One of the strategic goals of the International Plant Nutrition Institute (IPNI) is to facilitate research on the sustainable use of plant nutrients needed for agriculture to meet future global demand for food, feed, fiber, and fuel. We accomplish this objective through partnerships with colleges, universities, government agencies, and other institutions and organizations around the world where IPNI programs are established.

This past year we provided financial and in-kind support to over 140 projects around the world. Our scientists work closely with the researchers and cooperators carrying out the research … often assisting with the initiation, design, and implementation, monitoring of progress, and the interpretation and dissemination of results. The studies are diverse, including fertilizer best management practices, site-specific nutrient management, and other components of 4R Nutrient Stewardship in cropping systems, but increasing crop yields and productivity is a common objective with most of our research.

Projects typically run for 3 to 4 years, although we do support some longer-term studies. IPNI scientists compile short interpretive summaries highlighting key findings and progress of each project annually. This publication has the most recent updates. A complete history of interpretive summaries and other outcomes from our research is available online at our Research Database: >www.ipni.net/research<.

Terry L. Roberts
President, IPNI
3500 Parkway Lane, Suite 550
Peachtree Corners, Georgia
30092-2844 USA
E-mail: troberts@ipni.net
IPNI Interpretive Summaries 2014

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NOTES: The following are abbreviations and symbols for nutrients and related terms which appear routinely in the summaries on the following pages.

N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; S = sulfur; B = boron; C = carbon; Ca = calcium; Cl- = chloride; Cu = copper; Fe = iron; Mn = manganese; Mo = molydenum; Ni = nickel; Zn = zinc; ppm = parts per million; bu = bushels; A = acre; lb = pound; kg = kilogram; t = ton/tonne; hr = hour; yr = year; in. = inch; USD (or US$) = United States dollar; INR = Indian rupees; A$ = Australian dollar; RMB = Chinese Yuan

DISCLAIMER: Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or IPNI.
Special Projects

HarvestZinc Fertilizer Project: Use of Zinc-Containing Fertilizers for Enriching Cereal Grains with Zinc and Improving Yield

Project Leader: Ismail Cakmak, Sabanci University, Engineering and Natural Sciences, Istanbul, Turkey. Email: cakmak@sabanciuniv.edu


The HarvestZinc Fertilizer Project began in 2008 to explore and test fertilizer use to improve the zinc (Zn) concentration of staple food crops. Biofortification of cereal grains through Zn fertilization compliments plant breeding efforts in alleviating Zn deficiency in crops and related problems in human nutrition. Results of the first phase of the project were reported in Better Crops/Vol 96 (2012) No. 2.

The project, now in its second phase, has field experiments in Brazil, China, India, Pakistan, Thailand, Turkey, and Zambia. At each location, one set of field experiments is evaluating soil application of different Zn fertilizers and a second set is focused on the effectiveness of foliar fertilization. Wheat is targeted in India, Pakistan, Turkey, and Zambia; rice in China, India and Thailand; common bean in Brazil; and sorghum in Zambia. Second-phase activities are described in more detail at the HarvestZinc website (see http://www.harvestzinc.org/second-phase), but results are not currently available. IPNI-2008-GBL-10

Best Management Practices for Sustainable Crop Nutrition in Bulgaria

Project Leader: Margarita Nikolova, University of Forestry, Sofia, Bulgaria. Email: nikmargi@gmail.com

Project Cooperators: Toni Tomov, Damian Mihalev, Lilia Stanislavova, Dobrinka Pavlova, Svetla Kostadinova, Ivan Manolov, Jivko Jivkov, Nidal Shavan, Milena Yordanova, Maria Apostolova, Kiril Popov, Dimitranka Stoycheva, Damyan Michalev, and Sergei Bistrichanov

In 2008, a 5-year project was established in Bulgaria with the general goal of improving cultivation systems in Bulgaria’s agriculture through efficient and sustainable use of plant nutrients. About 50 researchers and discipline specialists are taking part in the project. Project activities include: 1) evaluation of soil nutrient status through summarization of past national soil surveys and more recent localized regional surveys; 2) systematic summarization of past relevant soil fertility research and identification of information gaps; 3) nutrient omission/addition plot trials on target crops; 4) development of tools for site-specific nutrient management that deliver updated recommendations to farmers and farmer advisers; and 5) outreach activities to assure appropriate use of the developed tools.
After conducting a soil test survey of pilot regions and creating a GIS database with soil and field data attributes in 2009 and 2010, layers were created with low, medium, and high content of P and K. The emphasis in 2011 was in the Northwest and Southwest parts of Bulgaria where additional soil sampling was conducted to better assess the soil fertility tendencies of these regions. In 2009, an Access database was structured for past soil fertility research and to accommodate new project data. In 2010, data obtained from long-term crop field experiments conducted after 1974 were entered into the database. The archive now consists of data from 87 experiments at 26 sites and 8 main soil types.

Four years of fertilizer omission/addition field plot trials (NPK or NPKMg as complete treatments) have now been completed. Crops tested were wheat, barley, maize, sunflower, oilseed rape, potatoes, tomatoes, pepper, apricots, peaches, chokeberry, and wine grapes. The average yield increase over four sites and four years from the NPK treatment compared to the no-fertilizer control for the five field crops was 56%. Average yield declines from omitting a nutrient from the NPK treatment for the field crops were 23%, 7%, and 8% for N, P and K, respectively. This was less response than expected for P and more response than expected for K based on the soil test levels of the study sites.

The project is in its recommendation development phase where data from the new field trials are being integrated with legacy data and soil resource considerations to create new recommended fertilizer BMPs for Bulgaria. These should be completed in 2014. IPNI-2010-BGR-1

Global Maize

Global Maize Project in China: Liufangzi, Gongzhuling, Jilin Province

Project Leader: Kuan Zhang, Agricultural Environment and Resource Research Centre Jilin Academy of Agricultural Sciences, Beijing, Jilin. Email: xiejiagui@163.com

Project Cooperators: Jiagui Xie and Xufang Wang

This long-term field experiment was initiated in 2009 in Liufangzi, Gongzhuling City, Jilin Province, where mono-cropping of spring maize is common. The aim of the experiment was to compare the performance of ecological intensification (EI) practices with common farmers’ practice (FP) for yield and N use efficiency. The main plots have two treatments: EI treatment with applications of 180 kg N, 75 kg P₂O₅ and 90 kg K₂O/ha, and FP treatment with applications of 251 kg N, 145 kg P₂O₅ and 100 kg K₂O/ha. Three subplots included: N applied in all years (N all yr); N applied in two out of three years (N 2/3 yr); and no N applied in any year (N 0 yr).

The EI treatment produced grain yields (11.4 t/ha) very similar to those produced in the FP treatment (11.0 t/ha), but with higher N, P and K applications in FP. As a result, the agronomic N efficiency (kg grain yield increase per kg N applied) was much higher (50.9 kg/kg) in EI treatment than in the FP treatment (36.0 kg/kg). Similarly, partial factor productivity of N (kg grain yield per kg N applied) was higher (63.4 kg/kg) in the EI treatment than in the FP treatment (43.7 kg/kg). Grain yield under N 2/3 yr treatment was similarly equal to the N all yr treatment, which resulted from the equal amounts of fertilizer N applied in 2013. IPNI-2009-GBL-GM20

Global Maize Project in China: Dahe, Shijiazhuang, Hebei Province

Project Leader: Mengchao Liu, Institute of Agricultural Resources and Environment Hebei Academy of Agricultural and Forestry Sciences, Shijiazhuang, Hebei. Email: lmchao1758@126.com

Project Cooperator: Liangliang Jia

This long-term field experiment was initiated in 2009 in the Dahe Experimental Station, Shijiazhuang, Hebei Province, where double cropping of summer maize in rotation with winter wheat is the main cropping system. The main plot had two treatments at this site: ecological intensification (EI) treatment with applications of 182 kg N, 107 kg P₂O₅ and 86 kg K₂O/ha in winter wheat and 182 kg N, 73 kg P₂O₅ and 70 kg K₂O/ha in summer maize; farmers’ practice (FP) treatment with applications of 225 kg N, 120 kg P₂O₅ and 55 kg K₂O/ha in winter wheat and 225 kg N, 120 kg P₂O₅ and 50 kg K₂O/ha in summer maize. Three subplots were included: N applied in all three years (N all yr), N applied in two out of every three years (N 2/3 yr), and no N applied in any year (N 0 yr).

Winter wheat (the eighth successive crop) was planted on October 5th, 2012 and harvested on June 19th, 2013, while summer maize (the ninth successive crop) was planted in the same plots on June 20, 2013 and harvested on October 4, 2013.
The EI treatment produced higher grain yields (13.8 t/ha) than the FP treatment (12.9 t/ha) in winter wheat, although less N was applied in EI treatment. Therefore, the agronomic N efficiency (kg grain yield increase per kg N applied) was higher in the EI treatment (12.8 kg/kg) than in the FP treatment (9.1 kg/kg). Similarly, partial factor productivity of N (kg grain yield per N applied) was considerably higher in the EI treatment (34.5 kg/kg) than in the FP treatment (26.0 kg/kg). For summer maize, no significant difference in grain yields was found between EI and FP treatments, although more N and P were applied in FP. *IPNI-2009-GBL-GM21*

**Global Maize Project in Argentina: Balcarce, Buenos Aires**

Project Leader: Fernando H. Andrade, Instituto Nacional de Tecnología Agropecuaria, Estación Experimental Agropecuaria Balcarce (INTA EEA Balcarce). Email: fandrade@balcarce.inta.gov.ar

Project Cooperators: Guillermo Studdert, Aníbal Cerrudo, Roberto Rizzalli, Pablo Barbieri, Hernán Echeverria, Liliana Picone, Cecilia Videla, José Luis Costa, Virginia Aparicio, and Pablo Abbatte

A long-term field experiment was established at Balcarce, Buenos Aires, Argentina in the 2009-10 growing season. The crop rotation was maize-wheat/double cropped-soybean, with both crop phases occurring each year. Soil samples were collected during site establishment to characterize initial conditions, especially the carbon content in the entire soil profile. Treatments included current farmer practice (FP) and Ecological Intensification (EI) practice. Treatments differed in cultivars, planting dates, pest and weed control, or nutrient management practices. Maize crop in the 2012/13 season grew under some periods of dry climatic conditions, which affected the expression of improved potential yields in the EI treatments.

Maize yields were 7.6 t/ha and 8.3 t/ha in FP and EI treatments, respectively - a significant difference of 10%. Wheat grew under normal conditions for the region, and yields were 2.95 t/ha in FP and 4.0 t/ha in EI treatments - again a significant difference of +37%. Double-cropped soybean was planted immediately after the wheat harvest in early January, but the crop was lost because of early frosts during March. Considering the first four years of maize, the EI treatment significantly improved water use efficiency (determined as kg grain per mm of ET) over FP. The EI treatment also showed higher N use efficiency and N removal and less negative N balances, but lower partial factor productivity of N compared to the FP treatment for maize crop. Determinations of nitrous oxide (N₂O-N) gas emissions were conducted in the 2012-13 maize crop, and the data obtained is currently being analyzed. Satellite field experiments evaluating hairy vetch as cover crop for maize showed a significant N supply from the winter legume to the summer crop without negative effects on yield, even in four years years of contrasting climatic conditions. *IPNI-2010-ARG-GM24*

**Global Maize Project in Argentina: Oro Verde, Entre Ríos**

Project Leader: Octavio Caviglia, Instituto Nacional de Tecnología Agropecuaria, Estación Experimental Agropecuaria Paraná (INTA EEA Paraná), Oro Verde, Entre Ríos. Email: ocaviglia@parana.inta.gov.ar

Project Cooperators: Ricardo Melchiori, Pedro Barbagelata, Carolina Sasal, Hugo Tassi, and Osvaldo Paparotti

A long-term field experiment was established at Oro Verde, Entre Ríos, Argentina beginning in the 2009 growing season. The crop rotation used was maize-wheat/double cropped-soybean, with both crop phases occurring each year. Soil samples were collected during site establishment to characterize initial conditions, especially the carbon content in the entire soil profile. Treatments included current farmer practice (FP) and ecological intensification (EI) practice. Treatments differed in cultivars, planting dates, pest and weed control, or nutrient management practices.

