placement on N_2O emissions from agricultural systems.

Summary

All controlled-release N fertilizers and UAN reduced growing season N_2O emissions from irrigated, ST and NT continuous corn cropping systems when compared to urea; and UAN+AgrotainPlus did so consistently in comparison to UAN. Growing season N losses as N_2O-N were consistently < 0.5% of N applied for all controlled-release N sources and UAN, with urea having a loss of < 0.8%. Expressing N_2O emissions as a function of grain yield and N uptake showed greater agronomic N use efficiency for the controlled-release N fertilizers than for urea, although N source did not affect corn yields. This study shows that N source can affect N_2O-N emissions following N fertilizer application. The fertilizer-induced component of N_2O-N emissions was reduced up to 66% by using controlled-release N sources in our semi-arid, irrigated corn studies. The degree of reduction may vary strongly in more humid regions depending on cropping system, tillage, and site-specific conditions. Choice of N source and placement can be valid management alternatives for reducing N_2O emissions to the environment in semi-arid areas. Our results suggest that irrigated soils in semiarid climates have relatively low N_2O-N losses provided irrigation is well-managed to avoid water logged conditions and potential for denitrification. Additional work is needed to verify the effectiveness of these fertilizer sources in reducing N_2O emissions in other rainfed and irrigated cropping systems, especially in humid areas with large amounts of untimely spring rainfall, which can contribute to N_2O losses through denitrification. The principle of applying the right N source, at the right rate, at the right time, in the right place (4R Nutrient Stewardship) becomes a key management decision for optimizing crop yields and economic returns while protecting the environment. BC

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Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or the International Plant Nutrition Institute.

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Site-Specific Fertilizer Recommendations for Oil Palm Smallholders Using Information from Large Plantations

By Michael J. Webb, Paul N. Nelson, L. Gary Rogers, George N. Curry, Julie M.C. Pasuquin, and Adrian M. Johnston

Research in Papua New Guinea developed a way of transferring to smallholder oil palm growers the fertilizer recommendations that have been developed for nearby plantation fields using large fertilizer trials. The procedures used were developed into a conceptual framework, which is transferable to other regions and also updateable as new information becomes available.

Intensification of land use can lead to soil fertility decline (Bailey et al., 2009), and often, even when fertilizer is used, it may not be sufficient to replace losses or balance other forms of supply. To maintain soil nutrient status at a particular level, nutrients lost in the crop and through other pathways must be replaced. In commercial practice, such replacement is only regarded as necessary when crops begin to respond to individual nutrient additions. However, producing the most appropriate fertilizer recommendations for smallholders in terms of type, timing of application, and balance is challenging due to variability in climate, soils, crop management, and the large number of farmers. While these challenges have been addressed in some regions and for some crops (Schnier et al., 1997; Das et al., 2009; Haefele and Konboon, 2009) there has been little attention to improving fertilizer recommendations for smallholder oil palm growers. Yet smallholders in PNG, typically those cultivating <10 ha, account for 37 to 40% of the area under oil palm and contribute about 33% of total palm oil production (Vermeulen and Goad, 2006). The mismatch between percent area planted and percent contribution to palm oil production represents a 'yield-gap' between smallholders and large-scale plantations. It is commonly believed by the oil palm industry that the lower production by smallholders can, among other things, be attributed to nutrient deficiencies and ineffective nutrient management. Therefore, methods are needed to improve smallholder fertilizer management in order to improve productivity and farmer incomes.

Plantation companies often invest considerable resources to develop optimum fertilizer regimes, and it would be beneficial to nearby smallholders if this information could be applied to their blocks. Fertilizer recommendations on plantation estates are usually made on a block-by-block basis. Irrespective of how these fertilizer decisions are made, such block-by-block information is usually not available to local smallholder farmers. In addition, as fertilizer represents a substantial cost for smallholders, recommendations should be based on fertilizer responses known to be economically justifiable. The objective of this study was to find a way in which the nutrient management information generated in large plantations could be transferred to surrounding smallholder growers in the largest oil palm-growing region of PNG.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; B = boron. PNG = Papua New Guinea; GIS = geographic information systems; MU = management unit.

The project was carried out in West New Britain Province (WNBP), where two companies, New Britain Palm Oil Ltd. (NBPOL) and Hargy Oil Palms Ltd. (HOPL), and 10,800 smallholders grow oil palm on a total of 43,800 ha (company area) and 36,960 ha (smallholder area). Smallholders are grouped into two project areas—Hoskins and Bialla. Virtually all of the study area has soils classified as Andisols (mostly Vitrands), formed in air-fall or alluvially-redeposited tephra (ash and pumice) ejected within the last 6,000 years (Bleeker, 1983; Machida et al., 1996). The area receives between 3,500 and 4,500 mm rainfall annually in a humid tropical climate.

To determine fertilizer recommendations, the physical attributes of plantation management units (MUs) were matched with those of smallholder blocks using soil map information. Eight soil maps and accompanying documentation of oil palm-growing areas in WNBP were obtained from the Department of Agriculture and Livestock Land Use Section (**Table 1**). These maps were digitized, rectified, and saved into a GIS as a single layer. Digital maps of all plantation MUs and 4342 smallholder blocks were obtained from Oil Palm Industry Corporation (OPIC) and the two plantation companies (**Figure 1**). While GIS information was available for all plantation MUs, less

Table 1. Soil surveys and maps used to generate base soil map in West New Britain Province (WNBP).

Map No.	Title	Author and date	Scale
164	Soil survey of WNBP. The Tiaru-Ala area	Aland, F.B. and P.G.E. Searle, 1966	1:50,000
176	Soil survey of WNB. The Balima-Tiauru area. Dept. of Ag., Stock and Fisheries. Soil Survey Report No. 1	Hartley, A.C., F.B. Aland, and P.G.E. Searle, 1967	1:50,000
440	Soil survey and land use potential of the Ala-Kapiura area, WNB, PNG. Dept. of Ag., Stock and Fisheries. Res. Bull. No. 17	Zijsvelt, M.F.W. and D.A. Torlach, 1975	1:50,000
441	Soil survey and land use potential of the Kapiura-Dagi area, WNB. DPI Res. Bull. No. 19	Zijsvelt, M.F.W., 1977	1:50,000
505	No report. Map title: Kapuluk (Gaho-Kulu).	Tyrie, G.R., 1986	1:100,000
192	No report. Map title: Dagi-Kulu Soils	Hartley, A.C., (no date)	1:50,000
167	Soil land soil survey report	Alland, F.B. and D.A. Torlach, 1971	1:31,522
166	Navo land soil survey report	Murty, 1967	1:31,522

than half of the smallholder blocks had been georeferenced.

Fertilizer recommendations (N, P, K, Mg, B) for each MU were added to the plantation MU layer. The recommendations used for this work were the mean of those made over the previous 3 years by PNG Oil Palm Research Association (PNGOPRA), but the period considered could be changed as appropriate. Soil maps were used to 'split' the MUs according to soil type. For each soil type, a fertilizer recommendation was calculated using an area-weighted average of all MUs containing that soil type. Thus each soil type has a fertilizer recommendation based on the oil palm company's fertilizer recommendations (**Figure 2**).

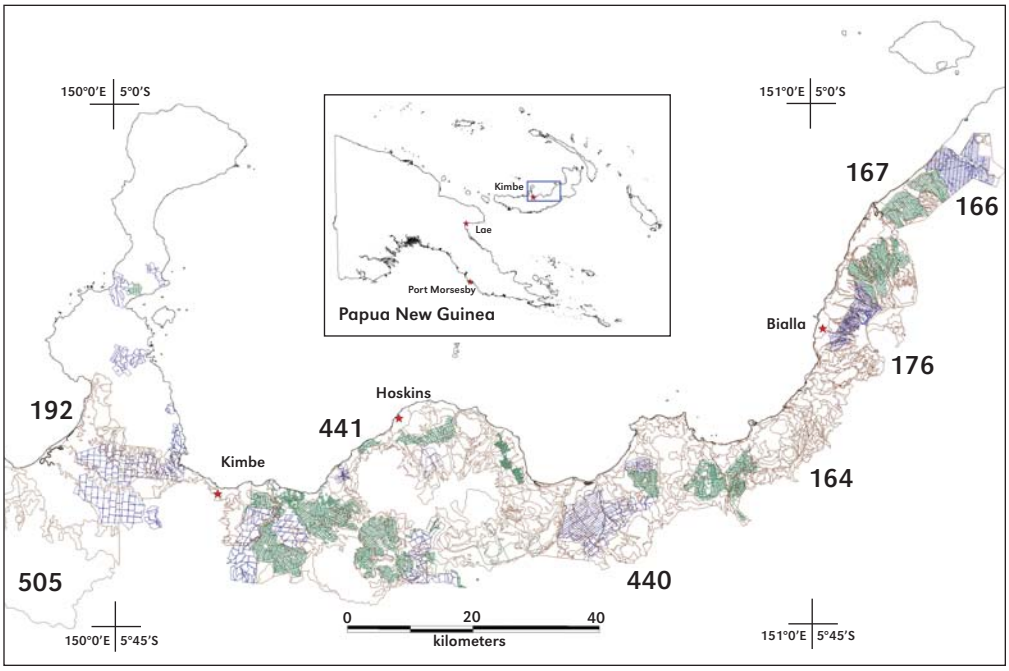

Figure 1. The GIS layers for soil (brown), plantation blocks (blue), and smallholder blocks (green) showing their relative distribution across the study area.

The smallholder blocks were also 'split' using the soil type map. Fertilizer recommendations for each smallholder block were then calculated from the area-weighted average of the fertilizer recommendation for the soil type underlying that block (**Figure 3**). Where an exact match was not possible, a recommendation was made based on the closest smallholder block that had a match, or the closest plantation MU, as appropriate. Those smallholder blocks constituted less than 3% of the 4,342 blocks considered. Smallholder recommendations for each nutrient were converted to units of fertilizer, rounded up to the next 0.5 kg (or 0.05 kg for calcium borate), displayed as maps (**Figure 4**) or tables (**Table 2**), and distributed to the milling companies, OPIC, and PNGOPRA. A more detailed account of the methodology can be found in Rogers et al. (2006).

Table 2. Typical fertilizer recommendation by smallholder block.

Block No.	Area, ha	AC[1]	DAP[2]	KIE[3]	MOP[4]	CaB[5]
		---------- kg/ha/yr ----------				
A-1	7.49	3.0	0.5	0.5	0.5	0.15
A-6	7.30	1.5	-	1.0	0.5	0.10
B-9	6.97	1.5	-	1.0	-	0.10
E-5	5.20	2.0	1.5	1.5	0.5	0.15

[1]AC is ammonium chloride; [2]DAP is diammonium phosphate; [3]KIE is kieserite (magnesium sulfate); [4]MOP is muriate of potash (potassium chloride); [5]CaB is calcium borate.

Framework Development and Discussion

Through the process described above, it was possible to make individual fertilizer recommendations for 4,342 smallholders based on existing data. Recommendations were possible only for blocks that had been georeferenced and were in the GIS. However, as more smallholder blocks are included in the GIS, the number of individual recommendations can be increased accordingly.

This work relied on the existence of soil maps at an appropriate scale covering the area of interest. However, in many parts of PNG and the world, soil maps are not available at that level of detail. Nevertheless, digital elevation data, available globally from the shuttle radar mission, can be used to improve the precision of broad-scale soil maps, and this has recently been done for PNG (Bryan and Shearman, 2008). While within-block variability in soil fertility is bound to exist in smallholder oil palm blocks, the framework used here represents a first step away from regionally uniform fertilizer recommendations to much more site-specific recommendations. Indeed, if smallholders also had access to leaf tissue nutrient analysis, some of these issues could be addressed more appropriately. A major part of the work involved obtaining copies of the original soil maps, digitizing and georeferencing them—a one-time requirement. Therefore, if plantation fertilizer recommendations change or as more smallholder blocks are georeferenced, the fertilizer recommendations can be easily updated.

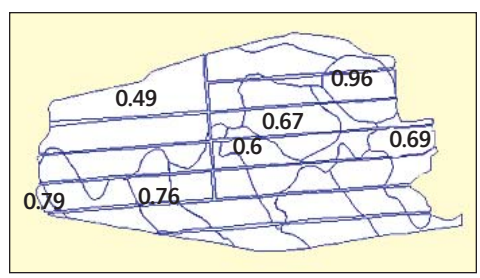

Figure 2. Fertilizer recommendations for soil map units (curved blue polygons) were derived from area-weighted averages of the MUs (rectangular blue polygons) overlapping each soil map unit. The numbers refer to kg N/palm/yr.

Incomplete harvesting, which is a common constraint to productivity by smallholders (Koczberski and Curry, 2008), drastically reduces the benefit:cost ratio of fertilizer application. Therefore, smallholders who are under-harvesting should be identified, and the constraints to full harvesting be addressed, before fertilizer recommendations are made.

It should be possible within 3 years of implementation of the framework to differentiate between farmers who are able to realize the benefits of fertilizer application as higher production (the high producers) and those who, for various socio-cultural reasons, are unable to realize fully the income gains from fertilizer because of under-harvesting. Thus, in future, fertilizer recommendations may also be able to accommodate some of the socio-cultural factors affecting smallholder productivity.