Grain yields in the 2012-13 season did not show significant differences between FP and EI treatments for any of the three experimental crops. Maize yields were 7.4 and 9.6 t/ha, wheat yields were 2.2 t/ha and 2.5 t/ha, and double cropped-soybean yields were 2.9 t/ha and 3.0 t/ha in FP and EI treatments, respectively. Considering the first four years of the experiment, the EI treatment significantly improved maize yields but it did not affect wheat and double cropped soybean yields. Water use efficiency (determined as kg grain per mm of evapotranspiration or ET) improved under EI over FP, but the treatments did not differ much in the capture of water (ratio of ET/total precipitation). The EI treatment also had higher physiological N use efficiency and less negative N balances, but lower partial factor productivity of N when compared with the FP treatment. Satellite field experiments evaluating cropping intensification (i.e., increasing numbers of crops per year) have shown that this approach would be an alternative practice to increase C inputs and soil organic C. Also, the evaluation of late season N applications in maize (V10-14) have shown positive preliminary results in improving grain yields and N use efficiency. *IPNI-2010-ARG-GM25*
Global Maize Project in the United States: Virginia

Project Leaders: Wade Thomason, Virginia Tech, CSES. Email: wthomaso@vt.edu; Paul Davis, Davis Produce. Email: padavis@vt.edu

A study was conducted near New Kent, Virginia in the summer of 2013 to compare the effect of various practices thought to increase corn productivity over standard farmer practice (FP). The trial was planted on April 24 with the corn hybrid Dekalb 65-19 used in the Ecological Intensification (EI) treatment and Pioneer Brand 1319HR used in the FP treatment. Changes in practices in the EI treatment from FP included: seeding rate was increased by 18.5%; additional P of 56 kg P₂O₅/ha supplied in the form of Mosaic MESZTM (12-40-0-10S-1Zn); additional potash of 75 kg K₂O/ha was supplied; sidedress N rate increased to a total of 134 kg/ha made over three applications, V4, V6 and V10; the triazone N product ‘Coron’ applied to foliage at VT at a rate equivalent to 22 kg N/ha; Headline fungicide applied to the crop canopy with a handheld CO₂ sprayer at a rate of 12 oz/A in 10 gallons/A of water, also at the VT stage. Treatments were arranged in a randomized complete block experimental design with four replications. Yield following the EI protocol was statistically improved over the standard FP (12.6 t/ha vs 12.2 t/ha). This study is part of a global network of long-term maize improvement studies and will be continued in 2014. IPNI-2012-GBL-GM45

Global Maize Project in the United States: West Lafayette, Indiana

Project Leader: Jeffrey Volenec, Purdue University, Department of Agronomy, West Lafayette, IN. Email: jvolenec@purdue.edu

Project Cooperators: Sylvie Brouder and Tony Vyn

The experimental area is located on a Mollisol with cultivation of maize/soybean system. The site is divided into two areas that are planted to maize in alternate years after soybean. Compared to farmer practice (FP), ecological intensification (EI) utilized a 25% higher plant population, a nitrification inhibitor, an additional N application at growth stage V6, and a 37% higher N rate. Grain yields in 2013 for both management practices were not significantly different: 12,697 kg dry matter (DM)/ha for EI and 12,612 kg DM/ha for FP. Total uptakes of N, P and K were also not significantly different. IPNI-2010-USA-GM27

Advancing Intensive Management of Corn Systems in Minnesota

Project Leaders: Jeff Coulter, University of Minnesota, St. Paul, MN. Email: coult077@umn.edu; Jeff Vetsch, University of Minnesota, Southern Research and Outreach Center, St;Waseca, MN. Email: jvetsch@umn.edu

This experiment was conducted on a Mollisol in a continuous maize system to determine yield differences between farmer practice (FP) and ecological intensification (EI) management. The FP standard was determined through discussions with growers, crop advisers and researchers. Both management systems incorporated the following: chopping stalks in the fall after grain harvest; disk-ripping in the Fall after harvest, and field cultivating in the Spring before planting; pre-plant application of 17 kg S/ha; 6 kg N/ha and 8 kg P/ha applied in the seed furrow at planting; and the use of pre-emergence and post-emergence herbicides. Ecological intensification management differed from FP in the following ways: removal of 40% of the maize stover remaining after harvest; use of a longer-season hybrid (more growing degree days until maturity); and a 26% higher seeding rate. In both management systems, two nutrient management approaches were tested: 1) standard practice that followed current university extension recommendations, and 2) advanced practice that used a 24% higher total N rate, P and K application rates that replaced nutrients removed by grain harvest, a portion of the N co-applied with additional S as a surface band located 5 cm to the side of the row, and another portion of the N applied at an early vegetative (V6) growth stage.

The highest average grain yield (12,353 kg dry matter (DM)/ha) was measured with the advanced nutrient management approach in the EI system. This yield was significantly greater than the 11,398 kg DM/ha yield with advanced nutrient management in the FP system (8% increase). In both management systems, advanced nutrient management practice produced significantly greater yields than standard practice. Nitrogen recovery efficiency as well as agronomic efficiency were greatest for standard nutrient management practice in the EI system. Physiological N use efficiency was greatest for standard nutrient practice in the FP management system. Thus, in 2013, advanced nutrient practice using the EI approach resulted in the greatest yield but not the greatest N use efficiency. IPNI-2013-USA-GM51
Global Maize Project in Brazil: Ponta Grossa, Paraná

Project Leader: Luís Prochnow, International Plant Nutrition Institute (IPNI), Piracicaba-SP, Brazil.
Email: lprochnow@ipni.net

Project Cooperators: Adriel F. Fonseca, Gabriel Bartz, Scott Murrell, Aildson P. Duarte, and Eros A.B. Francisco

Cropping system intensification will be necessary to meet the future demand for corn (maize). Ecological Intensification (EI) seeks cereal production systems that satisfy these future demands while developing cultivation practices with minimum interference to the surrounding environment. A Global Maize Project (GMP) was established to identify yield gaps between current technology and improved technology aimed at achieving EI. The experiment was first established at Ponta Grossa, Paraná, in May 2011, by seeding winter crops to respective treatment plots. The soil in the area is an Oxisol that has been in a no-till system for six years. The experiment had a split-plot design with the main plots involving three types of management systems and the sub plots being three levels of N input plus a control. Different management systems used were: farmer practice (FP) involving a 2-year complete crop rotation cycle of black oats, corn, and soybean; FP + silage production; and EI of black oats + forage peas, corn, black oats, and soybean. The EI treatment is planned to occur twice, alternating the crop rotation initiation point to permit the production of corn every summer. The levels of N application for the corn were 70, 140 and 210 kg N/ha, plus a control with no N added.

Dry matter yields of winter crops varied from 3.9 t/ha for black oats to 5.7 t/ha for ryegrass. Up to 140 kg N/ha was applied to the soil for growing winter crops. As mentioned earlier, it was possible to visualize the effect of winter forage peas on summer maize growth, through their addition of N to the soil. Grain yields were significantly higher when maize was cultivated after forage peas, compared to white or black oat. At higher N fertilizer application rates, grain yield averaged 13.3 t/ha. Soil samples were collected to evaluate soil physical properties and are being analyzed. Tissue samples were collected from the summer crop for laboratory analysis.

Results from 2013 showed a positive linear response between maize grain yield and N fertilizer application rates. At the higher N rates, grain yield averaged 11.8 t/ha. No significant difference was observed for grain yield among the types of cover crops grown before maize, although forage peas tended to support higher maize grain yields. Higher N application rates raised the N/S ratio of maize leaves, which correlated well with maize grain yields. No residual effect of N applied to maize was observed on the grain yield of the following wheat crop. IPNI-2009-BRA-GM19
Global Maize Initiative, Colombia

Project Leader: Dilia M. Coral, Fenalce, Soils and nutrition management program. Cota, Cundinamarca.
Email: dcoral@fenalcecolombia.org

Project Cooperators: Henry Vanegas, Carlos E. Molina, and Gustavo Lemos

After three years of activities in the Valle del Cauca in Southern Colombia, the global maize (GM) project was relocated to the Meta Department in Eastern Colombia. The Meta Department is part of a large expanse of semi-arid savannas (the Llanos) with important areas planted to soybean and corn rotations under no-till management. An important trait of Llanos is the seasonal drought that normally occurs from November to February. The soils at the new site are sandy Ultisols with pH 6, very low available P (1.2 ppm Bray II), very low K (0.06 cmol/kg), but relatively high Mg (1.6 cmol/kg). Total Cation Exchange Capacity (CEC) of the experimental soil is only 5.1 cmol/kg, but soils in the experimental region do not suffer from aluminum (Al) toxicity, which is a serious issue in neighboring areas. The first phase of GM-Colombia was arranged as a single crop experiment with different N management scenarios. Using the experience of the GM sites in Brazil as our guidance, in the second phase we introduced either regular managed corn (“Farmer Practice” FP) or Eco-intensified corn (EI) as part of several rotation systems with soybean, rice or Crotalaria (Sunn hemp) as alternatives to increase the accumulation of residues. We organized a split-plot experiment with crop rotations as the main plot (six levels) and three N application rates within the corn as sub-plots. Three replicates of the main plots were used for a total of 54 plots. The experiment is arranged to have a clear comparison of FP management (i.e., soybean-corn or corn-corn rotations with conventional fertilization of maize receiving 60 kg P$_{2}$O$_{5}$ and 80 kg K$_{2}$O/ha plus micronutrients) with EI corn management (i.e., soybean-corn; corn-soybean; or soybean-corn-sunhemp rotations with applications of 120 kg P$_{2}$O$_{5}$, 140 kg K$_{2}$O, 50 kg S and 1.5 kg B/ha in maize). The N application rates evaluated for corn in both FP and EI in the first year were 42, 146, or 250 kg N/ha.

In both 2013 and 2014, the dry season was longer than usual. In 2013, the first crop was planted only in April 2013, with one FP corn and one EI corn, plus other crops in rotations, where necessary. The second planting took place in August 2013 with two EI corn and two FP corn treatments. Overall, the grain yields with the lowest rates of N in both FP and EI corn treatments were significantly lower than yields in plots receiving the mid and high N rates. The low N treatments had maize yields of 2.5 t grain/ha, while the highest yield was obtained with the highest N application rate (250 kg N) at 10.2 t grain/ha.

Global Maize Project in India: Ranchi, Jharkhand

Project Leader: Rakesh Kumar Saxena, Birsa Agricultural University, Department of Soil Science & Agricultural Chemistry, Ranchi, Jharkhand. Email: rksascbau@rediffmail.com

Project Cooperators: A.K. Sarkar and S. Karmakar

The long-term evaluation of ecological intensification (EI) and farmers’ fertilization practices (FFP) continued in 2012-13 on a farm of Birsa Agricultural University, Ranchi, Jharkhand. The highest grain yields of maize (5.2 t/ha) and wheat (3.2 t/ha) were obtained with the NPK treatment (180:90:100 kg/ha for maize and 130:70:60 kg/ha for wheat). The NPK treatment recorded 74 % higher grain yield over FFP. In another experiment on the effect of application rate and the timing of N fertilization, the treatment that received application of N in maize at 160 kg/ha in three splits on the basis of leaf color chart (LCC) recorded the maximum yield of 8.0 t/ha. In wheat, 150 kg N/ha application in three splits dose on the basis of LCC resulted in the highest grain yield of 3.8 t/ha. Higher nutrient uptake by crop was recorded with higher levels of N application.

Under the omission plot experiments, a maize yield of 6.3 t/ha was achieved with the incorporation of wheat straw and ample NPK (250:120:120 kg/ha), which was on a par with the yield obtained (5.3 t/ha) with site-specific nutrient management (SSNM) treatment (200:90:100 kg/ha of N:P:K, respectively). The highest maize yield without incorporation of wheat straw was 5.2 t/ha, but with SSNM, it decreased to 3.6 t/ha. However, in wheat (rabi) the highest yields of 4.2 and 4.9 t/ha were found with 150:110:100 kg/ha of N:P:K application, respectively, and with and without the incorporation of maize straw. This was followed by SSNM (120:70:60 kg/ha N:P:K, respectively) with yields of 4.3 and 3.8 t/ha with and without residue incorporation, respectively. IPNI-2009-IND-GM22
Global Maize Project in India: Dharwad, Karnataka

Project Leader: Y.R. Aladakatti, University of Agricultural Sciences, Department of Agronomy, Dharwad, Karnataka. Email: dpbiradar@yahoo.com

Long-term evaluation of ecological intensification (EI) and farmer’s practice (FP) in the maize-wheat cropping system during the fourth year of experimentation revealed that the grain and stover yields of maize in EI were 6.5 and 8.3 t/ha, which were 20 and 16% higher than the yields obtained in FP, respectively. Compared to the previous year, the grain yield under EI improved by 2.5 t/ha (64% increase) in 2013. Pooled data for four years indicated 27% higher grain yield in EI than in FP, which was 3% higher than the previous year. The higher grain yield in EI treatment over FP may be attributed to higher nutrient uptake of N (121 kg/ha), P (49 kg/ha) and K (41 kg/ha) in EI, which were 40, 27 and 26.5% higher than in the FP, respectively. Also, net returns of INR 34,472/ha were obtained in the EI treatment, which were 29% higher than the net returns obtained with FP (INR 26,830/ha), an improvement over the previous year by 3%. In wheat, higher grain and straw yields of 3.5 and 6.6 t/ha were reported in EI treatment, which were 17 and 5% higher than the grain and straw yields recorded in FP, respectively. Considering the maize equivalent yield for wheat, pooled data averaged over four years indicated that EI could result in a higher maize grain yield of 9.8 t/ha with application of 310 kg N, 160 kg P₂O₅ and 160 kg K₂O, which was 22% higher than the yield obtained in the FP treatment with application of 185 kg N, 103 kg P₂O₅ and 105 kg K₂O, respectively.