A logical plan for application of this framework

1. Use plantation fertilizer recommendations (averaged over the last few years), soil maps, and GIS to provide initial fertilizer recommendations.
2. Use plantation data from comparable fields to estimate realistic potential yield under similar growing conditions.
3. Determine current (or average over a few years) yield of the smallholder block.
4. Determine the increased economic returns to be gained if fertilizer recommendations were followed.
5. Explore options for additional labor to meet the increased demand (fertilizer application, weeding, pruning, harvesting, etc) in balance with other economic and social commitments.
6. Re-evaluate steps 3 and 4 above to determine a practical and achievable harvested yield.
7. Determine fertilizer requirements to achieve that harvested yield consistently.
8. Develop a financial and management strategy to implement the plan.

Summary

The framework developed here enables production of fertilizer recommendations for individual smallholder oil palm growers using existing biophysical information. Adoption of the suggested framework would provide more appropriate fertilizer recommendations at the level of the individual grower than the current method of a single region-wide recommendation. More appropriate fertilizer recommendations at this scale are likely to improve the efficacy of fertilizer application and the returns to growers. BC

Figure 3. Fertilizer recommendations for each smallholder block (rectangular red polygons) were derived from area-weight averages of soil map unit (curved red polygons) fertilizer recommendations underlying each smallholder block. The numbers refer to kg N/palm/yr.

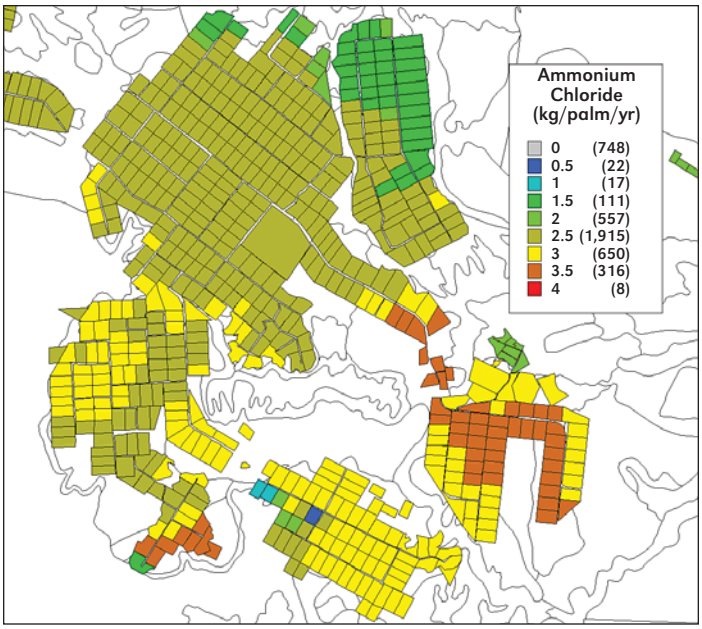

Figure 4. Example of a map of smallholder blocks with fertilizer N recommendations in 0.5 kg increments of ammonium chloride (only a portion of the total map is shown). The numbers in parenthesis refer to the number of blocks in each category out of the 4,344 blocks mapped and assessed. The 0 to 0.5 (gray) category mostly refers to blocks for which it was not possible to make a match with the plantation soil types and therefore not possible to make a reliable recommendation.

Acknowledgement

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Economics of Fertilizing Irrigated Cereals in the Indo-Gangetic Plains

By V.B. Shahi, A. Kumar, N. Gupta, K. Majumdar, M.L. Jat, T. Satyanarayana, M. Pampolino, S. Dutta, H.S. Khurana, and A.M. Johnston

On-farm studies in the Indo-gangetic plains (IGP) clearly indicated the positive response of cereals (rice, wheat, and maize) to NPK fertilization. Economic assessment of data, based on current as well as future fertilizer price and crop value or minimum support price (MSP) scenarios, showed favorable return on investment in N, P, and K fertilizers in the IGP.

Cereals constitute the staple food in India, and about 61% of the total protein requirement of the Indian population is met through cereals. They use about 63% of the total fertilizer consumed in India, of which rice, wheat, and maize use 37, 24, and 2% of the total, respectively (Chanda, 2008). Cereals are grown under variable conditions in the IGP (i.e. soil types, cropping systems, agro-ecological regions, etc.). Such variability in land characteristics and growing environments is reflected in the productivity (attainable yield) and subsequently in nutrient requirement by these crops. This necessitates the integration of crop response data with fertilizer decision support for increased productivity, higher economic returns, and better environmental stewardship. This study was conducted to estimate: (1) response of cereals to NPK application, (2) economic return on investment in N, P, and K fertilizers, and (3) profitability of NPK application under current and projected future fertilizer price and crop value or minimum support price (MSP) scenarios.

The International Plant Nutrition Institute (IPNI) and the International Maize and Wheat Improvement Centre (CIMMYT) under the Cereal Systems Initiative for South Asia (CSISA) project conducted 45, 141, and 36 on-farm trials in rice, wheat, and maize, respectively, across the IGP during 2009 to 2011. The objective was to capture the nutrient response of crops under variable soil and growing environments. The IGP covers the states of Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, and West Bengal representing irrigated, intensive production systems and a relatively large farm scenario in the Western IGP to rainfed, low intensity, fragmented farming systems of eastern India (**Table 1**).

The experiment consisted of four treatments including: T_1 - ample NPK, T_2 - omission of N with full P and K, T_3 - omission of P with full N and K, and T4 - omission of K with full N and P. For rice, NPK application rates were 125 to 175 kg N/ha, 50 to 80 kg P_2O_5/ha, and 60 to 90 kg K_2O/ha based on estimated yield targets of 5 to 8 t/ha. For wheat, N application rates were 150 to 180 kg/ha for yield targets of 5 to 6 t/ha, while P and K rates were fixed at 90 kg P_2O_5 and 100 K_2O/ha. Maize trials were concentrated in Bihar and West Bengal and ample NPK rates for maize were 150 to 180 kg N, 70 to 115 kg P_2O_5, and 120 to 160 kg K_2O/ha for yield targets of 6 to 8 t/ha. Nutrients were applied in excess of the actual requirement of crops, following the omission plot experiment protocol, to ensure no limitation of nutrients except for the omitted one. At maturity, total biomass (grain + straw) and grain yields were determined, and adjusted to 13% moisture content for all the three crops.

Yield increase (nutrient response in kg/ha) due to and economics of N, P, or K application were estimated using the following equations:

Nutrient response = Grain yield in ample NPK plot – Grain yield in a nutrient omission plot

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; INR = rupee; AE_N = agronomic efficiency of nitrogen; 1 US dollar = INR 51.85.

Table 1. Characteristics of the experimental sites (all irrigated).

State	Districts	Agro-climatic zone	Soil texture	Average annual precipitation, mm	Cropping system	Crops studied
Punjab	Ludhiana, Amritsar, Gurdaspur, Sangrur, Fatehgarh, Sahib	Central Plain Zone to Sub-Mountain Undulating Zone	Sandy loam to silt loam	600 to 1,020	Rice-Wheat, Cotton Wheat	Rice and Wheat
Haryana	Karnal, Kurukashetra, Kaithal, Ambala, Yumnanagar	North Western Plain Zone	Sandy loam to clay loam	400 to 600	Rice-Wheat	Rice and Wheat
Uttar Pradesh	Agra	South Western Plain Zone	Sandy loam	650	Pearl millet-Wheat	Wheat
Bihar	Vaishali, Samastipur, Purnea, Katihar, Begusarai, Patna, and Jamui	North West, North East, and South Bihar Alluvial Plains	Sandy loam to silty clay loam	1,100 to 1,400	Rice-Maize	Rice and Maize
West Bengal	Uttar Dinajpur and Nadia	Old and New Alluvial Zone	Sandy loam to silty clay loam	1,300 to 1,500	Rice-Maize	Maize

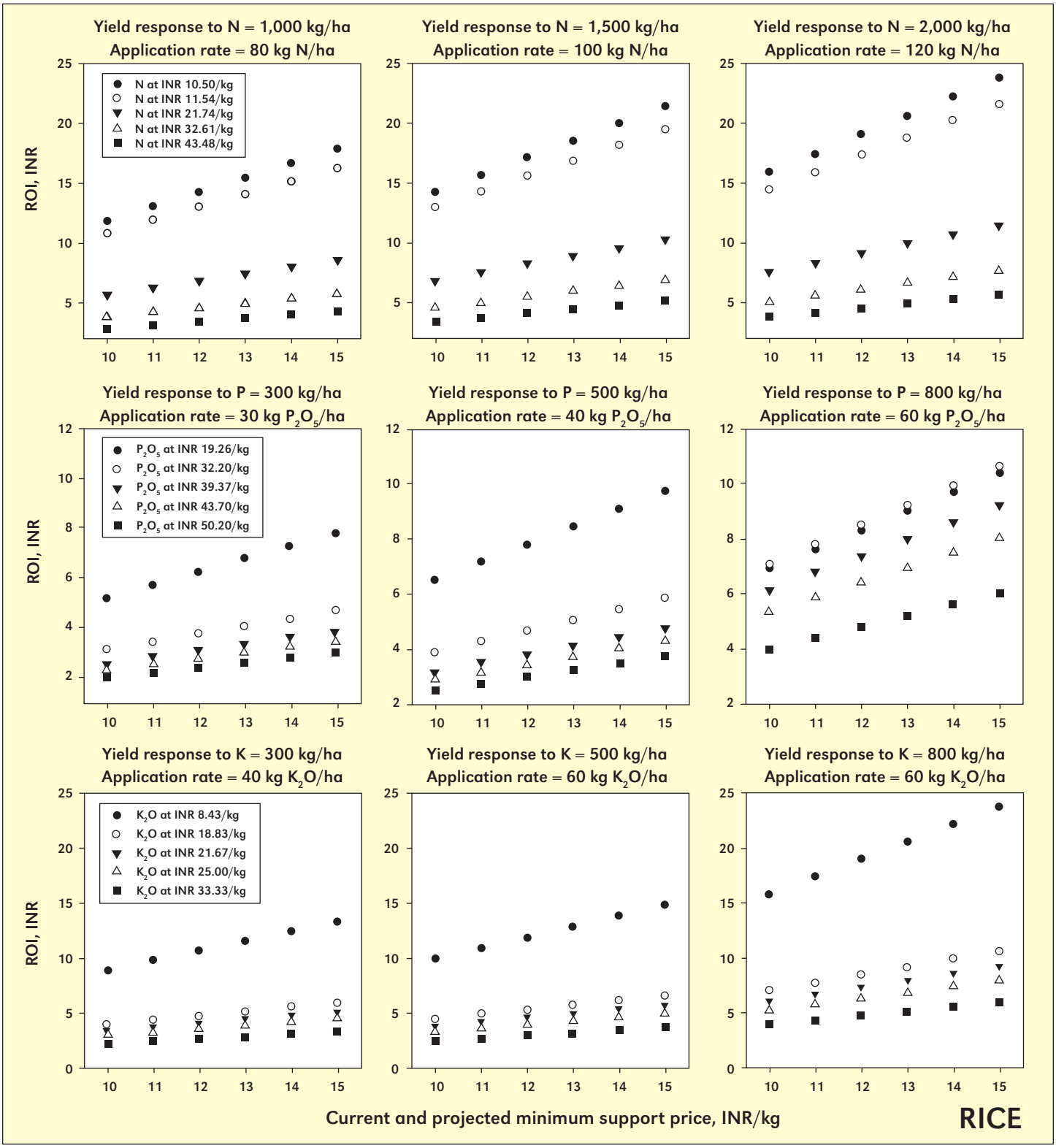

Figure 1. Top Row: Return on investment (ROI) in N fertilizer at different N response levels and projected costs of N fertilizer and minimum support prices for rice. Middle Row: ROI in P fertilizer at different P response levels and projected costs of P fertilizer and minimum support prices for rice. Bottom Row: ROI in K fertilizer at different K response levels, projected costs of K fertilizer and minimum support prices for rice.