Rate and application studies pooled over four years found that 240 kg N/ha application could generate 6.9 t/ha maize, which was higher than the 6.1 t/ha produced with 160 kg N/ha. Net returns (and B:C ratios) with 240 and 160 kg N/ha were INR 52,305 (3.83) and 46,179 (3.70), respectively. Application of N in three splits with and without the use of leaf color charts (LCC) resulted in equivalent maize yields of 4.9 and 4.8 t/ha, but these results were superior to N applied in two splits. Similarly, grain yields pooled over four years in the succeeding wheat crop were 3.8 and 3.3 t/ha with 150 and 100 kg N/ha applications, respectively. Application of N in three splits with and without the use of leaf color charts (LCC) resulted in equivalent wheat yields of 2.8 t/ha. However, the results were superior to N provided in two splits, which recorded a grain yield of 2.6 t/ha, respectively. The data generated in this project so far has helped to provide 4R strategies of nutrient management in the maize-wheat cropping system for the benefit of the farmers of Karnataka. IPNI-2009-IND-GM35

Global Maize Project in Mexico: Celaya, Guanajuato

Project Leader: Roberto Paredes, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Campo Experimental Bajío, Celaya, Guanajuato. Email: rparedem59@prodigy.net.mx, paredes.roberto@inifap.gob.mx

This project is being conducted near Celaya, in the state of Guanajuato, Mexico, at 1,830 meters above sea level. This environment is classified as mid-altitude, non-equatorial and tropical–subtropical. In 2013, the treatment design was modified to include two tillage systems: Conventional tillage typical of farmers current practices and conservation tillage, which involves direct seeding without tillage. These tillage treatments were combined with three N fertilization regimes: 0 N, 300 kg N/ha following 0 N in 2012, and 300 kg N/ha applied every year. No significant differences (p > 0.05) in grain yield were detected between the tillage treatments when no N was applied or when fertilized with 300 kg N/ha applied every year. No significant differences (p > 0.05) in grain yield were detected between the tillage treatments when no N was applied or when fertilized with 300 kg N/ha. IPNI-2009-MEX-GM28

Global Maize Project in Mexico: Cd. Obregón

Project Leader: Ivan Ortiz-Monasterio. Email: i.ortiz-monasterio@cgiar.org

This intensive maize production project, initiated in 2012, is located in Cd. Obregón, State of Sonora. Maize has not been a traditional crop of this area, but some climate change models indicate that a temperature increase in this region will make growing wheat, the most important crop currently grown in the region, unfavorable and could favor maize crop growth. Concerns over limited water supplies suggest that more efficient use of water through a combination of conservation agriculture and drip irrigation is a requisite of a sustainably intensive alternative. The experimental treatments comprised a complete factorial arrangement of two irrigation methods (furrow and drip), two tillage systems (conventional and conservation), three N fertilizer application rates (0, 200 or 400 kg N/ha), and two P rates (0 or 22 kg P/ha) with three replications.

Despite a non-seasonal frost in mid-January, fairly good yields were obtained. The most striking effect was observed in the lower yields (5.7 to 8.9 t/ha) obtained under conservation tillage and furrow irrigation for almost all the NxP combinations compared to the remaining treatments (i.e., drip and conventional tillage; 8.9 to 11.2 t/ha). Further analyses are required to explain this response. IPNI-2013-MEX-GM50
Improvement of Maize and Soybean Mineral Nutrition on a Calcareous Common Chernozem

Project Leader: O.A. Biryukova, Southern Federal University, Department of Soil Science and Land Resources Evaluation, Rostov-on-Don, Rostov Oblast. Email: olga_alexan@mail.ru

Project Cooperators: D.V. Bozhkov, M.A. Azarova, A.V. Kuprov, and S.R. Manaeva

This project, initiated in 2011, witnessed the lowest precipitation of 15 mm in June 2013 at the A-site since initiation. Rainfall during July was only 24 mm. Such weather conditions had a negative effect on maize production. Grower’s fertilizer practice (GFP) and the Ecological Intensification (EI) management system for maize and soybean were compared at the A site. The GFP treatment 30-40 kg N-P/ha led to a maize yield of 4.44 t/ha in 2013. A reduction in the N application rate from 30 to 9 kg/ha caused a 9% yield loss. The maize yield of 4.73 t/ha was obtained in the EI treatment (85-70-40 kg N-P-K/ha) was a 7% increase over GFP. Again, a reduction in the N application rate from 85 to 17 kg N/ha caused a yield decline of 10%. The GFP treatment 20-40 kg N-P/ha gave soybean yield of 1.90 t/ha, and decreasing N rate from 20 to 9 kg/ha caused both a 12% yield loss and a decrease in grain protein content from 50 to 47%. In the EI treatment 30-45-30 kg N-P-K/ha, a soybean yield of 2.16 t/ha was obtained, which was a 14% increase over GFP. Again, decreasing the N application rate from 30 to 10 kg/ha caused a yield decline by 6% and the grain protein content decreased from 51 to 48%. The highest protein output (963 kg/ha) was obtained in the EI treatment.

Soil at the C-site was characterized by a high nitrate-N concentration of 15.9 ppm and very high levels of Olsen-P (17.5 ppm) and exchangeable K (354 ppm) in the 0 to 20 cm soil layer (obtained using weighted averages from data for 0 to 5, 5 to 10 and 10 to 20 cm layers). Maize followed winter wheat in the agri-enterprise field and had higher productivity when compared with the A-site. The control treatment (i.e., no fertilizer applied) gave a maize yield of 4.78 t/ha and GFP (30 N 40 P) resulted in a 7% increase in yield over that obtained from the control treatment. The highest maize yield of 6.10 t/ha was attained in the treatment receiving ample NPK rates (100 N 80 P 60 K). This treatment gave a 28% increase in yield over the control treatment and 19% increase in yield over GFP. Decreasing the N application rate from 100 to 18 kg/ha resulted in a 9% yield loss. Omission of P and K decreased grain yields by 5 and 3%, respectively. Response to K fertilizer was, however, non-significant. These results corresponded well with the initial status of soil fertility. IPNI-2011-RUS-4-GM41
**Americas and Oceania Group**

**Australia/New Zealand Program:**  
Dr. Robert Norton, Director

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**Longerenong Cropping Challenge**  
Project Leader: Rob Christie, Nuseed, Horsham, Victoria. Email: robert.christie@au.nuseed.com  
Project Cooperators: Mark Slatter, Steve Drum, and Peter Howie

The Longerenong Cropping challenge gives local advisers the opportunity to put their agronomic skills on show by managing a crop within a three year cycle of canola, wheat and then chickpeas. The plots were all replicated and outcomes assessed annually on the basis of yield, quality and returns. Twelve groups participated in the challenge and while seasonal conditions - as always - varied from year to year, the average financial return for the challenge was AU$857/ha. The financial returns were highest in canola and lowest in wheat crops, which largely reflected seasonal conditions for each crop. The highest gross margin was achieved by a group of current students at Longerenong College with a return of AU$959/ha per year over the three years.

A cropping system experiment such as this also allows some estimates to be made of nutrient use. Phosphorus rates used by the groups varied from 7 kg P/ha/yr to 13 kg P/ha/yr. There was a weak relationship between P fertilizer application rate and return. The partial factor productivity for P averages 306 (+/- 56) kg grain/kg P combined over three crops in the rotation, even though the Colwell P soil test status of the site was considered moderate to high depending on crop. The partial nutrient balance for P over the three years (amount of P removed in grain divided by the amount of fertilizer P added) was nearly always greater than 1 and averaged 1.2 kg P removed for each kg P applied. *IPNI-2009-AUS-11*

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**Growth, Yield and Water Use under Elevated Carbon Dioxide**  
Project Leader: Glenn Fitzgerald, Victorian Department of Primary Industries, Horsham, Victoria.  
Email: glenn.fitzgerald@dpi.vic.gov.au  
Project Cooperators: Saman Seneweera, Garry O’Leary, Sabine Posch, and Michael Tausz

Rising atmospheric carbon dioxide (CO₂) concentration will result in drier and warmer conditions across much of the mid-latitudes, including Australia and New Zealand. Research at the Australian Grains Free Air Carbon Dioxide facility has shown that although wheat yield increased due to improved carbon supply, wheat grain protein, baking quality and important micronutrients such as Zn and Fe all declined. This research identified that nutrient management strategies will need review under elevated CO₂ conditions.

Changes in the pattern of wheat growth and the temporal pattern of nutrient demand mean new combinations of nutrient source, rate, time, and place will be needed, along with more efficient cultivars. Most important will be the development of strategies to stop protein changes and to maximize the benefits of the extra carbon available. This may be done by changing to ammonium-based N sources, use of foliar N fertilizer during grain filling, and by building on current research that is developing more N efficient cultivars. For current C3 crops such as wheat, estimated atmospheric CO₂ concentrations in the year 2050 could increase N demand by 20%, and that higher N demand will require balanced nutrition with extra P, K, S, and micronutrients. *IPNI-2010-AUS-02*
Ammonium Sulfate for Canola in Southeastern Australia

Project Leader: Rob Norton, International Plant Nutrition Institute (IPNI), Horsham, Victoria. Email: rnorton@ipni.net
Project Cooperators: MT Khan, Robert Edis, Deli Chen, and Charlie Walker

In alkaline-calcareous soils of southeastern Australia (Calcarosols), the main N fertilizer sources are either urea or ammonium sulfate (AS) in cereal and oilseed cropping systems. The relatively low N recovery in these systems is most likely associated with ammonia volatilization. In addition, S from AS may be immobilized by chemical precipitation with Ca, which may result in S deficiency, thereby reducing the N recovery further. Previous research showed that AS results in root zone acidification around the site of placement, which increased P availability, and could also reduce ammonia volatilization. To compare the effectiveness of N derived from urea with N derived from AS, a field 15N microplot study with canola as the test crop was conducted.

This study showed that when N was sourced from AS, N recovery in the grain was significantly higher than when the N was sourced from urea (31% vs. 23%, p=0.07). There were no differences in straw, root or soil recovery of the labelled N. Approximately 63% of N in total was recovered from AS, while 54% was recovered from urea. When AS and urea were used as a mixture, the recovery of N from either labelled urea-N or labelled AS-N was similar to the recovery from the straight AS. These data indicate that AS, either alone or in a mixture with urea, can increase the recovery of fertilizer applied N in canola.

IPNI-2010-AUS-03

Dahlen Long-term Nitrogen and Phosphorus Experiment

Project Leader: Craig Farlow, Incitec Pivot Fertilizers, North Geelong, Victoria. Email: Craig.Farlow@incitecpivot.com.au
Project Cooperators: Rohan Davies and Peter Howie

The long-term profitability of N and P use has been assessed at the Dahlen field experiment established in 1996. In 2012, the site was sown to wheat. The addition of 9 kg P/ha gave about a 1 t/ha yield increase (30%) while extra P gave no further significant responses. The first 20 kg N/ha gave a 0.6 t/ha yield increase (14%) and the highest yields occurred with 80 kg N/ha. The high N rate increased grain protein, but had no effect on grain test weights. Half the experimental treatments have had P application suspended, and even in the first year, a small (0.22 t/ha) but statistically significant yield decrease occurred in plots where no P fertilizer was added in 2012. High P application rates reduced grain Zn contents, but high N rates did not affect grain Cu contents. These sites would be considered non-responsive to added micronutrients.

The conclusions to date are that a set fertilizer strategy of 9 kg P/ha and 20 kg N/ha continues to be a sound investment, even in uncertain seasonal conditions. Long-term data on nutrient removal indicates that applications of 9 kg P/ha and 40 kg N/ha will about balance nutrient removal and will maintain soil fertility as measured by soil tests. A review of the changes in soil C over the period of the experiment has shown that applied N - even in excess - does not lead to a decline in soil organic matter. The impact of balanced nutrition - especially balancing N and P increased crop growth and so raises the input of N into the soil C cycle. The conclusion is that the best way to build soil C is to grow good crops with zero tillage and stubble retention.

IPNI-2010-AUS-08

Better Fertilizer Decisions for Crops

Project Leader: Simon Speirs, Industry and Innovation Wagga Wagga Agricultural Research Institute, Wagga Wagga, New South Wales. Email: simon.speirs@industry.nsw.gov.au
Project Cooperators: Graeme Watmuff, Ken Peverill, Doug Reuter, Geoff Anderson, Ross Brennan, Michael Bell, Charlie Walker, Mark Conyers, and Richard Bell

Soil test critical values are an important part of making good decisions about fertilizer inputs. In many cases, the original data behind those critical values is not in the public arena, nor can larger groups of data be collectively evaluated easily. The Better Fertilizer Decisions for Crops (BFDC) database was compiled from public and corporate crop yield response to N, P, K, and S using information from over 5,000 field experiments across Australian grain production regions. A web-based tool was developed to enable advisers to select data by crop species, nutrient, soil test method and sampling depth, as well as crop yield, soil pH, and crop stress. This tool has been used to estimate critical soil test values and ranges for current soil tests used in fertilizer decision making. These values have been published in a special edition of Crop and Pasture Science covering new calibrations, and these have been republished in technical bulletins for agronomists and farmers. Advisers have been trained in the use and interpretation of data within the database, and this training has increased the general knowledge of and interest in plant nutrition. The project developed a series of experimental protocols for future experiments, including the specific meta-data that are important to interpret.
the results. The most important gaps in the data set relating to the most particular crops, soils, and nutrients have been identified and are to be filled with new research investments supported by the Grains Research and Development Corporation and its partners. *IPNI-2010-AUS-09*

**The Response of Crops to Potassium Placement Depth and Band Spacing**

Project Leader: Mike Bell, University of Queensland, Kingaroy, Queensland. Email: mbell4@uq.edu.au

Project Cooperator: Cameron Ireland

Two sites were established in central Queensland in 2012, one at Capella and the second at Gindee. Both sites had low soil concentrations of P, K and S, especially in the subsoil layers. We established trials by adding single nutrients (P or K or S) into the 10 to 30 cm layer, or combinations (P+K, P+S, K+S, P+K+S). These sites were grown under commercial practice through successive crops; sorghum (2012) and the chickpea (2013) at Gindee and chickpea (2012) and wheat (2013) at Capella. No additional fertilizers were added after sowing of the first year.

In year 1 (a good year for moisture), both sites showed a 20% grain yield response to deep-applied P fertilizer. While no other nutrients affected grain yields, there was a suggestion of an additive effect of deep K at Capella in chickpea biomass. There was no S response. In year 2 (much drier), the effects of deep P were still evident at both sites and the effects of K were clearly evident at Gindee. There was a suggestion of an additive P + K effect at Capella and a very significant additive effect of P + K at Gindee. This suggests that K availability with added P gave a 51% grain yield increase. These experiments show that as soils reserves decline, it is essential to apply the right combination of fertilizer nutrients to maximize crop productivity and seasonal water use efficiency. *IPNI-2010-AUS-13*

**Nutrient Balances for Australian NRM Zones**

Project Leader: Robert Edis, Edis Consulting, North Melbourne, Victoria. Email: roberte@unimelb.edu.au

This project has collated additional fertilizer use data using information from the Australian Bureau of Statistics farm practices surveys. This collects small area (down to local government areas) data by industry and nutrient, and is reported every four years. The objective of this analysis is to estimate nutrient use by industry and region - as such data is not currently widely available. The first analysis indicates that small area data grossly overestimates the amount of nutrient used from industry figures. This conclusion was reached by aggregating regional industry data on fertilizer use to state level industry estimates of fertilizer use.

Some data validation undertaken using dairy industry survey data indicated that the average N use on grazed dairy pastures was 71 kg N/ha, and this is most commonly applied in two or more applications. The use of K declined over the past decade, but has now recovered to levels recorded in the 2000 survey. Superphosphate is still the main P source, although diammonium phosphate (DAP) is commonly used.

National nutrient use data were estimated using production data sourced from the Australian Bureau of Agricultural and Resource Economics and fertilizer data from Fertilizers Australia, along with estimates of fertilizer use by crop made by the International Fertilizer Industry Association. During the period of 2006-2007, wheat partial factor productivity (PFP) was 41 kg grain/kg N and 87 kg grain/kg P. In 2010-2011, PFP was 60 kg grain/kg N and 159 kg grain/kg P. Similarly, partial nutrient balances (PNB) for wheat were 0.86 for N and 0.36 for P in 2006-2007, and 1.27 for N and 0.67 for P in 2010-2011. These values indicate the temporal variability of these measures of nutrient use efficiency and that long terms trends are likely to be a more reliable indicator than values from one or two years. *IPNI-2010-AUS-16*

**More Profit from Crop Nutrition: Micronutrient Survey**

Project Leaders: Rob Norton, International Plant Nutrition Institute (IPNI), Australia and New Zealand, Horsham, Victoria. Email: morton@ipni.net

Project Cooperators: Alan Bedggood and Jan Edwards

Using data from regional soil tests, grain nutrient contents and a review of literature, the risk of plant micronutrient deficiencies (B, Cu, Mn, Mo, and Zn) was made across the Australian grains belt. The results indicate that the major micronutrient risk is from Zn deficiency and while Cu deficiency is not widely indicated, there are uncertainties about the risks associated with Cu. Future research should still focus on the deployment of these two micronutrients within cropping systems. Summary risk tables for each GRDC region were developed based on the relative area of each soil class. These were used for reference and discussion, and identified areas of uncertainty.

For the Northern Region the main soil micronutrient issue appears to be with Zn on Kandosols, Vertosols and Sodosols. There is uncertainty about Cu generally. For the Southern Region, the main soil types of
Calcarosols, Sodosols and Vertosols have high risk of Zn deficiency, while Mn is likely to be a significant deficiency risk on these soils if they contain more than about 60% free calcium carbonate. For the Western Region, Kandosols and Tenosols are more significant than in the eastern states, although Sodosols is the major soil order, and low Zn is seen on these soils. The acid soil types, such as the more strongly acidic Tenosols, are likely to be at risk of Mo deficiency, while Mn deficiency is moderately likely Kandosols and Tenosols. This review has been incorporated into the Grains Research and Development Corporation investment plan for 2014-15 and future research will focus on the issues identified here. IPNI-2012-AUS-15

Micronutrient Field Evaluation

Email: rnorton@ipni.net

Project Cooperators: Jarrod Brown, Rob Launder, and Brad McLean

Six field evaluations of micronutrients on wheat were undertaken in Mallee (1 site), Wimmera (3 sites) and Western District (2 sites) of Victoria, Australia, in collaboration with various research partners. Both Cu and Zn supplements were evaluated on sites typical of the regions to assess the likelihood of responses and to add additional field data to the GRDC Micronutrient Scoping study.

No significant yield responses to either Cu or Zn were seen at any of the sites in Wimmera or Western District. The site in the low rainfall Mallee region showed a small, but significant response to Cu additions when applied either as a foliar or fluid application, although there was also an apparent yield suppression noted with the basal P fertilizer (single superphosphate) applied at sowing. The sites selected had relatively low soil test concentrations of Cu and Zn, but yield responses were not seen. Nor were there any clear effects of supplementary Cu application on grain Cu concentration. In contrast, where Zn fertilizer was applied around anthesis, there were increases in grain Zn concentrations. A high Zn supply is particularly important for developing seedlings and, therefore, late Zn applications could be recommended where the grain was to be retained for planting seed. IPNI-2013-AUS-14

Wheat and Canola Potassium Responses

Project Leader: Mark Conyers, New South Wales Agriculture, Jonathon Holland, New South Wales Agriculture
Project Cooperator: Jon Midwood

The Better Fertilizer Decisions for Crops project identified gaps in the dataset for wheat and canola responses to K in eastern Australia. This project will support additional soil measurements of selected K fertilizer application rate experiments in southwestern Victoria, undertaken by the New South Wales Department of Primary Industries. Soil measurements will include the tetra-phenyl borate extractable K, ammonium acetate exchangeable K, and bicarbonate-extractable K taken at several depths. Selected clay mineralogy assessments will also be made to better evaluate the effect of clay type on response. The accompanying field experiments have not yet been harvested. IPNI-2013-AUS-18
Rates and Residual Effect of Potassium Fertilization in a Brazilian Soil

Project Leader: Luís Prochnow, International Plant Nutrition Institute (IPNI), Piracicaba-SP, Brazil.
   Email: lprochnow@ipni.net.
Project Cooperator: Toni Wiendl

Potassium is responsible for several vital functions for plant development (enzyme activation, translocation and stock of compounds, osmotic regulation, water maintenance etc.) and high yields. Potassium fertilization is essential for balanced plant nutrition in the acid soils of the tropics, including in Brazil. In many areas farmers are cutting back on fertilizer expenses, which could compromise good yields, profits and food security in the future. The main objective of this study is to verify the effects of reducing K fertilizer rates in some Brazilian soils. The study is also looking at some other important factors that may affect the effectiveness of K fertilizer in tropical soils (e.g., applications of P, lime, and phosphogypsum, time of application and locality effects) to evaluate their effects on soil K status with time, plant K status with time and grain yields.

Results for the third crop season (2013) (soybean and maize second crop) indicated statistically significant response to K rates for soybean yield and K leaf content, statistically significant response to K rates for maize seed weight and plant height, statistically significant response to K rates for soil K availability, a positive effect of lime and phosphogypsum application for maize yield and plant height, and for soil pH and base saturation, effect of locality of K application for soybean K leaf content. Thus far the results are in agreement with initial expectations demonstrating the importance of an adequate K supply. The project is planned to continue for three more years. *IPNI-2010-BRA-56*

Source, Rate, and Time of Nitrogen Fertilization for Sugarcane

Project Leaders: Fábio Dias, APTA Research Center Piracicaba - Sugarcane Program –IAC. Email: fabio@apta.sp.gov.br
   Luis Prochnow, International Plant Nutrition Institute (IPNI), Piracicaba-SP, Brazil. Email: lprochnow@ipni.net

Project Cooperator: Raffaella Rosseto

The main objective of the study is to evaluate the agronomic effectiveness of different N fertilizer sources for sugar cane. Other important factors that affect the effectiveness of N fertilizer in tropical soils, such as rate and time of application will also be studied. Three sources (UAN, Urea and Ammonium Sulfate), three rates of N (60, 120 and 180 kg N/ha), two times of application (100% at plant emergence versus 50% at plant emergence plus 50% when plant reaches a height of 60 cm), and two control treatments (zero N and 120 kg N/ha as Ammonium Sulfate) were used in different treatment combinations. The field trial was initiated in October 2013, but an unfortunate event jeopardized the trial in December. Decision was taken to start a new trial in March or April of 2014 and keep the first one under evaluation until the first harvest. *IPNI-2013-BRA-62*
Sustainable Production Systems under No-till in the Cerrado of Brazil - Mato Grosso

Project Leader: Eros Artur Bohac Francisco, International Plant Nutrition Institute (IPNI), Rondonópolis-MT, Brazil.
Email: efrancisco@ipni.net

Project Cooperators: Ciro Rosolem and Leandro Zancanaro

Continuous land cultivation with mono-cropping systems tends to promote soil degradation and increase the incidence of crop diseases, pests, and weeds. This, in turn, reduces the crop yield potential. A long-term research project was initiated to look into various aspects of sustainable agricultural systems. The project focuses on crop rotation and other alternatives to generating long-term profitability. Two experiments, one aimed at the production of fiber and the other at grain production, each containing seven different cropping systems, were initiated in 2008.

Results suggested that the production of dry matter of cover crops during the spring season, before sowing cotton, is sufficient for good soil protection and recycling of nutrients. Amounts of N, P, K, Ca, Mg, and S recycled by millet and by Brachiaria grass were identical, while the amount of K recycled was higher for systems utilizing Brachiaria in the autumn and millet in the spring. The type of cover crop utilized during the spring did not influence cotton yield. The soil density was higher under no-tillage compared to annual soil tillage, but no fiber yield reduction occurred. For farming systems under no-tillage, soil density may be alleviated using Brachiaria grass for periods longer than 12 months, which may be an advantage for farming systems that include pasture crops. The use of cover crops after soybean harvest is essential to sustain soil biological activity and nutrient cycling, and Crotalaria showed higher levels of N cycled than Brachiaria and millet. Soil P concentrations were found to be lower in the farming systems with no use of cover crops after soybean, whereas the use of Brachiaria grass increased P concentrations in the soil. Soybean yields were affected when it followed corn intercropped with Brachiaria. The intensification of the farming system with soybean and corn (second crop) in sequence resulted in higher amounts of nutrient export, which should be taken into consideration when planning fertilizer recommendations. If nutrient balance is not properly evaluated in intensive grain production farming systems, it may endanger its sustainability.

Results from the last season (2013) showed statistical difference in favor of no-till versus conventional tillage for grain production systems, but for fiber production systems, the difference remained nonexistent. After five cropping seasons, this difference was revealed probably due to the high buffering capacity of the clay-enriched soil (oxisol) where this study is being conducted. This is an important information for farmers in the region because a large portion of cultivated land in the Cerrado has clay to very clay-textured soils. More conclusive results from this long-term project will be possible with time.