Return on investment (ROI) in a fertilizer (nutrient) = Yield increase due to the fertilizer (nutrient) x Minimum support price (MSP) of crop / Applied fertilizer cost

Rice Results

The average rice yield with ample application of NPK was 4,700 kg/ha with a range of 3,070 to 7,140 kg/ha (data not shown). Likewise, omission of nutrients from the ample NPK treatment caused variable yield reduction in farmers' plots. Reduction of yield was highest for N omission plots (667 to 3,370 kg/ha) with an average of 1,739 kg/ha followed by P omission plots (range of -194 to 2,100 kg/ha with an average

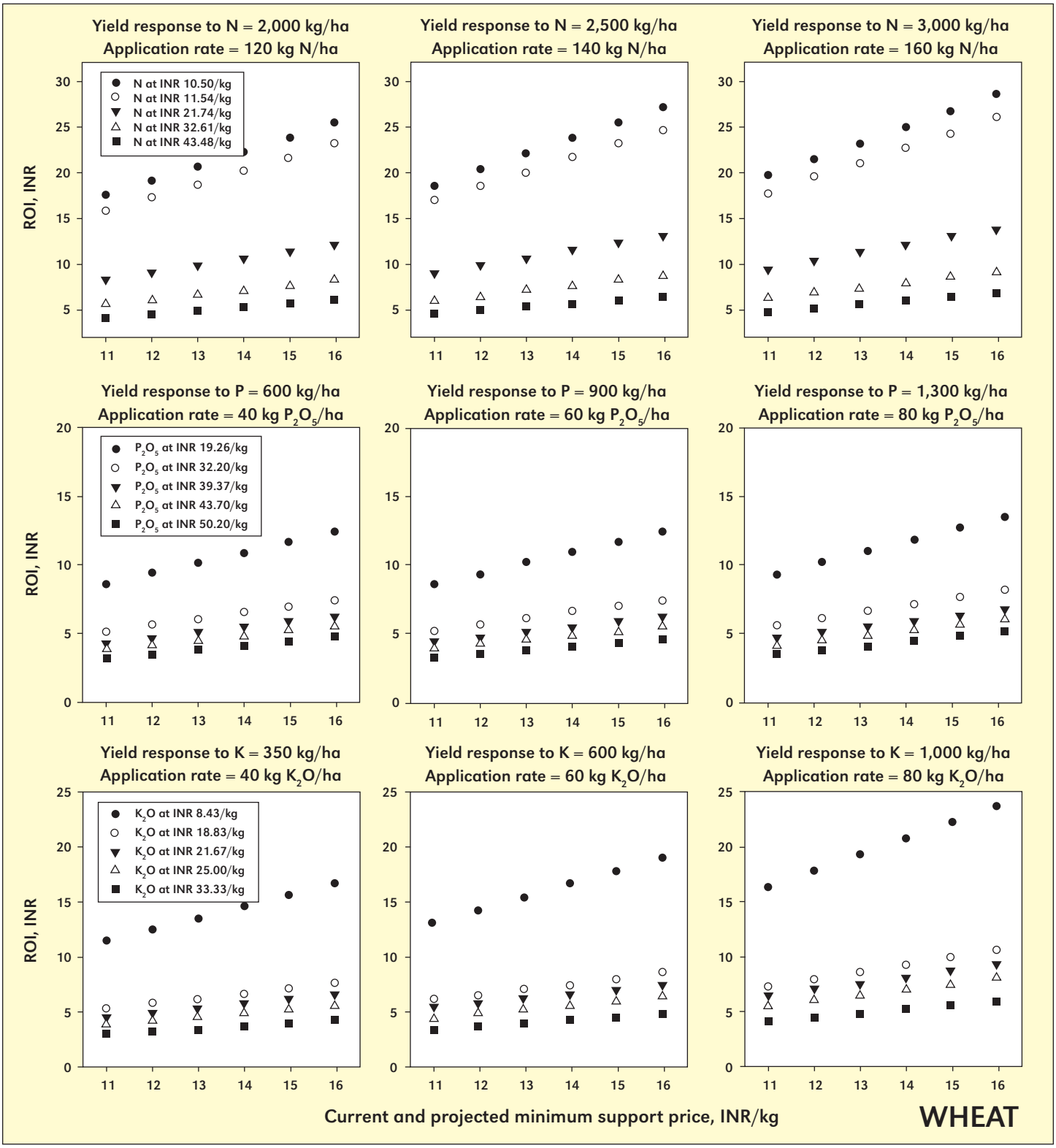

Figure 2. Top Row: Return on investment (ROI) in N fertilizer at different N response levels and projected costs of N fertilizer and minimum support prices for wheat. Middle Row: ROI in P fertilizer at different P response levels and projected costs of P fertilizer and minimum support prices for wheat. Bottom Row: ROI in K fertilizer at different K response levels, projected costs of K fertilizer and minimum support prices for wheat.

of 712 kg/ha) and K omission plots (range of 90 to 1,806 kg/ha with an average of 622 kg/ha). It is interesting to note that the average rice yield across trials with ample NPK application was more than double the current average yield of rice in India signifying how balanced nutrition can improve yields.

Figure 1 shows that N application, at pre-selected application rates, was economically profitable. At an application rate of 80 kg N/ha for a 1,000 kg/ha N response, the ROI at the highest price of N (INR 43.5/kg) and at the lowest MSP for rice (INR 10/kg) was 2.9, suggesting profitable return on N application—even in the worst case scenario. Further, the profitability increased with an increase in the MSP of rice

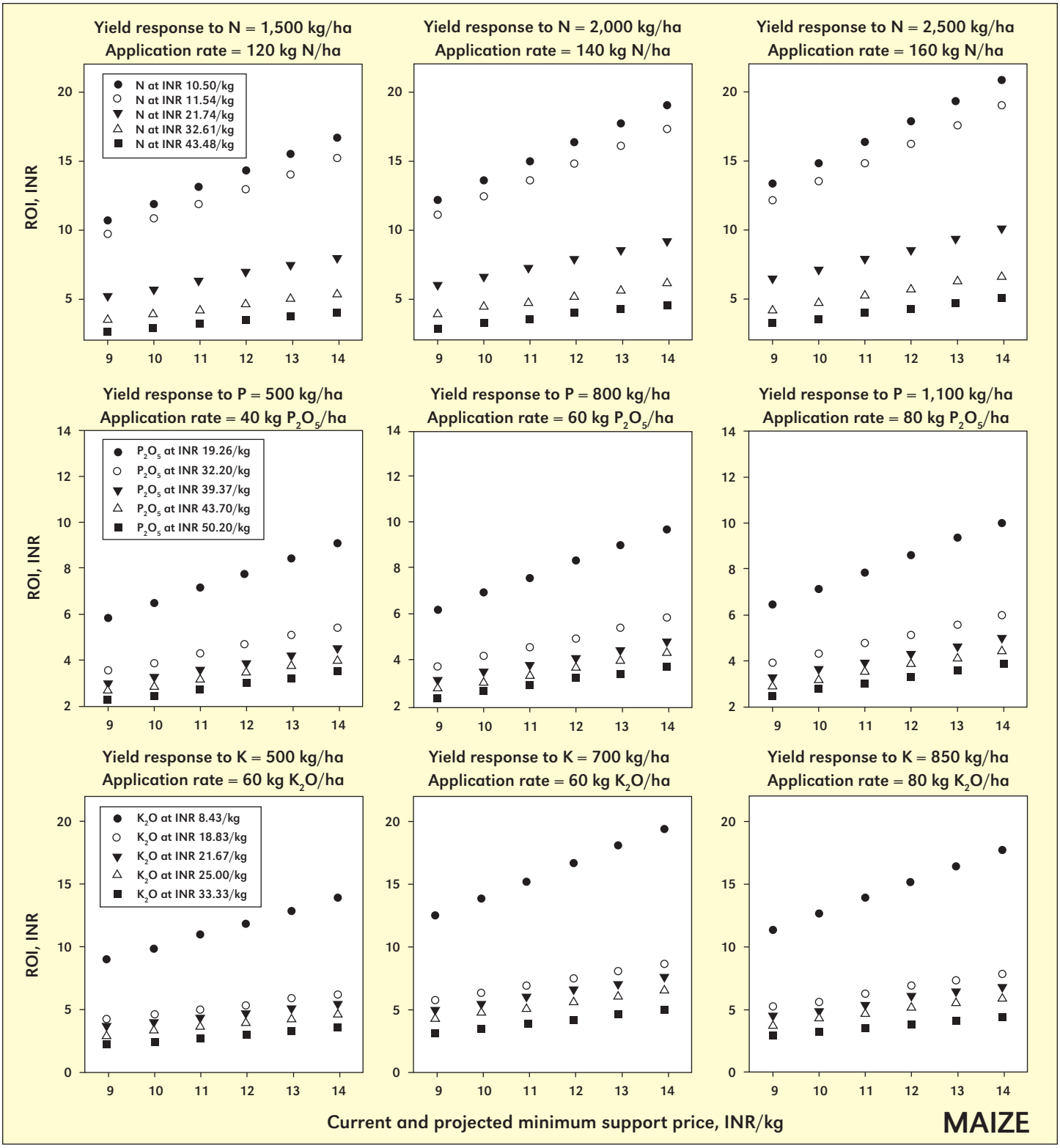

Figure 3. Top Row: Return on investment (ROI) in N fertilizer at different N response levels and projected costs of N fertilizer and minimum support prices for maize. Middle Row: ROI in P fertilizer at different P response levels and projected costs of P fertilizer and minimum support prices for maize. Bottom Row: ROI in K fertilizer at different K response levels, projected costs of K fertilizer and minimum support prices for maize.

as well as the crop response levels. Similarly, P application, in general, was economically profitable even in areas where P responses were low (300 kg/ha). At an application rate of 30 kg P_2O_5/ha, the ROI at the highest price of P fertilizer (INR 50/kg P_2O_5) and the lowest MSP (INR 10/kg rice) was INR 2 per INR invested—suggesting profitable return on P application even under low P response situations. Obviously the ROIs increased with increase in the crop response levels. Likewise, K application at the predetermined rates, in general, was economically profitable even in areas where K response is as low as 300 kg/ha. At an application rate of 40 kg K_2O/ha for a 300 kg/ha response, the ROI at the highest price of K

(INR 33.33/kg of K_2O) and the lowest MSP (INR 10/kg rice) was 2.3—suggesting profitable return on potash application. The profitability increased with increase in the MSP for rice. A yield loss of ≥ 500 kg/ha of rice due to no application of K was observed in more than half of the locations. This suggests that at these locations, application of 40 to 60 kg K_2O/ha will provide a good ROI to the farmers and also maintain the K fertility status of the soil. Interestingly, we observed that ROI was higher than INR 2 for all the three cereals even at the highest hypothetical fertilizer prices used in the economic assessment.

Wheat Results

The average rice yield with ample application of NPK was 5,096 kg/ha with a range of 3,111 to 6,500 kg/ha (data not shown). Likewise, omission of nutrients from the ample NPK treatment caused variable yield reduction in farmers' plots. Reduction of yield was highest for N omission plots (500 to 4,750 kg/ha) with an average of 2,566 kg/ha followed by P omission plots (range of 67 to 2,806 kg/ha with an average of 969 kg/ha) and K omission plots (range of 0 to 2,222 kg/ha with an average of 715 kg/ha).

Profit analysis considering the projected cost of N fertilizer at varying MSPs of wheat (**Figure 2**) revealed that ROI decreased with increasing N fertilizer price from INR 10.5/kg to a future forecasted price of INR 43.48/kg of N, but increased with increasing MSP of wheat, irrespective of N fertilizer cost. Return on investment recorded at the current MSP and the projected maximum price of N fertilizer, across all N response levels, was ≥ INR 4.2 per INR invested making it a profitable option for farmers. Likewise for P, ROI at the current MSP and the projected maximum price of P fertilizer would be INR 3.3 per INR invested, even at the low P response areas. At high P response areas (P response of approximately 1,300 kg/ha), the ROI at highest projected fertilizer P price would be INR 3.6 per INR invested at the current MSP of wheat, again making it a profitable option for farmers. Similarly, for K application, ROI at the current MSP and the projected maximum price of K_2O would be INR 2.9, even at the low response locations. At high response locations (K response of approximately 1,000 kg/ha), the ROI at highest projected K price was INR 4.1 at the current MSP of wheat, again making it a profitable option for farmers. Potassium response was > 1 t/ha in 25% of the locations in the present study, and those locations would produce ROI of INR 8 at the current cost of K and wheat MSP.

Maize Results

The average maize yield with ample application of NPK was 6,343 kg/ha with a range of 4,020 to 9,420 kg/ha (data not shown). Likewise, omission of nutrients from the ample NPK treatment caused variable yield reduction in farmers' plots. Reduction of yield was highest for N omission plots (400 to 5,160 kg/ha) with an average of 2,154 kg/ha followed by P omission plots (range of 3,910 to 8,040 kg/ha with an average of 853 kg/ha) and K omission plots (range of 140 to 1,320 kg/ha with an average of 700 kg/ha).

Among the three cereals, maize has the lowest MSP. However, ROI at the current MSP and highest cost of N fertilizer were 2.6, 3.0, and 3.2 at the three N response levels of 1,500, 2,000, and 2,500 kg/ha, respectively (**Figure 3**). This suggests that N application at the highest projected price of urea would provide reasonable economic returns to farmers. The fertilizer N rates used for the three levels of N response correspond to AE_N values of 13, 14, and 16 kg grain/kg N. This suggests that ROI at these N response levels could still be improved if AEN is improved through better N management. For P, ROI at the current MSP and highest cost of P fertilizer were ≥ INR 2 at all the three P response levels. This suggested that like N application, P application at the given rates would also be profitable to farmers. For K application, ROIs were 2.3, 3.2, and INR 2.9 per INR invested for 500, 700, and 850 kg/ha K responses, respectively, at the current MSP and the highest projected price of K_2O, again giving reasonable returns to farmers.

Conclusions

The results clearly highlight the large variability observed in nutrient supplying capacity of cereal-growing soils and system management practices by farmers with diverse socio-economic profiles. Average yield losses due to K omission were high for all cereals grown in the IGP. This is contrary to the popular perception that omitting potash application for a season or forever will not adversely affect cereal production in the country. The data also clearly demonstrated that most of the soils in the IGP have low K supply levels. Economic assessment based on observed NPK response levels with current and projected prices of these fertilizers and MSPs of cereals showed ROI > INR 2 under all scenarios. This indicated that NPK application in cereals in the IGP is economical at current and future price scenarios, and farmers' profit can be assured when fertilizer application is guided by indigenous nutrient supply and expected nutrient response at a particular location. BC

Acknowledgment

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Maize Response to Balanced Fertilizer Application in Northwest China

By Shutian Li, Jiyun Jin, Yu Duan, Tianwen Guo, Yan Zhang, and Youhong Li

On-farm trials determined the effect of K fertilization on maize production within a region that has typically relied on N and P alone. Balanced use of N, P, and K fertilizer generated an average yield increase of 1.2 t/ha and was shown to improve farm income by USD 300/ha when compared to common farmer practice. This case of long-term use of N and P in the absence of K illustrates the seriousness of nutrient imbalance in this and other regions of China.