Agronomic Effectiveness of Acidulated Phosphate Fertilizers with Different Water Solubility

Project Leader: Eros Francisco, International Plant Nutrition Institute (IPNI), Rondonópolis-MT, Brazil.
Email: efrancisco@ipni.net

Project Cooperators: Takashi Muraoka and Claudinei Kappes

There is a high demand for P fertilizers in Brazilian agriculture, where the most common sources are acidulated phosphates. Due to the high P fixation capacity and low P concentration of Brazilian soils in general, soluble P fertilizers have always been preferred for their high agronomic effectiveness. Recently, Brazilian legislation allowed the use of P fertilizers with low water solubility, but field trials are still needed.
to evaluate the effectiveness of such products. This project aims to study the agronomic effectiveness of four P fertilizer materials (acidulated phosphates) varying in water solubility (85, 70, 60, and 50%) for soybeans in an Oxisol in the Cerrado of Brazil.

Results from the second year of this study (2013) were in agreement with those obtained in the previous year and sustain the hypothesis that P fertilizers with medium water solubility (60%) present the same agronomic effectiveness as those with high water solubility. This project is expected to deliver very important information to agronomists and the fertilizer industry in Brazil, demonstrating that P fertilizers with lower water solubility are still suitable for agronomical use. This is a 3-year project, and more conclusive results will be available next year. *IPNI-2011-BRA-59*

**Brazilian Soil Fertility Survey**

Project Leaders: José Francisco da Cunha, Private Consultant, Tec Fertil, Vinhedo, Sao Paulo. Email: fmcunha@uol.com.br. Eros Francisco, International Plant Nutrition Institute (IPNI), Rondonópolis-MT, Brazil. Email: efrancisco@ipni.net

Soil fertility surveys of specific countries or regions are important tools to ascertain soil chemical properties for adequate crop nutrition. Due to a paucity of such information in Brazil, the IPNI program is currently developing comprehensive soil fertility information. The plan is to complete this endeavor in three phases. This summary presents results of Phase 1, which are also stored in the IPNI Brazil database as Brazilian Soil Fertility Survey based on soil samples.

For this phase, a total of 5,556 soil samples were collected, but only 3,365 samples were used to interpret and classify different levels of nutrient sufficiency. For plant available P, three types of interpretation were necessary (exchange resin (P-Res); Mehlich 1 + clay content (P-Meh); or remaining P in solution (P-Rem)), and all three types predicted plant response to P in the great majority of the samples (86, 63 and 38% for P-Res, P-Meh and P-Rem, respectively). Simulation of collected data, considering that only the soybean crop was grown in all areas, showed a requirement of about 1.5 to 2.0 million tons (M t) of P$_{2}$O$_{5}$ for Brazil. For K, the survey showed that 44% of the soil samples had K concentrations that are very low or low in terms of K bioavailability. A positive growth response to K is predicted in 78% of the samples. Simulations showed that about 2.2 M t of K$_{2}$O would be necessary to overcome this limitation considering the recommendations from EMBRAPA (Brazilian Agronomic Research Agency) and with soybean cropped in all areas. Among secondary nutrients, the survey showed that 76% of the soils would give a S response, while among the micronutrients considered (Zn, Cu, Mn, and B), the survey indicated low levels of their bioavailability in the great majority of samples. Interestingly, 98% of the analyzed soil samples showed a clear trend to some kind of response to B. Phase 2 will deal with results of soil samples utilizing the ion exchange resin methodology. Phase 3 will expand include the highest possible number of soil samples from laboratories around the country. This project has been reactivated in order to complete phase 3 by using data from the Midwest region of Brazil. *IPNI-2010-BRA-61*

**Brazilian Nutrient Balance**

Project Leader: Eros Francisco, International Plant Nutrition Institute (IPNI), Rondonópolis-MT, Brazil. Email: efrancisco@ipni.net

Nutrient balance is a valuable tool to evaluate the use of fertilizers and the removal of nutrients through harvested crops. In order to have a sustainable crop production system, it is necessary that the quantity of nutrients removed from the field be replaced at a minimum by nutrient applications with high nutrient use efficiency. The IPNI Brazil Program annually prepares a national nutrient balance for the main crops that cover over 90% of the fertilizer consumption, with information regarding every single state and crop. In 2014, IPNI Brazil will publish a 4-year national nutrient balance summary, with this effort continuing into the coming years. *IPNI-2014-BRA-63*
Americas and Oceania Group

Brazil Program

North and Northeast Region:

Dr. Valter Casarin, Deputy Director

Sustainable Production Systems Under No-till in the Cerrado of Brazil – Piauí

Project Leader: Valter Casarin, International Plant Nutrition Institute (IPNI), Piracicaba-SP, Brazil. Email: vcasarin@ipni.net

Continuous cultivation of lands under continuous monocropping systems tends to promote soil degradation and to increase the incidence of crop diseases, pests, and weeds that may reduce crop yield potential. This is a 3-year research project looking into various aspects of sustainable agricultural systems. The project gives emphasis to crop rotation and other alternatives to generating long-term profitability. This research is believed to be instrumental in supporting many farms located throughout the Brazilian Cerrado. Part of this project is dedicated to the study of soil fertility management under these systems. One experiment containing seven different cropping systems, involving soybean and maize, was initiated in 2011.

Results from the first year of this project (2012) showed that growing maize and brachiaria grass together increased the grain yield of maize. Increasing N application rates also increased grain yield and dry matter of cobs and husks. Results from the second year of this project (2013) showed that ecological intensification (EI) promoted higher grain yield and seed weight of maize as compared to other systems. EI promoted higher grain yield, plant height and seed weight of soybean as compared to other systems. Nitrogen fertilizer application increased grain yield and dry matter of leaves and cobs of maize, and previous N application promoted higher grain yield and seed weight of soybean. This project will end in 2014 and final report will be available by the end of the year. IPNI-2011-BRA-58

Sustainable Production Systems Under No-till in the Cerrado of Brazil – Maranhão

Project Leaders: Ronaldo Honostorio de Bastos, CEAGRO, Balsas, Maranhão. Email: ronaldo.bastos@ceagrobrasil.com; Valter Casarin, International Plant Nutrition Institute (IPNI), Piracicaba-SP, Brazil. Email: vcasarin@ipni.net

Continuous cultivation of lands under the same monocropping systems tends to promote soil degradation and increases the incidence of crop diseases, pests and weeds, which in turn, reduces the crop yield potential. This long-term research project is looking into various aspects of sustainable agricultural systems. The project gives emphasis to crop rotation and other alternatives to generating long-term profitability. This is believed to be instrumental in many farms located throughout the Brazilian Cerrado region. Part of this project is dedicated to the study of soil fertility management under these sustainable agriculture systems. One experiment containing eight different cropping systems was initiated in 2012 and general results for the first year are available. Main treatments used in the study include: (a) monoculture with continuous soybean with conventional tillage, (b) monoculture with continuous soybean with no tillage, (c) cover crop rotation (soybean followed by pear millet, or effect 1), (d) common farmer practice (soybean followed by a second maize crop), (e) cover crop (soybean followed by different cover crops, effect 2), (f) cover crop (soybean followed by different cover crops, effect 3), (g) cover crop (soybean followed by different cover crops, effect 4), and (h) maximum rotation (soybean or maize followed by different cover crops). Sub-treatments were added to investigate maize yield response to N fertilizer application, so every maize plot receives different N rates: 90 and 180 kg N/ha for the first maize crop, and 45 and 90 kg N/ha for the second maize crop, plus an unfertilized control.

Soybean yield did not differ among treatments and averaged 2.86 t/ha. The second maize crop yield was positively influenced by N fertilizer application and showed a significant response to fertilization. The application of 90 kg N/ha increased grain yield by 0.71 t/ha (25%), compared to the unfertilized control treatment (2.88 t/ha). The project will be conducted for six years and will end in 2018. IPNI-2012-BRA-60
Argentina

Establishing a Plant Nutrition Network for the CREA Region in Southern Santa Fé

Project Leaders: Miguel Boxler, CREA Southern Santa Fé Region, Santa Fe, Argentina. Email: miguelboxler@gmail.com; Ricardo Pozzi, CREA Southern Santa Fé Region. Email: rlpozzi@waycom.com.ar

Project Cooperators: Adrian Correndo, Santiago Gallo, Angel Berardo, Nahuel Reussi Calvo, Ricardo Pozzi, and Fernando García

The Regional Consortium of Agricultural Experimentation (CREA), a farmers’ organization based in Southern Santa Fé, Argentina, has established a network of field experiments with the objectives of: 1) determining direct and residual responses to N, P and S, and where indicated, to K, Mg, B, Cu, and Zn; 2) evaluating recommendation methods for N, P and S fertilization, 3) identifying the level of deficiency and potential response to nutrients other than N, P and S, and 4) evaluating the evolution of soil quality under contrasting nutrient management practices. In 2012-13, all five remaining sites of the network were planted to corn, with two sites under corn-wheat/soybean (C-W/S) rotation and three sites under corn-soybean-wheat/soybean (C-S-W/S) rotation.

Contrasting climatic conditions across sites resulted in variable grain yields. Grain yield responses to NPS were significant at Balducchi and La Hansa sites; to NS at San Alfredo, Lambaré, and La Blanca sites; and to NP at San Alfredo and Lambarés sites. Responses to NPS averaged 5.4 t/ha (+102%) and 6.4 t/ha (+109%) for C-W/S and C-S-W/S rotations, respectively. There were no significant responses to nutrients other than NPS. Considering the 13 seasons with 45 sites under corn, 38 sites under wheat, 57 sites under full-season and double cropped soybean, significant relationships were observed between Bray P-1 soil P concentrations and P responses, with critical P concentrations ranging between 12 and 20 ppm for the three crops. Below these critical levels, P responses are highly probable. Significant relationships were observed between grain yields of corn and soil N supply as predicted by soil nitrate-N concentrations measured at sowing plus the fertilizer N rate. When 270 to 280 kg N/ha was available at planting (soil + fertilizer N), corn yields were approximately 12 t/ha. A high probability to S response in corn has been determined for sites when the pre-plant sulfate-S test (0 to 20 cm) had concentrations less than 10 mg/kg. The analysis of the first 13 years of the nutrition network has shown that adequate NPS management increased grain yields, contributed to improved water use efficiency, tended to increase soil organic matter, decreased soil pH, and allowed for soil P build-up. During the 2013-14 season, three sites will be planted to full season soybean (C-S-W/S rotation) and two sites to wheat/double cropped soybean (C-W/S rotation). IPNI-2002-ARG-12
Long-term Nutrient Management Network for Southern Buenos Aires Province

Project Leaders: Fernando García, International Plant Nutrition Institute (IPNI), Acassuso, Buenos Aires. Email: fgarcia@ipni.net; Ernesto Caracoche, ASP Southern Division

Project Cooperator: Ernesto Caracoche

In 2007-08, IPNI and Agroservicios Pampeanos (ASP) established a network of field experiments with the objectives of: 1) determining direct and residual responses to N, P and S, 2) evaluating recommendation methods for N, P and S fertilization, and 3) identifying the level of deficiency and potential responses to other nutrients such as K, Mg, B, Cl, Cu, and Zn. Three sites (Pieres, Tandil and Tres Arroyos) were planted to barley during the 2012-13 growing season.

Barley yields from unfertilized plots varied from 1.7 to 3.2 t/ha, and yields from NPS-fertilized treatments varied from 2.3 to 4.0 t/ha. A positive yield response to P was significant at the Tandil site (+434 kg/ha, +23%) and NPS response was significant at Pieres (+885 kg/ha, +28%). No responses were observed to nutrients other than N, P and S. No responses to applied fertilizers were observed at the Tres Arroyos site. Grain yield responses at Tandil and Pieres related well to low Bray-1 P concentrations and good weather conditions during the growing season. In these first 6 years of evaluation, which included soybean and barley crops, the NPS treatment outperformed the check treatment in increasing barley yields by 3.4 t/ha (+23%). These sites will be planted to soybean during the seventh season of evaluation in 2013-14.

Response to Zinc in Maize Crops in the Argentinian Pampas

Project Leader: Fernando García, International Plant Nutrition Institute (IPNI), Acassuso, Buenos Aires. Email: fgarcia@ipni.net

Project Cooperators: Carlos Michiles, Matias Ruffo, and Laureano Boga

Grain crops grown in the Pampas region of Argentina, especially maize, often show zinc (Zn) deficiencies. However, research on maize response to Zn fertilization is scarce. The objectives of this research project were to: 1) quantify maize responses to Zn fertilization in the Pampas region, 2) determine the optimum Zn application rate for maize, and 3) validate local Zn analyses and critical levels. Eighteen field experiments were carried out between 2009 and 2012 in the maize-growing seasons at different locations in the Pampas region including: Alejo Ledesma, Chaján, Adelia María, Guatimozin, and Rio Cuarto sites in Córdoba; San Justo, M. Teresa, Rafaela, Wheelwright and Oliveros sites in Santa Fe; and 9 de Julio, Balcarce, Lincoln, Pergamino, and Gral. Villegas sites in Buenos Aires. Treatments included NP, NPS and NPS with different Zn application rates (0, 0.5, 1, 1.5, and 2 kg Zn/ha). Fertilizer sources used were MAP + urea (NP treatment), MicroEssentials S10TM (12-40-0-10S; NPS treatment), and MicroEssentials ZnTM (12-40-0-10S-1Zn; NPS plus Zn treatments). Nitrogen, P and S rates used were 80 kg N, 35 kg P and 20 kg S. All fertilizer applications were made at planting time.