Spring maize is one of the main crops in China's northwest region. In 2010, total maize production taken from an area of 5.4 M ha within the provinces of Gansu, Inner Mongolia, Xinjiang, and Ningxia was nearly 30 M t (MOA, 2010) with an average yield of 5,540 kg/ha. Fertilizer use in the northwest has been inadequate for years—mainly because of economic constraints. Therefore, little information is available on nutrient-limiting factors and the economic value of balanced fertilizer application to maize grown in the region.

Since 2003, IPNI has conducted a series of field experiments in collaboration with the provincial Soil and Fertilizer Institutes to evaluate the response of spring maize to N, P, and K fertilizer application. A total of 16 field trials were conducted—six in Gansu province, four in Xinjiang, four in Inner Mongolia, and two in Ningxia. **Table 1** shows some chemical properties of soils at these sites before the field trials began. All trials had four treatments including an optimum (OPT) NPK treatment recommended by the Agro Services International (ASI) soil testing and fertilizer recommendation procedure (Portch and Hunter, 2005) based on target yields in the different locations, and three nutrient omission plots (OPT-N, OPT-P, and OPT-K.) All experiments were set up in a randomized complete block design with three replications. Economic comparisons were made between the OPT and FP treatments at some sites in Gansu and Xinjiang.

Results

Maize yields varied greatly for different years and sites (**Figure 1**). Nitrogen was the main nutrient limitation since the crop gave significant responses in 12 of the 16 sites-years (**Table 2**). Although available P in most soils was above 10 mg/L, a deficient level for the soil testing system used, application of P fertilizer still increased maize yields significantly at 9 of the 16 sites. This response to P reflects the high rates of N being applied. Similarly, K application increased maize yields at 7 of the 16 sites. Interestingly, no significant relationship existed between the relative yields of maize in the OPT-P and OPT-K plots (i.e., the ratio of yield in either the OPT-P or OPT-K plot to the yield in the OPT plot) and soil test P and K (**Figure 2**). This is most likely due to the impact of other confounding factors such as high levels of soil P or the climatic conditions.

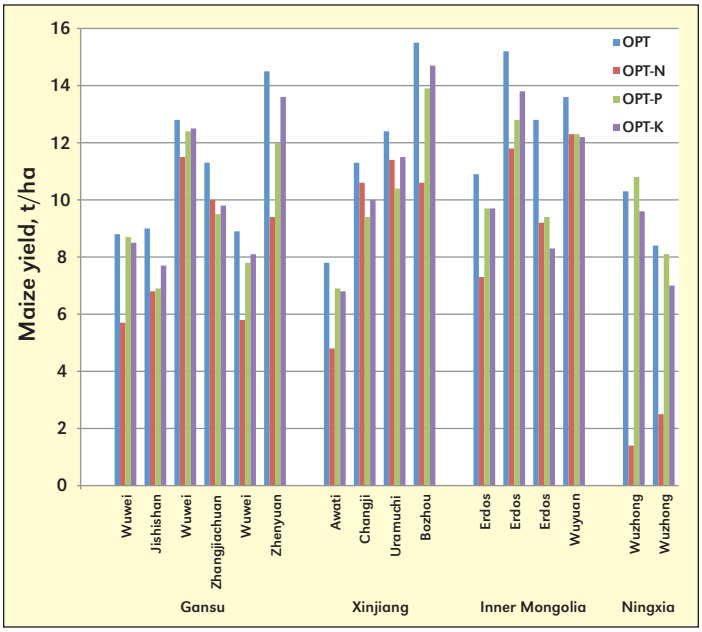

Figure 1. Average maize yields in different treatments at different sites within Gansu, Xinjiang, Inner Mongolia, and Ningxia.

The agronomic efficiencies of N (AE_N), P_2O_5 (AE_P), and K_2O (AE_K) averaged 13.4 (range 2.8 to 32.7), 12.8 (-5.1 to 28.5), and 13.9 (1.6 to 35.6) kg/kg, respectively. These values were slightly higher than those reported for China (i.e., 12.2 kg/kg,

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; OPT = optimum NPK treatment; FP = farmer practice; M = million; USD = US Dollar; RMB = Chinese Yuan.

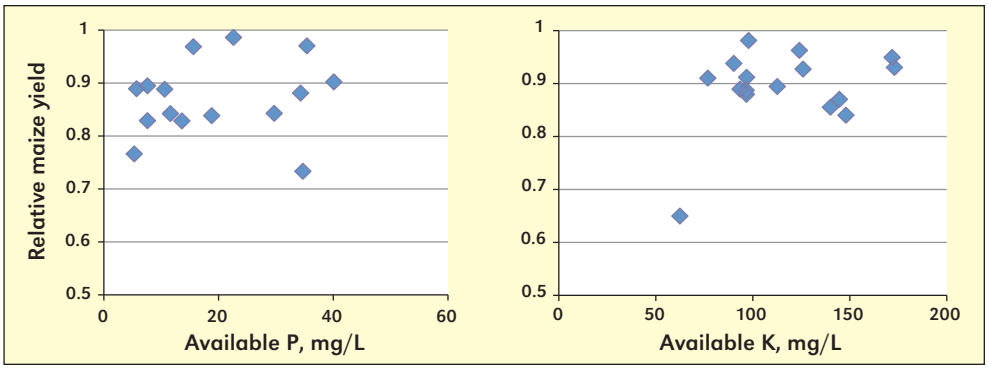

Figure 2. Relationship between relative yield of maize in the OPT-P and OPT-K plots (i.e. ratio of yield in OPT-P or OPT-K plot to the yield in the OPT plot) with available soil P (left) and exchangeable soil K (right) for 16 site-years.

Table 1. Some chemical properties of soils at the experimental sites.

Locations	Year	pH	OM, %	N, mg/L	P, mg/L	K, mg/L
Wuwei, Gansu	2003	7.9	0.75	14.5	22.6	124
Jishishan, Gansu	2004	7.6	0.12	81.4	5.3	140
Wuwei, Gansu	2006	7.8	0.85	4.3	15.6	98
Zhangjiachuan, Gansu	2006	8.2	0.85	0.0	11.6	144
Wuwei, Gansu	2007	8.2	0.93	23.1	34.3	96
Zhenyuan, Gansu	2007	8.1	0.78	13.4	7.6	90
Awati, Xinjiang	2005	8.0	1.41	47.0	5.7	97
Changji, Xinjiang	2006	8.2	1.17	21.3	13.6	93
Uramuchi, Xinjiang	2007	8.5	1.29	25.3	18.8	126
Bozhou, Xinjiang	2009	8.3	0.53	56.2	7.6	172
Erdos, Inner Mongolia	2009	8.8	0.24	16.2	10.6	97
Erdos, Inner Mongolia	2010	8.7	0.24	11.2	29.7	77
Erdos, Inner Mongolia	2011	8.5	0.18	16.7	34.7	62
Wuyuan, Inner Mongolia	2011	8.7	0.24	55.3	40.1	113
Wuzhong, Ningxia	2006	8.2	0.38	15.0	50.6	173
Wuzhong, Ningxia	2007	8.1	0.23	10.3	35.4	148

Table 2. Yield response to N, P, and K fertilizer applications and agronomic efficiencies (AE) of macronutrients.

Location	Yield response, %			AE, kg/kg		
	N	P	K	N	P_2O_5	K_2O
Wuwei, Gansu	55.3	1.4	3.9	10.5	1.0	4.4
Jishishan, Gansu	32.4	30.5	16.9	12.2	17.5	21.7
Wuwei, Gansu	11.5	3.2	1.9	4.9	2.7	1.6
Zhangjiachuan, Gansu	12.5	18.7	14.9	4.2	11.9	12.2
Wuwei, Gansu	52.8	13.5	9.7	11.4	14.1	8.7
Zhenyuan, Gansu	55.0	20.6	6.6	22.9	16.6	6.0
Awati, Xinjiang	60.5	12.4	13.7	15.1	11.5	31.3
Changji, Xinjiang	6.2	20.7	12.4	2.8	27.3	35.6
Uramuchi, Xinjiang	8.3	19.3	7.8	4.5	19.0	12.0
Bozhou, Xinjiang	46.0	11.7	5.3	21.7	15.5	17.4
Erdos, Inner Mongolia	49.3	12.6	12.7	14.1	11.6	13.7
Erdos, Inner Mongolia	28.2	18.6	9.9	12.4	19.9	7.6
Erdos, Inner Mongolia	39.4	36.4	53.9	13.4	28.5	24.9
Wuyuan, Inner Mongolia	11.0	10.8	11.8	5.0	11.1	8.0
Wuzhong, Ningxia	607	-4.3	7.5	32.7	-5.1	8.0
Wuzhong, Ningxia	235	3.1	19.0	26.1	1.4	9.9
Average	81.9	14.3	13.0	13.4	12.8	13.9

11.5 kg/kg, and 10.4 kg/kg for N, P_2O_5, and K_2O, respectively) by Jin (2012). Thus it would appear that the crop response to nutrients in northwest China is higher than the national average. This could be attributed to the lower soil organic matter (and soil fertility) in the northwest compared to other regions of China. But the low soil fertility in this region is also a result of the lack of significant nutrient accumulation in these soils compared to other intensive agricultural regions within China (Li and Jin, 2011).

The pattern of macronutrient accumulation by maize grown in Inner Mongolia is shown in **Figure 3**. Most of the accumulation (80% for N, 92% for P, and 85% for K) occurred within 80 days after sowing (tasseling stage), after which the accumulated nutrients (especially N and P) were rapidly transferred to the seeds. These trends suggest that the application of macronutrients needs to be done earlier in the season to match plant demand.

Using examples from Gansu and Xinjiang, the OPT increased grain yields by an average of 1,207 kg/ha, and farmer's income by more than USD 300/ha, when compared to FP (**Table 3**). Again, this difference can be attributed to a traditional reliance on under- or over-application of N and P, and the fact that most farmers ignore K application for their maize crops.

These results illustrate three clear recommendations to maize growers in northwest China: 1) addition of K to N and P fertilizers is critical to optimizing yields and profits; 2) the large variability in crop response to all nutrients indicates the

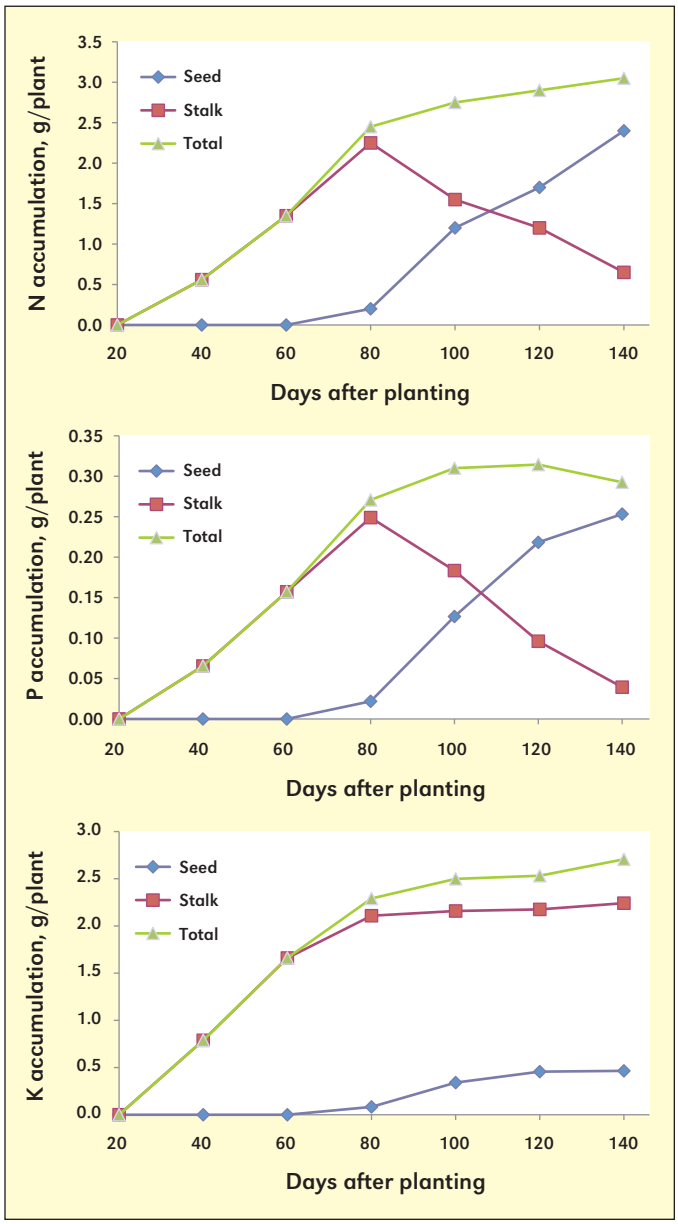

Figure 3. Accumulation of N, P, and K by maize in Inner Mongolia.

Table 3. Comparison of optimum NPK (OPT) and farmer practices (FP) in Gansu and Xinjiang.

Location	Year	Treatment	N	P_2O_5 kg/ha	K_2O	Mean yield†, t/ha	Cost‡, USD/ha	GRF§, USD/ha
Gansu	2006	OPT	225	120	150	12.0a	393	3,807
		FP	300	150	0	11.3b	350	3,617
Gansu	2007	OPT	300	120	150	13.2a	447	4,161
		FP	450	120	0	11.9b	431	3,734
Gansu	2007	OPT	300	120	150	10.4a	447	3,181
		FP	450	120	0	9.5a	431	2,894
Gansu	2007	OPT	225	150	150	11.3a	420	3,544
		FP	150	120	0	9.4b	215	3,073
Gansu	2007	OPT	225	150	150	14.5a	420	4,667
		FP	225	150	0	12.7b	296	4,159
Gansu	2007	OPT	300	120	150	8.9a	447	2,663
		FP	450	120	0	7.9b	431	2,336
Gansu	2009	OPT	225	120	90	9.0a	344	2,816
		FP	150	105	0	8.2b	201	2,659
Gansu	2009	OPT	225	90	60	9.4a	292	2,989
		FP	150	120	0	9.0a	215	2,937
Xinjiang	2006	OPT	232	70	34	11.3a	259	3,691
		FP	274	172	0	11.0a	351	3,489
Xinjiang	2009	FP+K	192	138	225	16.6a	448	5,375
		FP	192	138	0	14.4b	261	4,783
Xinjiang	2007	FP+K	192	138	90	9.8a	336	3,081
		FP	192	138	0	8.8b	261	2,821
Xinjiang	2008	FP+K	192	138	225	16.6a	448	5,375
		FP	192	138	0	14.6b	261	4,845
Xinjiang	2010	FP+K	192	138	225	13.8a	448	4,385
		FP	192	138	0	12.4b	261	4,082

†For each location, mean yields followed by the same letter are not significantly different at $p<0.05$.
‡Total costs (USD) of N, P, and K fertilizers: N = \$0.72/kg, P_2O_5 = \$0.89/kg, K_2O = \$0.83/kg. (1 USD = 6.30 RMB)
§GRF = gross return to fertilizers; Maize price = \$0.35/kg.

desperate need to develop fertilizer recommendation tools that consider more than just a soil test; and 3) the rates of N and P applied by farmers in northwest China are very high given the yield responses obtained and this needs to change to avoid unnecessary losses in profitability and as well as negative environmental impacts. BC

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Crop Nutrient Deficiency Photo Contest Entries Due December 11

December 11, 2012, is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. An individual can submit an entry for each of the four nutrient deficiencies categories: nitrogen (N), phosphorus (P), potassium (K), and other (i.e. secondary nutrients and micronutrients).

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

Soil Potassium in Uruguay: Current Situation and Future Prospects

By Mónica Barbazán, Carlos Bautes, Licy Beux, J. Martín Bordoli, Alvaro Califra, Juan D. Cano, Amabelia del Pino, Oswaldo Ernst, Adriana García, Fernando García, Sebastián Mazzilli, and Andrés Quincke

Recent field research in Uruguay has revealed K deficiencies in the main field crops of the country. A preliminary survey indicates that almost 5 M ha would be deficient in K. A critical soil test K (STK) level of 0.34 meq/100g (133 ppm) has been estimated based on 50 field trials conducted on the six primary field crops.

Efforts to understand K dynamics in soils of Uruguay have been scarce compared with those that have measured soil N and P dynamics. These latter studies have already been conducted for numerous cropping situations and systems. Historically, soil P experimentation has had a much higher priority over K (**Figure 1**).

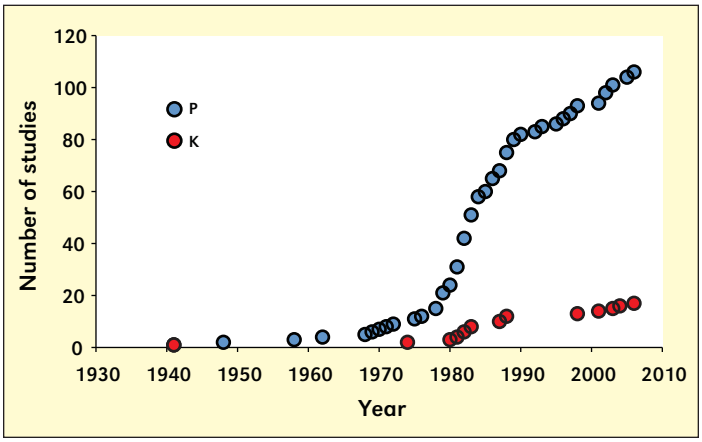

Figure 1. Number of P and K studies in Uruguay for grain crops and forages made between 1950 and 2010.

Earlier studies on crop response to K fertilization have been done for those with high K requirements such as sugarcane, sugar beet, potato, onion, and cotton. Some guidelines for fertilizer recommendations, based on soil type, have also been established (Oudri et al., 1976). In grain crops, the first K studies were made in the 1960s where K responses were observed in wheat grown in soils developed from cretaceous sandstones (Moir and Reynaert, 1962; Castro, 1965). Two decades later, a few studies in soybean showed little or no K response in Uruguay's northeastern soils (Docampo et al., 1981; Marella et al., 1981; Colombo and Collares, 1982; Pereira et al., 1983).

The lack of K studies has likely been due to the development of agriculture on high K soils under conventional tillage, and crop rotations that included pastures, which resulted in no K fertilizer recommendations. Potassium fertilization was recommended only below 0.30 meq/100g (117 ppm), following references from the U.S. Corn Belt, which reported low K response probability with STK levels over 0.23 to 0.33 meq/100g (90 to 130 ppm) in soybean and maize under conventional tillage (Voss, 1982).

More recently, Morón and Baethgen (1996) and Barbazán et al. (2007) reported some cases of K deficiency symptoms in soils with low STK in maize and *Lotus corniculatus* L. Moreover, the increasingly frequent occurrence of visual symptoms of K deficiency, confirmed by plant analysis, has led to more specific studies showing K responses in several crops (Almada, 2006; Cano et al., 2007, 2009; Bautes et al., 2009; García et al., 2009). Determining a critical STK level for a wide range of situations has been a key challenge. Barbazán et al. (2010, 2011) summarized 50 recent studies (which had the same tillage system, and similar experimental design, rate, and K source), and found a critical STK level of 0.34 meq/100g (133 ppm; 0 to 20 cm depth), representing a breakthrough in K research in Uruguay (**Figure 2**).

Common abbreviations and symbols: N = Nitrogen; P = phosphorus; K = potassium; KCl = potassium chloride; M = million; meq = milliequivalents; ppm = parts per million.

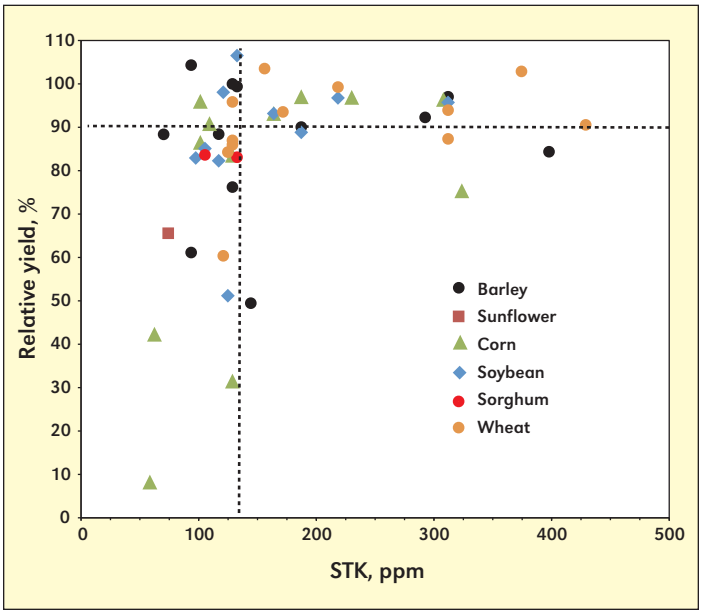

Figure 2. Relationship between relative crop yield (RY) and soil test K (STK; 0 to 20 cm) in Uruguay. Based on data of 50 field experiments. RY expressed as the percent ratio between averaged yields of check and fertilized plots (100 to 200 kg/ha of KCl). Source: Barbazán et al. (2010, 2011).

Soil K levels: Distribution and Nutrient Balances for Uruguay

Soils of Uruguay present a wide range of STK levels (Hernández et al., 1988) (**Figure 3**). According to the Soil Survey Guide of Uruguay (Altamirano et al., 1976), soil units covering approximately 5 M ha would have low K availability. In the typical agricultural area of western Uruguay, STK levels are medium to high.

However, agricultural scenarios of Uruguay have changed during the last two decades. Cropping systems have intensified to a current index of 1.5 crops per year (DIEA, 2010) result-

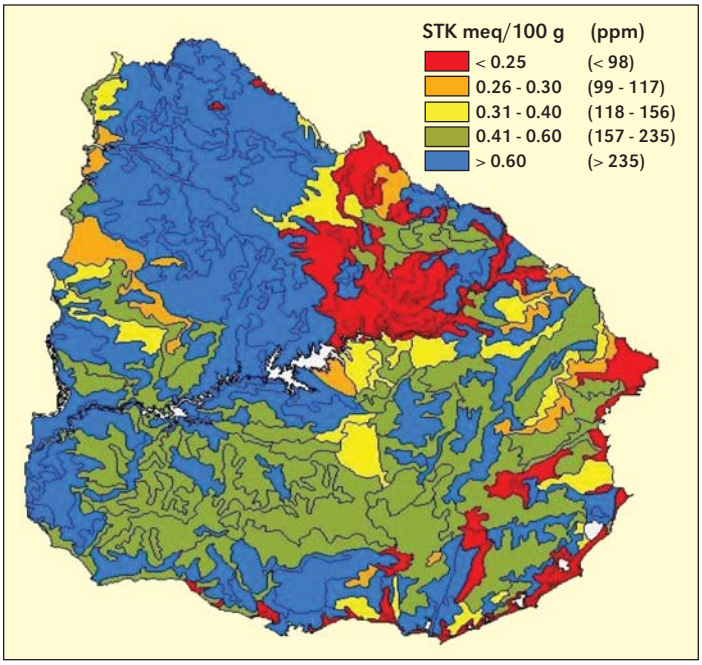

Figure 3. Soil test K (STK; 0 to 20 cm) according to the soil recognition guide of Uruguay. Scale: 1:1,000,000. From Califra and Barbazán (unpublished).

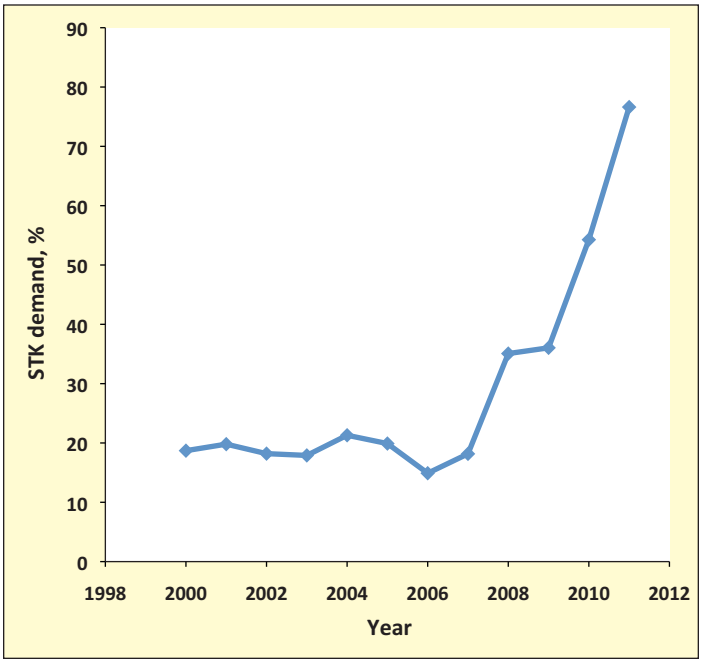

Figure 5. Evolution of soil test K (STK) demand in Uruguay. Values are expressed as a percent of total amount of samples analyzed.

ing in significant soil K depletion. To this effect, Morón and Quincke (2010) reported that STK levels in soils under agriculture within the Department of Soriano (western agricultural area) have decreased by 40% (0 to 7.5 cm depth) and 44% (7.5 to 15 cm depth) from levels observed in the same soils without agricultural history. In addition, agriculture has expanded to marginal regions where low STK soils are already common.

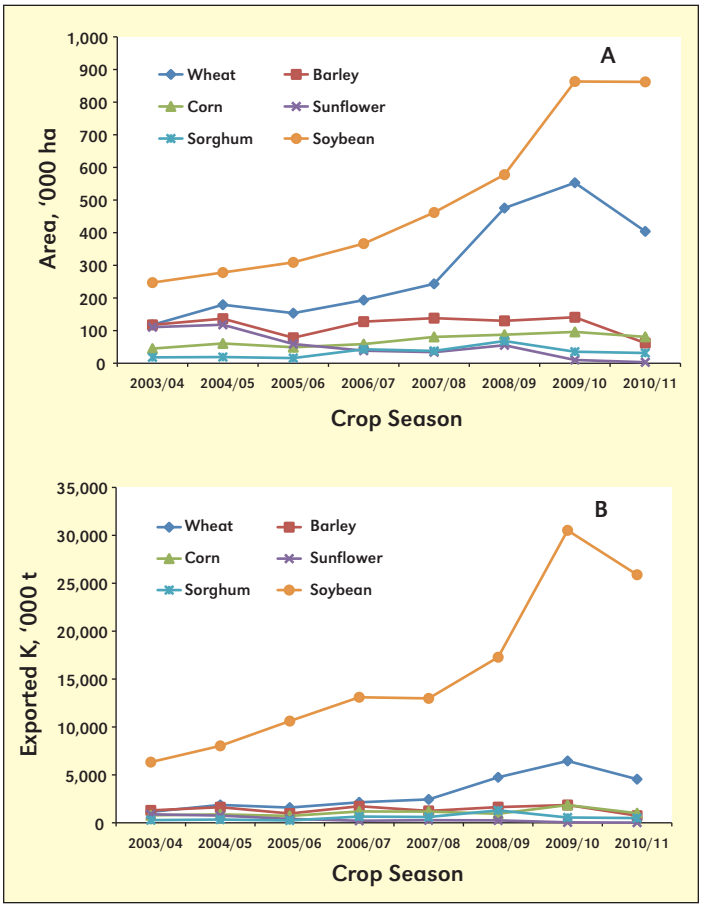

Figure 4. Cropped area (A) and exported K (B) by the six main crops in Uruguay during the 2003 to 2010 period. Based on DIEA (2010) and IPNI (2012).