Visual deficiency symptoms of Zn were observed at most locations. Significant positive grain yield responses to Zn additions were observed at 12 of the 18 sites. Average maize grain yields for the 18 experiments were 10.3, 10.5, 10.6, 10.8, and 10.7 t/ha for Zn application at 0, 0.5, 1, 1.5, and 2 kg Zn/ha, respectively. Optimum Zn rates varied between 1.0 and 2 kg Zn/ha, depending on the location. The average Zn response, when Zn was applied at 1.5 kg Zn/ha, was 4.7% (+487 kg/ha). No negative responses to Zn application were observed at any of the studied locations.

Four additional experiments were carried out in the 2012/13 growing season to evaluate Zn response in late-season maize crops. Experiments were located at southern Córdoba and western and northern Buenos Aires. Response to Zn application was significant at Pergamino site, with a yield increase of 9% (+720 kg/ha) when Zn was applied at 1.5 kg Zn/ha. Four field experiments will be established in the 2013/14 growing season to complete the evaluation of Zn response in late season maize.
Uruguay

Exploration of Responses to Potassium in Western Uruguay

Project Leaders: Monica Barbazan, Universidad de la República, Producción Vegetal, Paysandú, Paysandú.
Email: mbarbaz@fagro.edu.uy; Oswaldo Ernst, Universidad de la República, Producción Vegetal
Project Cooperators: Martin Bordoli, Oswaldo Ernst, Esteban Hoffman, Andres Quincke, Agustin Nuñez, Sebastian Mazzilli, and Javier Coitiño

This research is based on previous observations of K deficiency and responses to K fertilization in field crops grown within the northwestern Uruguay region. Data from the first three years of field work and other studies, including 50 experiments under wheat, barley, maize, soybean, sunflower, and sorghum crops, indicated a critical K concentration of between 0.30 to 0.40 cmol/kg (i.e., soil test K [STK] of 117 to 156 ppm), below which there is a high probability of response to K fertilization. Integration of soil survey data with this field work has allowed researchers to estimate that an area of 4 million ha is potentially K deficient in Uruguay.

Field work in the 2012-13 growing season included thirteen trials - eight with full-season soybean, one with sorghum, two with wheat, and two with barley. Potassium fertilizer application increased (p=0.10) grain yield in four of the seven sites where we expected yield response because of the low STK. Grain yield responses to K fertilization averaged 2.25 t/ha (+46%) for sorghum, and ranged from 0.11 to 1.1 t/ha (+3 to 75%) for soybean compared with unfertilized controls. The variability in K response is being investigated in a long-term field experiment initiated in 2012-13 at Soriano Department where STK ranges from 125 to 211 ppm. Crops grown in low-STK areas showed a higher occurrence of visible K deficiency symptoms. Double-cropped soybean yields tended to be higher in K-fertilized treatments, but the differences were not significant.

IPNI-2007-URY-2
Americas and Oceania Group
North America Program
Northern Great Plains Region:
Dr. Tom Jensen, Director

Alberta

**Large Urea Granules for Broadcast Application for No-till Cropping - University of Alberta, Ellerslie, AB**

Project Leader: Dick Puurveen, University of Alberta, Sustainable Resources Department, Edmonton, Alberta. Email: puurveen@ualberta.ca

It is generally accepted in the Canadian prairies that the use of so called “double-shoot” air-drill planting equipment capable of planting and banding fertilizer in one field operation is the most effective way to apply N fertilizer. Granular urea is the most widely used N fertilizer in this type of operation. The urea is sideband placed (1.5 in. to the side and 1.5 in. deeper) than the bottom of the seed furrow. However, handling all the urea at planting requires numerous stops to fill the separate air-drill tanks with urea, seed grain, and starter fertilizer. In order to speed up planting operations and allow more acres planted between fill stops, numerous farms are instead applying urea as a broadcast surface application prior to planting. The urea is broadcast on the soil using pneumatic fertilizer application trucks capable of speeds up to 25 mph making it easy to quickly cover large areas of crop land in a day. These broadcast urea applications can be made either in the late fall or early spring. Usually the spring timing of broadcast applications results in greater crop yields, and higher fertilizer use efficiency compared to fall applications due to less opportunity for denitrification or leaching losses of applied N. There are urease and nitrification inhibitor additives available that can reduce over-winter losses of applied urea. Research in the 1980’s also showed increased fertilizer use efficiency resulted from using large granule urea (0.5 in. diameter) compared to regular size urea (0.125 in. diameter).

This research study was conducted to compare crop yields from regular and large sized urea, with and without urease and denitrification inhibitors, that were broadcast applied to no-till fields in the late fall, or the early spring, for spring planted barley. All the broadcast treatments were compared to the industry accepted standard of one-pass planting described above.

Generally the fall or spring broadcast applications resulted in crop yields similar to the side-banded one-pass planting treatment. During the four years of this study, there was little advantage observed to using the urease and nitrification inhibitors. There was little difference between the surface fertilizer applications using regular-sized urea compared to large granule urea. This does not mean that the urease and denitrification inhibitors did not work, however in the four years of measurements at this site, the weather conditions were not conducive for large ammonia volatilization or denitrification losses. IPNI-2009-CAN-AB27

**Large Urea Granules for Broadcast Application for No-till Cropping in Alberta Spring Wheat**

Project Leader: Audrey Bamber, Chinook Applied Research Assn, Oyen, Alberta. Email: cara-ab@telus.net

Project Cooperators: Dick Puurveen, Ross McKenzie, and Chengci Chen

It is generally accepted in the Canadian prairies that the use of so called “double-shoot” air-drill planting equipment capable of planting and side-banding fertilizer in one field operation is the most effective way to apply N fertilizer. Granular urea is the most widely used N fertilizer in this type of operation. The urea is sideband placed (1.5 in. to the side and 1.5 in. deeper) than the bottom of the seed furrow. However, handling all the urea at planting requires numerous stops to fill the separate air-drill tanks with urea, seed grain and starter P fertilizer. To speed up planting operations, numerous farms are now applying urea as a broadcast surface application prior to planting. Usually the spring timing of broadcast applications results in greater crop yields, and higher fertilizer use efficiency compared to fall applications due to less opportunity for denitrification or leaching losses of applied N. There are nitrification inhibitor additives available that can reduce over-winter losses of applied urea, and a urease inhibitor to reduce ammonia volatilization losses of surface-applied urea. Research in the 1980’s demonstrated the potential for increased fertilizer use efficiency.
from large granule urea (0.5 in. diameter) compared to regular-sized urea granules (0.125 in. diameter). This research study was conducted to compare crop yields from regular and large-sized urea, with and without urease and denitrification inhibitors, broadcast onto no-till fields in the late fall, or the early spring, for spring wheat (one site near Acadia Valley, Alberta), or winter wheat (planted at two sites one near Acadia Valley and the other near Stavely, Alberta). All the broadcast treatments were compared to the commonly accepted standard of one-pass planting/fertilizing described above for wheat.

The fall or spring broadcast urea applications resulted in crop yields similar to the side-banded one-pass planting treatment. During the three years of this study, there was little yield advantage to using the urease and nitrification inhibitors. Also, there was little difference in yield between the surface applications using regular urea, compared to large-granule urea. This does not mean that the urease and denitrification inhibitors did not work, but while conducting this study, the weather conditions were not conducive for large ammonia volatilization or denitrification losses. IPNI-2011-CAN-AB29

Large Urea Granules for Broadcast Application in Perennial Forage Grasses

Project Leader: Dianne Westerlund, Chinook Applied Research Assn, Oyen, Alberta. Email: cara-dw@telus.net

Project Cooperators: Dick Puurveen, Ross McKenzie, and Chengci Chen

Urea is the most common N fertilizer for surface broadcast applications for perennial forage grass production in the Northern Great Plains (NGP). There is interest to know whether various N fertilizer additives, specifically a urease inhibitor alone or in conjunction with a nitrification inhibitor, can increase N availability and the production of forage grasses. There is also interest in whether larger urea granules (e.g. 0.5 in. diameter) could supply N more efficiently than regular-sized granules (0.125 diameter). This study consisted of two years (2012 and 2013) of experiments evaluating both large and regular-sized urea granules, with or without treatment with urease and nitrification inhibitors. The urea treatments were broadcast on the soil in both the fall and spring. Some band-applied urea fertilizer treatments were also included, with and without urease and nitrification inhibitor, using a no-till disc drill in both the fall and spring. The research site was a mixed grass stand pasture that had been previously established for eight years (near Youngstown, Alberta). The N application rate for all treatments was 36 lb N/A (40 kg N/ha), except for a unfertilized treatment. A broadcast application of 25 lb P₂O₅, 20 lb K₂O, and 4 lb S/A were also applied to all plots. The fall treatments were applied in mid October of each year, and the spring treatments were applied in mid April of each year. A forage cut was taken from the middle of each plot at the end of June.

In 2012, there were higher forage yields from both the larger urea granule treatment compared to regular sized urea, and from spring urea applications compared to fall applications. There were no differences in forage yield between untreated urea and yields from grass fertilized with urea treated with urease and nitrification inhibitors. In 2013, there were no yield differences between the two sizes of urea granules, or the timing of applications. The use of combined urease plus nitrification inhibitor on the urea resulted in greater forage yields than the use of untreated urea or urea treated only with a urease inhibitor. The research experiment will be continued at this site for one more growing season. There appears to be potential for improved grass forage yields from using urease and nitrification inhibitors with urea fertilizer, and a potential benefit from larger a granule size, but more research is needed to verify this finding. IPNI-2012-CAN-AB30

Montana

A Micrometeorological Study to Quantify Ammonia Volatilization Losses from Surface Applied Urea in the Semiarid Northern Great Plains

Project Leader: Richard Engel, Montana State University, Land Resources and Environmental Sciences, Bozeman, Montana. Email: rengel@montana.edu

Urea fertilizer hydrolyzes to release volatile ammonia gas when broadcast on the soil surface under certain moisture and temperature conditions. It had been generally accepted that such losses are accelerated under conditions of a moist soil surface under warmer temperatures in spring and summer, and when additional precipitation (e.g. 0.5 to 1 in. of rain) was not received within a number of days following application. Under Montana weather conditions, significant ammonia losses from urea fertilizer were not expected in late fall, winter, or early spring if soil and air temperatures were 50 °F (10 °C) or lower, and snow cover was minimal (less than 2 in.). This research initiative was designed to measure and compare volatile ammonia losses from surface-applied urea fertilizer and from urea treated with a urease inhibitor under cool late fall, winter and or early spring temperatures.

A micrometeorological technique was used that made actual measurements from circular areas 130 ft. in diameter (approx. 40 m) where urea was broadcast without incorporation. This research has generated valuable information showing that there are potential volatile losses of ammonia after late fall, winter, or...
early spring broadcast applications. Conditions for cold weather loss are similar to conditions for warm weather losses. There is an interaction between surface soil moisture and the length of time to when enough precipitation to dissolve the urea granules and move it into the topsoil is received. Moisture received after urea application is more important than soil temperature. However, if the soil surface remains dry until sufficient rainfall is received, volatile losses are minimal.

In recent studies, ammonia losses have been measured from 10 to 20%, of the urea N applied, occurring over a few-week period. To determine the crop uptake of applied urea-N, 15N-enriched urea fertilizer, with and without NBPT, was applied to microplots, in close proximity to the micro-meteorological measurement sites. The increase in fertilizer N uptake for urea treated with NBPT compared to untreated urea uptake was approximately 10% for late-fall and winter applications in both years. This research is planned to continue for one additional year. IPNI-2008-USA-MT17

**Nitrogen Fertilization Methods for No-till Cropping of Winter Wheat in Central Montana**

Project Leader: Chengci Chen, Montana State University, Central Ag Research Center (CARC), Moccasin, MT.
Email: cchen@montana.edu

Project Cooperators: Audrey Bamber, Dick Puurveen, and Ross McKenzie

The primary way to apply N fertilizer to winter wheat in Montana is to broadcast urea onto the soil surface in the late fall, or early spring. Because urea can quickly convert to ammonia, there can be some initial losses due to volatilization. Once urea moves into soil with precipitation, it is eventually converted to nitrate by soil microbes. The nitrate form of N is readily available for crop uptake, but can be subject to either leaching or denitrification losses if very wet conditions occur during the early spring portion of the crop year. This project was conducted to assess the potential benefits of using various additives or enhanced sources of urea fertilizer compared with regular broadcast applications of urea. These include a urease inhibitor with urea by itself or in conjunction with a nitrification inhibitor. A controlled-release or polymer coated urea (ESN) was also compared with untreated urea. The three years of experiments were conducted on different no-till fields at the Central Agriculture Research Center, Moccasin, Montana. The precipitation received was 21.6, 11 and 13.3 in. in 2011, 2012 and 2013 crop years, respectively. These years were categorized as wet, very dry and dry year, respectively. There were some at-planting (late September) applications of urea. A second treatment received seed-furrow-applied fertilizer as regular urea or as ESN. The third treatment was a mid-row band application of regular urea.