The soil K balances for fields in Uruguay (application minus removal) have historically been negative due to the absence of K fertilization. Soil K removal has grown with soybean production, which currently covers about 1.0 M ha through a wide range of soils with different availability and stocks of K. As the area under soybean has increased (**Figure 4**), soil K balances have become more negative due to the crop's high K requirements [i.e. soybean exports for 2010 were 1.8 M t, implying a K removal of approximately 36,000 t of K_2O considering an average grain content of K (IPNI, 2012)].

Considering the large agricultural area and current fertilizer prices in Uruguay, priority must be maintained on improving our understanding of soil K dynamics in order to define research areas that are able to produce the most useful information on soil K management. Agronomists and farmers are already concerned about STK in their different regions, which is reflected by the increasing demand in soil K analysis (**Figure 5**).

Future research and experimentation will have to focus on the medium- and long-term relationships of K dynamics as impacted by soil mineralogy and physical properties, cropping system changes, and soil management history. The effect of crop residue quality and its management may affect K distribution with soil depth, and it should be considered by soil survey/sampling and fertilizer recommendations. These studies would be useful in developing K fertilization guidelines. Potassium use efficiency depends on the understanding of K dynamics in the soil-plant system, as well as crop and soil responses to soil fertility management. Long-term studies would greatly contribute to finding solutions to existing and anticipated problems. BC

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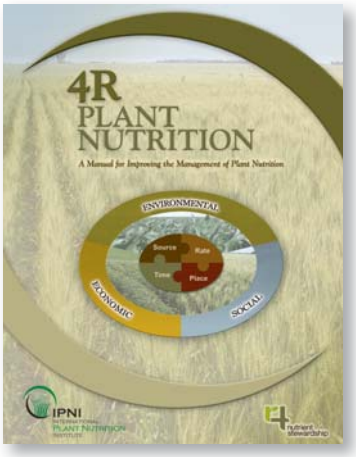

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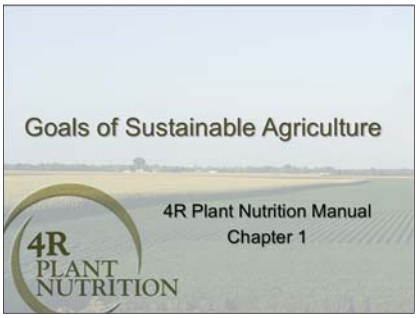

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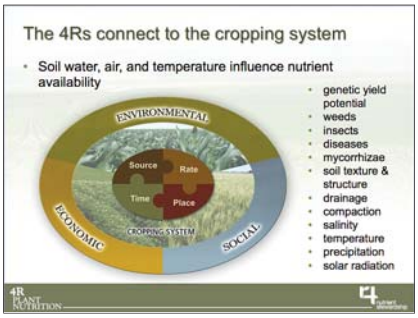

Role of Nitrogen Fertilization in Sustaining Organic Matter in Cultivated Soils

By Jagdish K. Ladha, C. Kesava Reddy, Agnes T. Padre, and Chris van Kessel

This article summarizes work published by Ladha et al. (2011) using data from long-term studies around the world to evaluate the impact of commercial fertilizer N on SOM. The results show that commercial fertilizer N leads to a slower decrease in SOM content, or may cause a small increase, after a new soil equilibrium is reached following N application.

Soil organic matter is essential for sustaining food production and maintaining ecosystem services . (i.e., resources and processes that are supplied by natural ecosystems) and is a vital resource base for storing C and N. The impact of long-term use of commercial fertilizer N on SOM, however, has been questioned recently. We tested the hypothesis that long-term application of N results in a decrease in SOM. We used data from 135 studies of 114 long-term experiments located at 100 sites throughout the world, over time-scales of decades under a range of land-management and climate regimes, to quantify changes in SOC and SON.

Today, commercial fertilizer N supplies approximately 45% of the total N input for global food production, and world use is approximately 100 million metric tons (M t) (FAO, 2010). It is projected that annual total global N use will grow to approximately 112 M t in 2020, and approximately 171 M t in 2050.

Soil organic matter is a key indicator of soil fertility, provides an energy source for heterotrophic soil micro-organisms and is an important source of plant nutrients; particularly, but not exclusively, N. However, SOM changes with cultivation and fertilizer N inputs; normally, it decreases with cultivation without N fertilization and may increase with fertilizer N amendment (Brye et al., 2003). Potentially, there can be two mechanisms whereby fertilizer N affects SOM: (i) fertilizer N may augment SOM (Glendining and Powlson, 1995; Khan et al., 2007; Mulvaney et al., 2009; Powlson et al., 2010;) by promoting plant growth and thereby increasing the amount of litter (plant residue) added to soil compared with soil not receiving N and (ii) fertilizer N may lead to enhanced loss of SOM by accelerating its rate of oxidation or decay of litter and indigenous organic material.

If commercial fertilizer N does decrease SOM, a spiral of decline in soil functioning and crop productivity would be expected. It is therefore important to determine whether the long-term use of commercial fertilizer N does indeed lead to a general decline in SOM. Here, we address a pressing question of importance to global agriculture and food production: Does the long-term use of commercial fertilizer N lead to a decline in SOM in our soils?

A total of 917 and 580 observations for C and N, respectively, derived from 135 studies at 114 long-term experimental sites were included in the analyses. Carbon or N was reported either (i) as gravimetric concentration (i.e., g/kg) or (ii) as volumetric content (i.e., kg/ha). The data set was divided by (i) fertilizer type: unfertilized or zero N, fertilized with commercial N, fertilized with an organic source, and fertilized with combination of organic and commercial N; (ii) land use: flooded, flooded dryland, and dryland; and (iii) climate: tropical, subtropical, and temperate. The responses of fertilizer N input to SOC and SON content were calculated in two ways: (i) percentage difference in SOC and SON content following the application of fertilizer N between time (t) = 0 and t = 1, referred to as time response (TR) ratio, and (ii) percentage difference between the change in SOC and SON in N-fertilized treatments compared with the change in SOC and SON in the zero-N treatment, referred to as time by N-fertilizer response (TNR). The TR addresses the impact of the whole system (tillage, residue management, erosion, fertilizer amendment) on changes in SOC and SON, whereas the TNR specifically assesses the impact of a fertilizer N amendment. All the data were analyzed using the SAS mixed model procedure and meta-analysis.

Common notes and abbreviations: N = nitrogen; C = carbon; SOM = soil organic matter; SOC = soil organic carbon; SON = soil organic nitrogen.

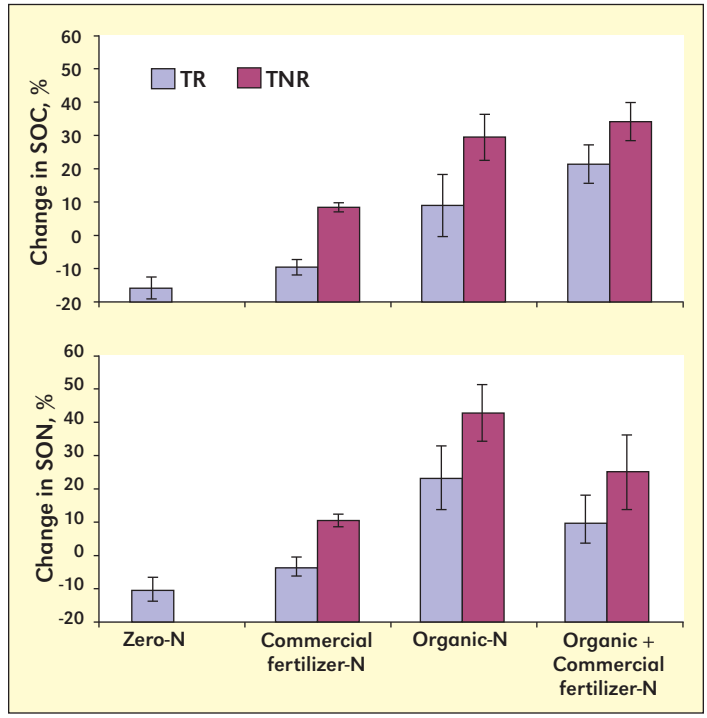

Figure 1. Percentage response in SOC and SON to fertilizer N input as calculated by time response (TR) and N-fertilizer response (TNR) ratios using meta-analysis. Vertical brackets over the data bars represent standard deviation at 95% confidence interval.

Overall, zero-N showed a larger decrease in the TR ratio of SOC and SON than when commercial N was applied (**Figure 1**). Under zero-N inputs, SOC declined by 16% and SON declined by 11%, based on meta-analysis.

When commercial N was applied, SOC decreased by only 10% and SON by 4%. It is important to consider the TNR ratio,

which is based on changes in the paired comparisons. On the basis of overall averages, SOC and SON were 8 to 10% higher with commercial fertilizer N than with zero-N (**Figure 1**). These gains were statistically different from zero-N ($p < 0.05$). In general, SOC and SON declined over time from the initial to final sampling period. However, the declines in SOC and SON were lessened (or smaller) with commercial N fertilization.

Among the three subgroups of land use, flooded soils showed a marginal increase in SOC and SON, respectively, in both zero-N (3 to 9%; 1 to 4%) and commercial N treatments (9 to 15%; 8 to 12%) using the TR ratio approach. Both flooded dryland soils and dryland soils showed significant losses of SOC (4 to 19%) and SON (3 to 23%), with and without the application of commercial fertilizer N. The TNR ratios indicated that commercial N led to a relative increase in SOC. For TNR, the commercial fertilizer N response ratios more than doubled in flooded dryland (17% for SOC and 20% for SON) compared with flooded (7% for SOC and 8% for SON) and dryland (7% for SOC and 9% for SON) agro-ecosystems. This indicates that flooded soils and dryland soils are likely to respond less to commercial fertilizer N than will flooded dryland agro-ecosystems.

The general decline in SOM content across a wide range of agricultural production systems (**Figure 1**) will probably have long-term repercussions on the soil's ability to store and regulate the supply of plant-available nutrients (especially N) and ability to improve soil structure. Maintaining SOM levels will therefore remain a key component in sustainable agricultural systems (Swift and Woomer, 1993). To meet crop N demand, the decline in the N-supplying capacity of the soil will need to be compensated by an increase in commercial or organic fertilizer N use. An increase in commercial or organic fertilizer N use to sustain crop yield, however, will lead to potential increases in N losses to the environment, with reactive N becoming part of a cascade effect through the biogeochemical pathway. Therefore, new and advanced management practices should focus on maintaining or increasing SOM levels.

In conclusion, SOM content generally declined over time at virtually all of the long-term sites. However, the use of commercial fertilizer N led to a slower decrease in SOM content and not to a further additional decrease as suggested by Mulvaney et al. (2009). The primary function of commercial fertilizer N is to provide the crop with an immediately available source of N; often the nutrient most limiting plant growth. The secondary function, as shown in this analysis, is that commercial fertilizer N can reduce the decline in SOM content; or cause a small increase after a new equilibrium in SOM content has been reached following a change in management practices, such as; converting grassland to cereal cropping or the implementation of zero-tillage (no-till). BC

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The Effect of Reduced Tillage and Mineral Fertilizer Application on Maize and Soybean Productivity in Kenya

By Job Kihara and Samuel Njoroge

Conservation Agriculture (CA) has been promoted for adoption by smallholder farmers in maize-based cropping systems in sub-Saharan Africa with limited success, mainly due to a reduction in crop yields in the initial years of transition from conventional tillage (CT) to CA. Results from this study confirmed the initial yield reduction with CA and showed that at least six seasons were required for maize yields under CA to match those under CT. However, soybean yields were not affected by tillage practice and may offer opportunity to accelerate the agronomic benefits of CA in rotation and intercrop systems.

Conservation agriculture, based on reduced tillage (RT) and surface retention of crop residues, offers smallholder farmers in sub-Saharan Africa an opportunity to reverse land degradation that is prevalent in the region and support sustainable intensification of crop production (Fowler and Rockstrom, 2001). Conservation agriculture has been found to enhance physical, biological, and chemical properties of the soil when compared to CT practices (Madari et al., 2005). Despite the benefits of CA on soil quality restoration, adoption among farmers in Kenya and elsewhere in sub-Saharan Africa has been low (Rockstrom et al., 2003). Among the reasons for low adoption of CA by smallholder farmers is the initial lower crop productivity associated with CA compared to CT commonly practiced by farmers (Taa et al., 2004).

A long-term on-farm experiment was established in 2003 to investigate the effect of tillage and crop residue application on maize and soybean productivity over different cropping seasons in the sub-humid zone of western Kenya. The aim of the study was to identify cropping systems that may offer opportunities to enhance the soil fertility benefits of CA, while preventing the initial depression of yields associated with the transition from CT. The experiment was conducted over nine seasons from 2003 to 2007.

Soils in the study site had the following characteristics: 64% clay, 15% sand, pH (water) 5.1, 1.35% SOC, 0.15% N, and 3.0 mg/kg available P. The mean annual rainfall is 1,800 mm and occurs in two seasons: long rains from March to August and short rains from September to January.

A cooperating farmer in western Kenya planting maize in the conservation tillage plots.

The experiment was set up as a split-split-split plot design with four replicates and had a factorial combination of tillage system (reduced and conventional tillage), crop residue management (+/- crop residue) and cropping system (continuous cereal, soybean-maize rotation and soybean-maize intercrop). All plots received a blanket application of 60 kg P/ha and 60 kg K/ha each year. Additionally, the maize crop in the monocrop and maize-soybean rotation systems received 60 kg N/ha. No N was applied to the maize-soybean intercrop system. Maize residues were applied seasonally at 2 t/ha before planting. The maize residues were left on the surface in RT plots and incorporated in CT plots. Soybean residues were not removed after harvesting, and were either incorporated in the CT treatment or left on the surface in the RT treatment. Maize was planted at a spacing of 0.75 m x 0.25 m with one plant per hill. Soybean was planted at 0.05 m x 0.75 m.

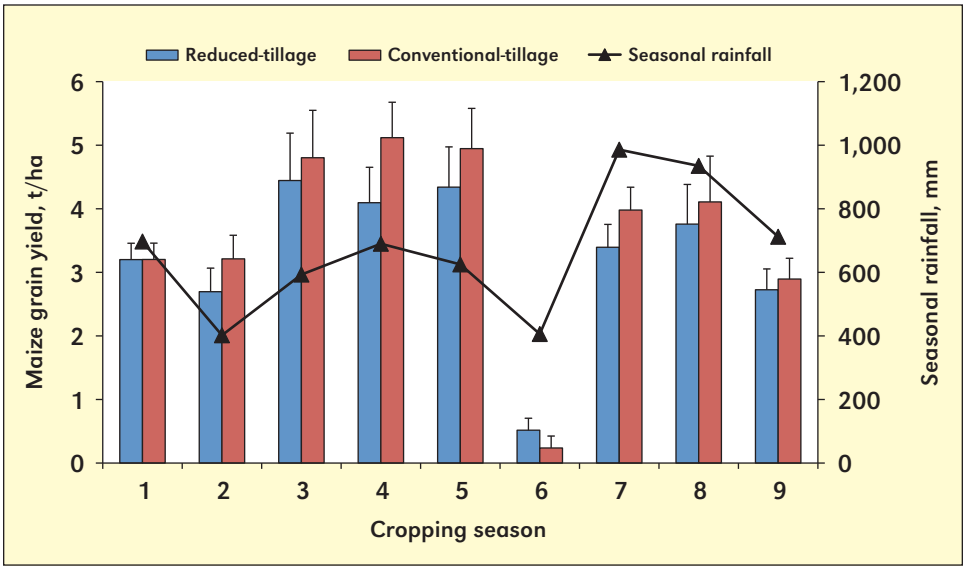

Figure 1. Maize grain yield in reduced and conventional tillage as observed in continuous maize cropping system in Nyabeda, western Kenya, from March 2003 to August 2007.

Common abbreviations and notes: N = nitrogen, P = phosphorus, SOC = soil organic carbon, USD = United States dollar.

Table 1. Maize yield in continuous maize, soybean-maize rotation, and soybean-maize intercropping in Nyabeda, western Kenya, March 2003 and August 2007.

Treatment	Continuous maize	Rotation	Intercrop
	----------	t/ha	----------
Reduced tillage -CR	3.24 c	3.18 b	1.75 b
Reduced tillage +CR	3.58 bc	3.00 b	1.89 b
Conventional tillage -CR	3.97 ab	3.91 a	2.77 a
Conventional tillage +CR	4.07 a	3.74 a	2.58 a
SE	0.20	0.20	0.16
Tillage	**	**	**
Tillage x Crop residue	-	-	-

Numbers in the same column followed by a different letter are significantly different at $p<0.05$; CR = crop residue; SE = standard error; **significant at $p<0.01$; Season 6 was not included due to crop failure as a result of drought.

Table 2. Average soybean yield (t/ha) in soybean-maize rotation and intercropping systems in Nyabeda, western Kenya, March 2003 and August 2007.

Tillage	Crop residue	Rotation	Intercrop
Reduced tillage	-CR	0.95	0.56
Reduced tillage	+CR	0.92	0.60
Conventional tillage	-CR	0.99	0.52
Conventional tillage	+CR	0.98	0.53
SE		0.107	0.092

CR = crop residue; all treatments received 60 kg P/ha but not N; season 1 (common beans) and crop failure season (season 6) not included; SE = standard error.

The crop spacing was maintained for the intercrop system. Analysis of variance for maize yield data was conducted using Statistical Analysis Software (SAS). Gross margin was calculated as the difference between gross revenue and total variable costs (**Table 3**).

Maize Yields

There was no significant effect of crop residue addition on maize yield and only small variations (-9 to +11%) were observed. This is in agreement with the finding of Erenstein (2003) that there are no clear immediate benefits of crop residue in sub-humid environments. However, addition of crop residues may improve maize yields in the long-term, as improved soil structure with addition of crop residues was observed for this site (see Kihara et al., 2012).

Maize yields varied from year-to-year due to variability in seasonal rainfall (**Figure 1**). Average maize yields for the nine seasons, were 3.2 to 4.1 t/ha in continuous maize, 3.0 to 3.9 t/ha in soybean-maize rotation and 1.8 to 2.8 t/ha in the soybean-maize intercropping system (**Table 1**). CT resulted in 11 to 26%, 17 to 30%, and 36 to 58% higher maize yields than RT, in continuous maize, soybean-maize rotation and intercropping systems, respectively. Although yields for CT were initially higher than under RT in the continuous maize and rotation systems, there were no significant differences in yields observed during the last three seasons. A time lag of six seasons was therefore necessary for maize yields in RT to match those in CT systems. The improved performance of RT after six seasons is likely due to soil improvement under reduced tillage, including soil structure as reported in Kihara et al., 2012. This is consistent with other studies which have reported initial lower yields in RT compared with CT systems and increased RT yields after several seasons of continued practice (Malhi et al., 2006). For the intercrop systems, higher yields were consistently produced under CT than RT. Maize yields were lower for the intercrop systems compared to the monocrop and rotation systems as no N fertilizer had been applied and the possible competition from the associated soybean crop.

Table 3. Average seasonal gross margins of different tillage and crop residue combinations in different cropping systems in Nyabeda, western Kenya, from March 2003 to August 2007.

Treatment	Cropping system	Gross margin*, USD/ha	SE
Reduced tillage -CR	Maize monocrop	247	165
Reduced tillage +CR	Maize monocrop	289	105
Conventional tillage -CR	Maize monocrop	322	143
Conventional tillage +CR	Maize monocrop	322	137
Reduced tillage -CR	Intercrop	344	254
Reduced tillage +CR	Intercrop	374	313
Conventional tillage -CR	Intercrop	435	393
Conventional tillage +CR	Intercrop	401	347
Reduced tillage -CR	Rotation	337	216
Reduced tillage +CR	Rotation	305	211
Conventional tillage -CR	Rotation	384	171
Conventional tillage +CR	Rotation	359	195

SE = standard error.
*The gross margin analysis was based on 2007 prices (USD) for harvested grain including: $185.50/t for maize and $694.40/t for soybean. Crop input prices included $690/t for maize seed, $690/t for soybean seed, $444/t for urea, $514/t for triple super phosphate, and $590/t for potassium chloride.

Soybean Yields

Average soybean yields ranged between 0.92 to 0.99 t/ha in the soybean-maize rotation, and between 0.52 to 0.60 t/ha in the soybean-maize intercropping system (**Table 2**). Although soybean yields were expected to respond to tillage and crop residue management as observed with maize yield, no such effects were observed. The lack of differences can be attributed to faster establishment and maximum canopy (reaching up to 100% in about two months after planting), which completely covered the soil and protected soil water from surface evaporation. The soil under the bushy soybean was observed to be wetter than in the other cropping systems. The similar soybean yields under RT and CT suggest that including soybean in rotation with maize in RT systems could reduce the overall yield losses in the initial years of establishment of RT.

Profit Analysis

Conventional tillage gave higher mean gross margins than

RT for the nine seasons under the three cropping systems. Average annual gross margins over the nine seasons ranged from USD 247 in the continuous cereal (RT minus crop residue) to USD 435 in the soybean-maize intercropping system (CT minus crop residue) (**Table 3**). These gross margins were influenced by the cropping system and were in the order intercropping > rotation > continuous maize. Although savings in labor in RT lowered the costs of production, this could not compensate for the reduced income from lower yields in the RT system. Longer time periods (> nine seasons) are required to make RT economically viable for farmers, and this is one of the key factors discouraging wide-scale adoption of conservation agriculture in mixed maize and legume-based smallholder farming systems.

Summary

RT with application of residues resulted in soybean yields comparable to CT system treatments, for rotation and intercrop systems, with no yield reduction observed over nine seasons. However, maize yields were initially suppressed in RT treatments under monocrop, rotation and intercrop systems, and at least six seasons of continued RT practice were required for the yields to match those under CT. The lower yields under RT resulted in lower mean gross margins for nine cropping seasons, and this is a disincentive for farmers to switch from conventional tillage to conservation tillage. More work is required to develop effective management practices to control weeds and to supply greater soil cover in the RT system to avoid soil-crusting problems which lead to the initial lower maize yields with RT under smallholder condition in sub-Saharan Africa. BC

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Potassium Nutrition for Small Grains Grown on Chestnut Soils

By V.N. Bagrintseva and V.V. Nosov

Long-term trends in soil K forms and available K status for Russian chestnut soils reveal that available K declines more rapidly in chestnut soils than in chernozems. Potassium fertilization of chestnut soils resulted in improvement of small grain (winter wheat and winter barley) yield and quality in the dry zone of Stavropol Krai.

Stavropol Krai is one of the largest grain-growing regions in Russia. However, about 50% of its cereal grain output comes from areas that suffer from season-to-season fluctuations in yield due to moisture deficit. Soil and climatic conditions in these drier areas do allow for fairly high cereal yields if adverse weather conditions are avoided. However, insufficient precipitation, non-uniform distribution of rainfall between growth stages of cereals, soil drought, and hot, dry winds cause large reductions in yield. Since optimal mineral nutrition improves water use efficiency in crops (Nikitishen and Lichko, 2007), balanced fertilization can be an effective method to increase yield and improve quality of grains in these dry areas.

Chestnut soils (Ustolls, Borolls, and Xerolls) occupy about 11% of arable land in Russia and are the fourth largest, in terms of area, after chernozems, grey forest soils, and soddy-podzolic soils (Russian Agriculture, 2010). The zone of chestnut soils is located in the northeastern and eastern parts of Stavropol Krai—located between the Black and Caspian Seas. Chestnut soils and their complexes with alkali soils (solonetz) and saline soils (solonchak) occupy 46% of the land area in the region (Antykov and Stomorev, 1970). The eastern part of Stavropol Krai is also characterized by small amounts of precipitation and non-uniform distribution of rainfall over the year. The long-term average precipitation in the area is 354 mm. Light chestnut soils are found in the driest area of the dry steppe zone and these soils have lower organic matter content compared to chestnut soils.

Soil K Availability in Chestnut versus Chernozem Soils

Chestnut soils and light chestnut soils generally have higher contents of water-soluble, available [extracted with $(NH_4)_2CO_3$ solution], and so-called "easily exchangeable" K (extracted with $CaCl_2$ solution), but lower non-exchangeable K (**Table 1**) when compared with chernozems (Bagrintseva, 1993).

Table 1. Different forms of K (ppm K_2O) in the surface (0 to 20 cm) layers of calcareous chernozem and chestnut soils.

Soil subtype	Water-soluble	Easily available	Available	Non-exchangeable, 2M HCl	
				24°C	Boiling
Calcareous chernozem[1]	20	8	214	1,260	4,750
Chestnut soil[2]	16	20	277	992	3,800
Chestnut soil[3]	40	60	345	700	3,395
Light chestnut soil[3]	80	96	600	863	3,254

[1]Shpakovsky district; [2]Buddenovsky district; [3]Levokumsky district.

A successive soil K extraction study (procedure according to Cherkasova, 1991) found the total amount of available K was 1.6 to 1.9 times higher in a chernozem soil than in chestnut soils (**Table 2**). However, for chestnut and light chestnut soils 68 to 76% of the total amount extracted was contained within the first extract—a considerably smaller proportion was extracted in the first filtrate taken from the chernozem. All available K in chestnut and light chestnut soils was extracted over 6 to 8 successive extractions, while extractable K appeared to level-off at a moderate rate of release even after a tenth successive extraction for the chernozem. It is apparent that chestnut soils could not sustain a rapid replenishment of available K from its slowly available forms in the same manner as chernozems. The content of available K in chestnut soils may, therefore, decline more rapidly than in chernozems under similar negative K balance (Cherkasova, 1991).