There was a significant effect of precipitation amount and precipitation timing on the relative wheat yields of the various N fertilizer treatments. For example, grain yields in the very dry year were higher from fall-broadcast compared to spring-broadcast urea. Conditions experienced during the three years were not conducive to large volatile losses of ammonia, so significant yield differences were not observed between untreated urea and urea treated with a urease inhibitor. ESN fertilization resulted in a greater yield (32.5 bu/A) than fall-broadcast urea (27.7 bu/A) in the wet year, probably due to reduced denitrification and or leaching losses. However, wheat yields in the very dry year were 25.5 and 31.9 bu/A for ESN and fall-broadcast urea, respectively. The very dry growing conditions likely restricted N release and availability from ESN, compared to urea. There was a benefit of adding a nitrification inhibitor only during the wet year, compared to untreated urea. In summary, the use of ESN or an added nitrification inhibitor are potentially more beneficial in higher moisture years compared to drier years. IPNI-2011-USA-MT18

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**North Dakota**

**Nitrogen Recalibration for Corn in North Dakota**

Project Leader: David Franzen, North Dakota State University, Department of Soil Science, Fargo, North Dakota.
Email: david.franzen@ndsu.edu

This was the final year of a three-year project initiated in 2010 with the objectives to a) build a data base of N application rate trials across important corn-producing regions of North Dakota with the goal of improving N fertilizer rate recommendations for corn growers, and b) develop algorithms with active optical sensors with the purpose of directing in-season N application rates for corn. Each research site had six N fertilizer application rates (0, 40, 80, 120, 160, and 200 lb N/A) with four replications. In the individual plot to which treatments were imposed, measurements taken and harvest was made from subplots (10 feet wide and 20 feet long). At the end of 2013, there have been 77 harvested locations. Crop measurements were made with the Greenseeker (Trimble) and the Holland Scientific Crop Circle sensors at the V6 leaf stage at all the eastern sites and in the western sites only in 2013. Corn yield was compared with total known available N (i.e.,
An economic production function is being imposed with the data to determine the economic N rate.

The field work for constructing the data set has been completed. Additional site-years of recent N rate trials from southern Manitoba, northwest Minnesota and northern South Dakota have been added to the data set for a total of 117 site-years. The statistical relationship between N application rate and corn yield improved greatly by including soil nitrate concentrations to a 2 ft. depth. There will be a separate rate structure based on the MRTN model for west-river, eastern high-clay soils, eastern medium-texture soils, and eastern long-term no-till soils. Active-optical sensor algorithms for all areas are currently being developed to help direct in-season N fertilizer application. The new N fertilizer rate recommendations and the algorithms will be available in the summer of 2014. IPNI-2009-USA-ND16
Variability in Soil Test Potassium and Crop Yield

Project Leader: Antonio Mallarino, Iowa State University Department of Agronomy, Ames, Iowa.
Email: apmallar@iastate.edu

The primary objective of this project is to improve Iowa State University K fertilizer recommendations for maize and soybean. This research project is actually a compilation of several interrelated experiments being conducted to meet this objective. These projects include long-term K soil fertility trials, maize and soybean residue decomposition experiments, on-farm K fertility trials, examination of different soil sample preparation techniques, and studies that are examining the interaction of nitrogen (N) and K on maize nutrient composition and yield. In this summary, we highlight research on an alternate laboratory method for preparing soil samples prior to K determination. This research focused on the effects of drying soil samples on soil K extracted by a solution of ammonium acetate and then used field response data to correlate K tests based on oven-dried (35 to 40°C) and field-moist samples for maize and soybean based on 162 single- and multi-year response trials conducted during six years.

Potassium concentrations extracted from dried samples were higher than those extracted from field moist samples (an average of 1.92 times higher). The ratio of dried: moist soil test K levels decreased exponentially with increasing K. Soil test K concentrations analyzed with field-moist preparation were better correlated with grain yield response than those associated with oven-drying. Critical concentration ranges for maize were 144 to 301 mg K/kg for dried samples and 49 to 84 mg/kg for field-moist samples. Field-moist samples predicted crop response to K fertilization better than the commonly used oven-dried samples. These new guidelines have now been published in the extension bulletin of the university and Soil Science Society of America Journal. IPNI-1999-USA-IA9

Comparative Nutrient Use Efficiency by Candidate Biofuel Crops

Project Leader: Jeffrey Volenec Purdue University, Department of Agronomy, West Lafayette, IN.
Email: jvolenec@purdue.edu

Project Cooperators: Sylvie Brouder, Keith Johnson, and Brad Joern

Our understanding of how mineral nutrition affects productivity and composition of bioenergy crops grown on marginal lands remains fragmented and incomplete despite the worldwide interest in using herbaceous biomass as an energy feedstock. Our aim was to determine switchgrass (Panicum virgatum L.) biomass production and maize (Zea mays L.) grain yield on marginal soils used previously for research to evaluate the effect of soil P and K fertility on alfalfa (Medicago sativa L.) forage production.

Grain yield of maize was reduced on P- and/or K-limited plots that also previously impaired alfalfa forage yield, whereas switchgrass biomass yields were high even in plots possessing very low available P (4 mg/kg) and K (< 70 mg/kg) concentrations. Linear-plateau regression models effectively described the relationship of soil test P and K to tissue P and K concentrations, and tissue P and K concentrations accurately predicted removal of P and K in harvest biomass. However, neither soil-test P and K, nor tissue P and K concentrations were effective as diagnostics for predicting switchgrass biomass yield nor could soil tests and their change
with cropping predict nutrient removal. Concentrations of cellulose, hemicellulose, lignin and ash were not influenced by P and K nutrition. Predicted bio-ethanol production was closely associated with biomass yield, whereas high biomass K concentrations reduced estimated bio-oil production per ha by as much as 50%. Additional research is needed to identify diagnostics and the types of management to meet the bioenergy production co-objectives of having high yield of biomass with very low mineral nutrient concentrations (especially K) while sustaining and improving the fertility of marginal soils. *IPNI-2008-USA-IN25*
Performance of Sulfur Fertilizer Products for Corn Production in Michigan

Project Leader: Kurt Steinke, Michigan State University, Plant and Soil Science, East Lansing, MI. Email: ksteinke@msu.edu

Forms of a double-salt fertilizer containing a 2:1 molar ratio of ammonium nitrate and ammonium sulfate have shown some potential to reduce ammonia volatilization and sulfate leaching. This field study compared forms of S in corn N programs for Michigan corn in 2012 and 2013. The S fertilizers were applied pre-plant and incorporated into the soil.

Corn yields did not respond to application of S fertilizers in either year. Fused forms of ammonium sulfate-nitrate did not differ from granular forms, and produced the same yields as a monoammonium phosphate product containing both sulfate and elemental forms of S. In 2012, drought conditions limited yield to an average of 125 bu/A, and possibly prevented expression of differences among these S sources. In 2013, corn yields approached 200 bu/A, but the soil extractable sulfate-S concentrations of 10 ppm (only slightly below adequate) may have been sufficient to preclude crop response to applied S.

IPNI-2012-USA-MI13

Beta-testing the Adapt-N Tool in On-farm Strip Trials

Project Leader: Harold van Es, Cornell University, Soil Crop & Atmospheric Science, Ithaca, New York Email: hmvl@cornell.edu

Project Cooperators: Bianca Moebius-Clune and Jeff Melkonian

The Adapt-N program provides N fertilizer recommendations adapted to the spring rainfall and temperature conditions of the current season, using high-resolution weather data, a sophisticated computer model, and field-specific information on soil properties and soil and crop management. The objectives of this project are to validate the Adapt-N tool for on-farm use and promote greater grower adoption of Adapt-N as part of their tool kit for adaptive N management, focused on rate and timing of fertilizer application. The main hypothesis is that the Adapt-N tool provides more accurate estimates of the current season’s optimum N rate than conventional methods and tools. In 2011 and 2012, on-farm strip trials compared corn yields with Adapt-N recommended rates to those with growers’ conventional N management.

Adapt-N increased profit in 80% of the 56 trials in New York, and in 75% of the 28 trials in Iowa. Profit increases were due primarily to reduced fertilizer application rates, owing to dry conditions in those two years. These results are documented in Better Crops 2013 issue #4. In contrast, the wet conditions of the 2013 growing season proved to be a good opportunity for Adapt-N to demonstrate its value in identifying where large N losses needed to be corrected to prevent deficiencies and support high yields. More than 100 on-farm trials were conducted, and many growers were shocked to discover how the N they had applied before or at planting had been lost prior to plant uptake because of the wet conditions. Thus the use of this tool is motivating producers to consider improving the timing of N fertilizer application to achieve higher efficiency. The number of registered users of Adapt-N has increased to nearly 1,000, and the active users cover over 150,000 acres with the fields that have been entered. Further analysis of the 2013 results is underway, and plans are being made to continue this project in 2014. IPNI-2012-USA-NY10
Ontario

Long-term Optimum Nitrogen Rate for Corn Yield and Soil Organic Matter
Project Leader: Bill Deen, University of Guelph, Department of Plant Agriculture, Guelph, Ontario.
Email: bdeen@uoguelph.ca
Project Cooperators: John Lauzon and Greg Stewart

Decisions on optimum N rates are often made on the basis of single-year responses. Data are limited on the long-term impact on productivity and soil organic matter of rates higher or lower than these short-term optima. This controlled experiment was designed as a base for testing the application of dynamic soil-crop-atmosphere models as predictors of N rates for corn that optimize sustainability. The specific objectives include the assessment of both short- and long-term effects of N rate and application timing on productivity, environmental impact, profitability and cropping system sustainability as well as the validation of crop models, such as Maize-N. Treatments include five application rates of N fertilizer ranging from 27 to 230 lb/A in a factorial arrangement with two times of application (preplant and sidedress) and differing levels of N applied the previous year.

The 2013 growing season saw the highest rainfall, the highest yields, and the highest optimum N rates of the five years of this field experiment. Over the course of this trial so far, optimum N rates have ranged from 120 to 215 lb/A, correlating directly to yields ranging from 115 to 220 bu/A. In four of the five years, optimum rates have exceeded local recommendations. Timing of application did not affect grain yields or optimum N rates. Neither were they affected by a wide range of N rates applied to the previous year’s corn crop. Grain N concentrations were higher with sidedress than with preplant fertilizer applications (0.62 versus 0.59 lb/bu). The same grain N concentration were observed comparing corn following corn that had been fertilized at N rates of 195 and 27 lb/A, respectively. These values compare to grain crude proteins levels of 8.3 and 7.8%. The 2013 season also saw the highest levels of N use efficiency in the five-year period. Agronomic efficiency in 2013 was 34 lb of grain yield increase per lb of N applied, as compared to 16 to 31 in the previous four years. Recovery efficiency in 2013 was 64% as compared to 41 to 61%. There were no significant effects of N rate, previous crop N rate, or application timing on the level of residual mineral N in the soil just after corn maturity in 2013 (average level was 40 lb/A).

This project also receives support from the Ontario Agri Business Association, for sampling soil residual nitrate and soil organic carbon, and from the Canadian Fertilizer Institute, for measuring nitrous oxide emissions. These data are currently being analyzed. The study will continue in 2014.

Investigating Hybrid Interactions with Nitrogen and Foliar Fungicides
Project Leader: David Hooker, University of Guelph, Ridgetown, ON. Email: dhooker@ridgetown.uoguelph.ca
Project Cooperator: Laura Sharpe

Producers recognize that corn hybrids can differ in their response to N fertilizer applications. This study was conducted to investigate such differences among six soon-to-be-released experimental hybrids from two major seed companies. The trial was conducted in Ridgetown, Ontario in 2012 and 2013. The hybrids were compared at two plant densities (32,000 and 42,000 plants/A) with and without fungicide.