For a long time, research on effect of K fertilizer on winter wheat grown on chestnut soils did not receive adequate attention simply because of the common perception that chestnut soils had higher contents of available K than chernozems (Chelyadinov and Stomorev, 1964). This absence of experimental data to support the efficient use of K fertilizer occurred within a period of declining soil K status in chestnut soils. In the face of decreasing levels of available K, declining arable land area

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; $CaCl_2$ = calcium chloride; $(NH_4)_2CO_3$ = ammonium carbonate; HCl = hydrochloric acid; DM = dry matter; ppm = parts per million.

Table 2. Potassium extracted through successive extractions in calcareous chernozem and chestnut soils with 1% ammonium carbonate $(NH_4)_2CO_3$ solution.

Soil subtype	Successive extractions of K, ppm K_2O											Percentage of 1st extraction from total extracted K
	1	2	3	4	5	6	7	8	9	10	Total	
Calcareous chernozem[1]	235	126	65	75	63	49	34	32	34	34	747	31
Chestnut soil[2]	266	32	28	21	17	10	8	8	0	0	390	68
Chestnut soil[3]	345	44	32	16	8	8	0	0	0	0	453	76
Light chestnut soil[3]	606	98	49	28	12	8	0	0	0	0	801	76

[1]Shpakovsky district; [2]Buddenovsky district; [3]Levokumsky district.

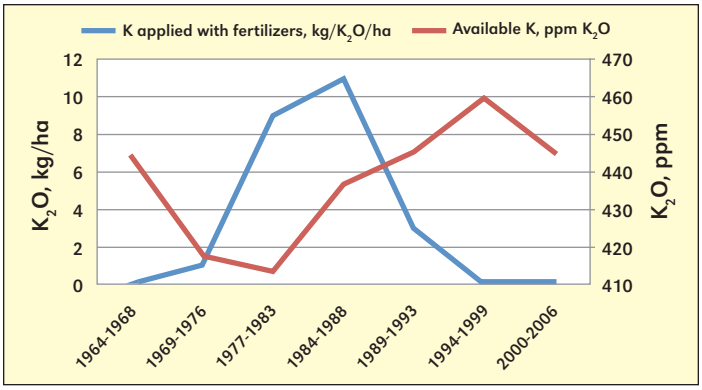

Figure 1. Trends in fertilizer K applications and contents of available K (weighted average) in the zone of chestnut soils, Stavropol Krai.

in "increased" and high soil fertility classes for available K (i.e., 201 to 400 ppm K_2O using $(NH_4)_2CO_3$ extractant), and increasing arable land area in low and medium classes (i.e., 51 to 200 ppm K_2O) scientists were forced to recommend K fertilization in winter wheat to replenish K removed by harvest (Karandashov and Podkolzin, 1987). However, agronomists employed by agricultural enterprises did not follow them at the time since these recommendations offered no experimental evidence that K fertilizers had any effects other than maintaining available K levels.

Subsequent soil fertility surveys conducted by Podkolzin (2008) revealed trends in the dynamics of available K in chestnut soils in response to K fertilizer use (**Figure 1**). More significant application of K began in the early 1980s until the mid-1990s. It was estimated that each 3 kg K_2O/ha applied to winter wheat after bare fallow increased available K content in chestnut soils by an average of 1 ppm K_2O. However, more recently, negative K balances have been commonplace with practically no use of K fertilizers, and this has already had a negative effect on available K content in these soils. Based on soil test results, it was concluded that the status of available K has returned to the initial level of the 1960s, when the use of K fertilizers first began.

Effect of K Fertilizers on Yield and Quality of Small Grains

The Prikumskaya Research Breeding Station of the Stavropol Research Institute of Agriculture conducted a series of fertilizer experiments on chestnut soil with available K content between 250 to 300 ppm K_2O (the so-called "increased" class ranges from 201 to 300 ppm K_2O). It was revealed that K fertilizers, when properly applied, gave substantial yield increases in cereals and high grain quality (Bagrintseva, 1996). Field experiments were conducted mainly with the following crop rotation: bare fallow – winter wheat – winter wheat – bare fallow – winter wheat – winter barley. In these studies, P fertilizers were applied only to the first winter wheat crop after fallow (i.e., twice per rotation). The repeated cropping of winter wheat is a rather common practice in agricultural enterprises of the region.

Potassium chloride fertilizer increased DM accumulation in winter wheat and winter barley through all stages of crop development (**Table 3**). The increase in DM yield of the second wheat crop after fallow due to applied K was relatively higher compared to the first wheat crop, probably because soil K availability fell during the second wheat crop after fallow. The highest DM accumulation by the second wheat crop was obtained with 60 kg K_2O/ha, which gave DM increases of 37%, 15%, and 10% at the tillering, heading, and grain filling stages, respectively. Interestingly, the positive effect of K fertilization on barley DM accumulation was visible through the years with different weather conditions. The application of only 30 kg K_2O/ha to barley resulted in a DM increment of 27% at grain filling stage. Similarly, the application of fertilizer K had a positive effect on total and productive tillering capacity in the first wheat crop after fallow, and hence, the number of tillers and heads per m^2 (**Table 4**). Weight per m^2 of straw, heads, and grain was also slightly increased due to K application. As a result, grain yield of the first winter wheat after fallow increased by 0.26 t/ha (or 6%) due to K application of 60 kg K_2O/ha (**Table 3**). The same rate of K gave a yield increase of 0.35 t/ha (or 12%) in winter wheat grown repeatedly. The efficiency of K fertilizer use was high in winter barley with a yield increment of 14%. Taking into consideration such a high response of barley to K application in a relatively low rate, the agronomic

Winter barley (shown) and winter wheat provide half of the cereal grain output in southern Russia.

Table 3. Dry matter (DM) accumulation, grain yield (GY), and agronomic efficiency of K (AE_K, kg grain/kg K_2O) in cereal crop rotations (3 yr. average)

Treatment[1]	DM at different crop stages, t/ha: Tillering	Heading	Grain filling	GY, t/ha	Yield increase, t/ha	Yield increase, %	AE_K
1st Winter wheat (after fallow)							
$N_{60}P_{120}$	3.32	9.02	13.65	4.23	-	-	-
$N_{60}P_{120}K_{60}$	3.70	9.45	14.13	4.49	0.26	6	4.3
2nd Winter wheat							
N_{60}	1.77	6.50	7.87	2.93	-	-	-
$N_{60}K_{60}$	2.43	7.45	8.67	3.28	0.35	12	5.8
Winter barley							
N_{60}	1.77	4.13	5.01	2.58	-	-	-
$N_{60}K_{30}$	1.92	4.97	6.35	2.93	0.35	14	11.7

[1]Fertilizer N, P_2O_5, and K_2O rates are given in subscripts.

Table 4. Yield components of winter wheat with K fertilizer application (3 yr. average)

Treatment[1]	Number per m² Plants	Tillers	Heads	Tillering capacity Total	Productive	Weight g/m² Straw	Heads	Grain
1st Winter wheat (after fallow)								
$N_{60}P_{120}$	263	607	541	2.3	2.1	1,013	557	400
$N_{60}P_{120}K_{60}$	259	627	580	2.4	2.2	1,043	579	411
2nd Winter wheat								
N_{60}	199	408	389	2.1	2.9	484	427	321
$N_{60}K_{60}$	228	493	448	2.2	2.0	612	488	367

[1]Fertilizer N, P_2O_5, and K_2O rates are given in subscripts.

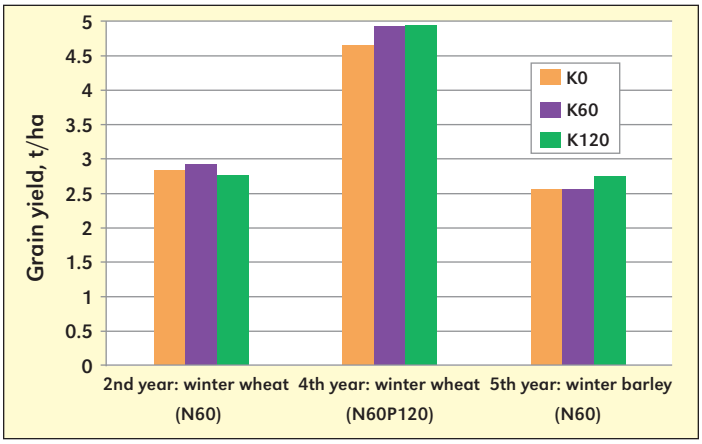

Figure 2. Residual effect of fertilizer K applied at 0, 60, and 120 kg/ha K_2O rates to the 1st winter wheat after fallow (with 60 kg/ha N and 120 kg/ha P_2O_5) on grain yields of successive cereals in crop rotation.

efficiency (AE) of K fertilizer was the highest in this case and reached 11.7 kg grain/kg K_2O. It is estimated that K fertilizer use in winter wheat and winter barley could be profitable in 2011 if the AE of K exceeded 1.5 kg grain/kg K_2O, excluding the costs of fertilizer delivery to the farm, fertilizer application, and additional harvesting and drying for the yield increment.

Studies on the residual effect of K fertilizer on grain yield of cereal crops do show an effect (**Figure 2**). Potassium fertilizers applied to the first winter wheat after fallow slightly increased grain yield of the wheat crop grown repeatedly. The residual effect of K fertilizer was observed in winter wheat even in the fourth year after K application. Again, grain yield of winter barley increased in the fifth year after K application probably due to the residual effect of highest K application of 120 kg K_2O/ha. It is, therefore, important to take into consideration the uptake of residual K by cereal crops when planning nutrient management for the whole crop rotation. At the same time, the rate of applied K should not exceed 60 kg K_2O/ha to exclude leaching and accumulation of K in subsoil horizons of chestnut soils because fertilizer K is weakly fixed in topsoil layers of these soils.

Like with the positive effects of fertilizer K on grain yield and other yield attributes of small grains, K application also had a positive impact on grain quality (**Table 5**). Potassium improved grain filling for the first wheat crop after fallow—the highest in a year when soil and atmospheric drought occurred during heading and grain-filling stages. The application of 60 kg K_2O/ha to the first wheat crop increased the test weight of grain from 709 to 727 g/l, 1,000 grain weight from 28.6 to 31.1g, gluten content from 20.5 to 21.5%, and the gluten deformation index from 36 to 46 units (data not shown). The results revealed the role of K in improving utilization efficiency of N accumulated under bare fallow conditions as a result of soil organic matter mineralization. Fertilization with K was particularly effective in improving grain quality of the second wheat crop. Only N application (and residual P) to repeatedly grown winter wheat yielded low quality grains, while K application increased grain glassiness and gluten content. The highest increase (6%) in grain gluten content due to fertilizer K was observed in a year with adequate precipitation during heading and grain-filling stages. Grain of the second winter wheat crop after fallow met the "valuable" wheat quality class (gluten content of 23 to 27%) only with the balanced application of mineral fertilizers.

Table 5. Effect of fertilizer K on grain quality of winter wheat (3 yr. average).

Treatment[1]	Test weight, g/l	Glassiness, %	Gluten, %
1st Winter wheat (after fallow)			
$N_{60}P_{120}$	764	38	22.8
$N_{60}P_{120}K_{60}$	767	43	24.9
2nd Winter wheat			
N_{60}	761	33	17.9
$N_{60}K_{60}$	763	40	21.1

[1]Fertilizer N, P_2O_5, and K_2O rates are given in subscripts.

Summary

Fertilizer K application in chestnut soils helped to increase yield and quality of small grains. Application of K is more important for the second winter wheat crop after fallow as compared with the preceding wheat crop. It should be noted however that even when chestnut soils have so-called "increased" content of available K, measured using routine soil testing method, it is not guaranteed that plants will receive adequate K nutrition and produce the highest attainable yield. Perhaps soil test K interpretation classes need to be adjusted and updated for chestnut soils. BC

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Fertilizer … Humanitarian Aid?

Humanitarian aid is material or assistance provided for charitable purposes, typically in response to a crisis or natural disaster. Its primary purpose is to save lives and alleviate suffering. Much of the world's suffering from insufficient food occurs in sub-Saharan Africa. Andrew Youn, Senior Partner, Executive Director, and Co-founder of One Acre Fund, a not-for-profit corporation serving small-scale farmers in east Africa recently told delegates at the 2012 TFI World Fertilizer Conference "… that fertilizer is the most important humanitarian product."

I couldn't agree more.

Half the world's food production comes from fertilizer. Fertilizer feeds the soil that feeds the plants we all depend on. Fertilizer means food, not just more food, but better quality food, more nutritious food. Africa needs to use more fertilizer. Fertilizer will allow African farmers to double and triple their yields and take them from subsistence to surplus.

The old adage — give a man a fish and you feed him for a day. Teach a man to fish and you feed him for a lifetime — applies to fertilizer. It's not enough to just provide fertilizer as humanitarian aid. When the giving stops, yields drop and the hunger returns. What is needed is to develop a fertilizer-based food production system that includes access to markets for the excess production farmers will get from fertilizer allowing them to purchase good seed, fertilizer, and other needed inputs from their earned profits. The production system must be economically sustainable, not just for the farmer, but also for the input supplier and other supporting businesses.

Fertilizer is the most important humanitarian tool. It will fuel the economic engine that will take subsistence farmers out of poverty. But farmers need more than access, they need to be trained on how to use fertilizer properly and how to integrate it with other good agronomic practices.

We have much to do … fertilizer is part of the solution to world food security.

Terry L. Roberts
President, IPNI

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