Yield response to applied N varied from 56 to 125 bu/A in 2012 and from 31 to 70 bu/A in 2013, depending on hybrid and plant density. The lower yield response in 2013 arose from both higher check yields and lower maximum yields, as compared to 2012. The same hybrid yielded highest in both years, and also showed the largest response to higher N rates and higher plant density. Its mean agronomic efficiency, across the two years at higher plant density, was 0.46 bu of corn yield increase per lb of applied N. This hybrid also showed greater visual drought tolerance during a water deficit at the VT (tasseling) growth stage in 2012. Yield did not respond to fungicide application in either year in any hybrid, owing to low disease pressure. While these results represent only two growing seasons and a single site, they suggest that genetic improvement in hybrids may lead to yield increases as large as 40%, resulting from an increase in N use by 34%. The trial continues into its third and final year in 2014.
Regional Investigation on Interaction of Nitrogen Management, Hybrid Selection, and Population on Corn Production

Project Leader: Richard Ferguson, University of Nebraska - Lincoln, Plant Science Department, Lincoln, NE.
Email: rferguson1@unl.edu

Project Cooperators: Newell Kitchen and Dave Franzen

Making sound recommendations for N fertilizer rate and timing for optimal corn yield and minimal N loss can be complex and challenging, especially considering seasonal and locational variability. Splitting N applications between pre-plant and in-season allows room for adjustment to specific seasonal conditions. Tools such as crop sensors and the Maize N model have been developed to help fine-tune corn N management. The general objective of this study, initiated in 2012, is to evaluate these two approaches for determining in-season application N rates for corn over a three state region (Nebraska, North Dakota and Missouri). Other factors such as plant population, hybrid drought score and soil productivity were also evaluated.

Two experimental sites were selected in each state, making a total of 6 sites. Sites within states were in close proximity, each state having a high and a lower soil productivity site. At each site, a high and an average seeding rate were evaluated for both low and high drought score hybrid for Nebraska and Missouri; the two hybrids used in North Dakota in 2013 were not selected based on drought score. Four basic N treatments were used: unfertilized check, N-rich strip (preplant), sensor-based approach and model-based approach. The two latter treatments involved in-season application. Sensor-based treatments were determined by canopy reflectance using a Handheld Crop Sensor (Holland Scientific). The initial and in-season N application method and source varied by state.

In-season fertilizer application N rates for the model-based treatments were higher than in-season N rates for the sensor-based treatments at 4 of the 6 sites in 2013. Sensor-based treatments had a significantly lower yield than model-based treatments at 2 of the 6 sites, while model-based treatments had a significantly lower yield than sensor-based treatments at 1 of the 6 sites. Overall, it appears from 2013 results that yield is better protected using the model-based approach than the sensor-based approach. However, the sensor-based approach generally produced higher N-use efficiency than the model-based approach. This project will continue in 2014. IPNI-2011-GBL-47

Colorado

Nitrogen Management Strategies for Winter Wheat Yield and Grain Protein Improvement in Southeastern Colorado

Project Leader: Wilma Trujillo, Colorado State University, Department of Soil and Crop Sciences, Lamar Colorado.
Email: wilma.trujillo@colostate.edu

Project Cooperators: Jessica Davis, Scott Haley, and Jerry Johnson

Nitrogen fertilizer management is an important factor affecting wheat grain yield and protein content. The protein content in grain can often be improved by a N fertilizer topdress application later in the season. Where a premium is paid for grain protein, growers are more likely to adjust N management practices to improve this important quality parameter. Wheat production in Colorado has traditionally mostly been hard red winter wheat. But in recent years growers have been given incentive to plant more hard white wheat varieties, where a premium is paid for grain protein. As a result, white winter wheat acreage in the state has increased in recent years. This has caused more interest among growers in how N fertilizer can be used to impact grain
The objectives of this project are to i) develop N management strategies for optimum yield and protein content for dryland wheat production, ii) compare yield and grain protein responses of red and white wheat varieties to contrasting N rates and application timing, iii) determine if flag leaf N content, chlorophyll readings and GreenSeeker measurements are reliable predictors of yield and protein content, iv) evaluate the agronomic and economic performance of predicted N rates using the chlorophyll meter and GreenSeeker relative to common grower N rates, and v) develop and disseminate comprehensive N management guidelines for dryland winter wheat.

The experiment will be conducted at two farmer field locations in southeastern Colorado. Wheat variety (red and white), N application timing (pre-jointing and boot) and rate (40, 80 and 120 lb N/A) will all be evaluated. Phosphorus, K and micronutrients will be preplant applied according to soil test. Chlorophyll and NDVI (Greenseeker) readings will be taken at strategic times throughout the season, as will tissue samples for analysis for total leaf N content. Grain yield and protein content will also be determined. This research project was originally designed to start in the fall of 2012; however, drought and extreme temperatures resulted in a decision to delay the first planting until the fall of 2013. Total precipitation from July 2012 to June 2013 was only 6.6 inches, which is about one-third of the 30-year average. Most of southeastern Colorado wheat was lost due to severe drought and multiple freeze events. Support for the project is scheduled to continue.

**Kansas**

**Effect of Long-term Nitrogen, Phosphorus and Potassium Fertilization of Irrigated Corn and Grain Sorghum**

Project Leader: Alan Schlegel, Kansas State University, Southwest Kansas Research and Extension Center, Tribune Kansas. Email: schlegel@ksu.edu

This long-term western Kansas study was initiated in 1961 to evaluate responses of irrigated continuous corn and grain sorghum to N, P and K fertilization. Furrow irrigation was used through 2000, and sprinkler irrigation since that time. No yield benefit to corn from K fertilization was observed in the first 30 years and soil K levels remained high, thus the K treatment in the corn study was discontinued in 1992 and replaced with a higher P rate. Nitrogen treatments for corn and grain sorghum were 0, 40, 80, 120, 160, and 200 lb N/A. Annual P treatments for corn were 0, 40 and 80 lb P$_2$O$_5$/A, and grain sorghum were 0 and 40 lb P$_2$O$_5$/A. The K treatments for grain sorghum were 0 and 40 lb K$_2$O/A.

Nitrogen applied alone in 2013 increased corn yield by up to 69 bu/A, while N and P applied together increased yield up to 150 bu/A. This is similar to the 10-year average, where N and P fertilizer together increased yields up to 150 bu/A. Application of 120 lb N/A (with P) was sufficient to produce 92% of maximum yield in 2013, which is similar to the 10-year average. The highest yield (220 bu/A) was produced with the highest N and P rates, 200 lb N and 80 lb P$_2$O$_5$/A. At this N rate, 40 lb P$_2$O$_5$ increased yield by 59 bu/A and 80 lb P$_2$O$_5$ increased yield by 81 bu/A. Nitrogen fertilizer alone increased sorghum yield by 57 bu/A, while N plus P increased yield by up to 84 bu/A. Application of 40 lb N/A (with P) was sufficient to produce about 80% of maximum yield in 2013. Potassium fertilization had no effect on sorghum yield, as has been the case throughout the study. This is one of the few continuous, long-term crop nutrition studies in the U.S., and support is planned to continue in 2014. *IPNI-1991-USA-KS23*

**Applied Fertility Management for Irrigated Soybean Production**

Project Leader: J. Randall Nelson, Kansas State University, Department of Agronomy, Courtland Kansas. Email: jnelson@ksu.edu

Past research from Kansas State University’s (KSU) North Central Kansas Experimental Field near Scandia has demonstrated that more intensive fertility management, including direct application of P and K, has the potential to significantly improve irrigated soybean yield. Despite these findings, soybean producers have been slow to adopt more intensive fertility management programs. This project, initiated in 2012, sought to expand upon previous soybean fertility work by performing both a small plot study and a farmer field strip trial to increase awareness of irrigated soybean yield potential with proper fertility management.

The small plot work in 2012 was conducted at the KSU Irrigation Experimental Field, and the field-scale study on a producer’s field in the same region. Small plot treatments included a zero fertilizer control, and all combinations of 30 and 80 lb P$_2$O$_5$/A, and 80 and 120 lb K$_2$O/A. The effects of N and S were evaluated at higher P and K rates. Soil test P concentration in the small plot study was low (7 ppm Bray-1) while soil test K was high (542 ppm). The zero fertilizer control yield in the first year was 53 bu/A and yield with fertilizer
input ranged from 59 to 63 bu/A. The effect of fertilizer treatments over the control was significant, but there was no significant difference among the fertilizer treatments. Field scale plot design was simpler, with a zero fertilizer control, one P (30 lb P$_{2}$O$_{5}$) and one K (80 lb K$_{2}$O) rate and a combination of the two. During the second year (2013) of this study the principal investigator suddenly and unexpectedly left his position with the university. Consequently no data or reports were available for the 2013 season, despite numerous requests. This project will not be continued in 2014. *IPNI-2011-USA-KS41*

**Micronutrient Fertilization for High Yield Wheat Production in Kansas**

Project Leader: Dorivar Ruiz Diaz, Kansas State University, Manhattan, Kansas. Email: ruizdiaz@ksu.edu

Project Cooperators: Randall Nelson and James Shroyer

Kansas produces more winter wheat than any other state in the U.S. Over recent years, questions have arisen about the benefit of S and micronutrient fertilization in high yield wheat production. Science-based information on the benefit of these nutrients for wheat is limited for the state. The objectives of this project, initiated in 2012, are to evaluate wheat response to S and micronutrients and evaluate soil and tissue analysis as a diagnostic tool. This project consists of two components 1) small plot studies, and 2) replicated strip trials in farmer fields. Small-plot studies were established at four Kansas locations. Treatments consisted of S fertilizer and micronutrients (Zn, Cu, B, Mn, Fe) as individual treatments and in combination. The strip trial studies were conducted at two locations in farmer fields, simply comparing a combination of S + micronutrients (Zn, Cu, B, Mn and Fe) with an untreated control. The application rate of major nutrients was constant within sites. Producer-owned yield monitors measured yield in the strip trials. Standard soil sampling and analyses (including micronutrients) were conducted for each study site. Tissue samples were collected for analysis of total N, P, K, and micronutrients.

Results for the second year are similar to year one, and indicate inconsistent yield response to S and micronutrients with no statically significant responses. However, average values suggest a small increase in yield with S and micronutrient application, varying by soil type and location. Tissue nutrient concentrations were significantly affected by treatments. This project is scheduled to continue 2014. *IPNI-2012-USA-KS42*

**Nebraska**

**Soil Test Phosphorus Level and Yield Potential**

Project Leader: Charles Wortmann, University of Nebraska-Lincoln, Lincoln, Nebraska. Email: cwortmann2@unl.edu

Project Cooperator: Tim Shaver

This University of Nebraska-Lincoln (UNL) research project is designed to test whether maintaining high soil P availability is important to corn yield in enough years to justify the cost of building and maintaining high levels of soil P. The work was started in 2011 and is being conducted at three locations: 1) the Haskell Agricultural Laboratory (HAL) near Concord, 2) the Agricultural Research and Development Center (ARDC) near Lincoln, and 3) the West Central Research and Development Center (WCREC) near North Platte. All sites have a history of conservation tillage. The HAL site is rainfed and the others are irrigated. The effect of five P treatments on yield of continuous corn is being compared under no-till and disk till conditions at all sites. Initial soil P concentration (Bray 1-P) was less than 15 mg/kg at all sites. The P treatments are: i) Bray 1-P <15 mg/kg - no P applied; ii) P applied according to the UNL recommendation; iii) Bray 1-P raised and maintained at 25 mg/kg; iv) Bray 1-P raised and maintained at 35 mg/kg; and v) P applied based on crop removal. Initial P application was made before planting and tillage in the spring of 2011, assuming 12 lb P$_{2}$O$_{5}$ was needed to raise Bray 1-P by 1 mg/kg. Zinc was applied to minimize the chance of P-induced Zn deficiency. All trials have 4 replications.

The rainfed site (HAL) continued to be affected by drought in 2013, although not as much as in 2012. Tillage had no significant impact at HAL as it did in 2012, nor was its impact significant at the other sites in 2013. The effect of P treatments on yield was mixed in 2013, with only the HAL site showing a significant impact. Although P treatments in some cases at each site resulted in large numeric yield increase, there was no apparent trend in yield response to P application across sites. This study is scheduled to continue in 2014. *IPNI-2011-USA-NE14*
**Texas**

**Evaluation of Cotton Yield, Quality, and Plant Growth Response to Soil-applied Potassium**

Project Leader: Gaylon Morgan, Texas A&M University, AgriLife Extension Service, College Station, Texas.
Email: gdmorgan@tamu.edu

Project Cooperators: Mark McFarland

The frequency and severity of K deficiency symptoms in crops grown on the clay soils of the Central Blacklands and Gulf Coast regions of Texas have increased in recent years. While drought has contributed to the occurrence, the frequency and widespread geographic nature of the K deficiencies in multiple row crops, especially cotton, is a major concern to producers, scientists and other ag professionals. The objective of this research is to evaluate the effect of K application rates and methods on cotton growth, development, yield and fiber quality. Studies were initiated in 2013 at two field sites, one the Central Blacklands and one in the Gulf Coast region of Texas, with soil test K levels of 60 and 150 ppm, respectively. Five rates of banded liquid K (20, 40, 80, 120, and 160 lb K₂O/A as 0-0-15, KCl) and four rates of granular broadcast K (40, 80, 120, and 160 lb K₂O/A as KCl) were evaluated. The liquid treatments were banded pre-plant approximately 4 in. to the side of the row and 6 in. deep. Granular (dry) treatments were broadcast pre-plant and lightly incorporated. A zero K control was included at both sites. Phosphorus and N were applied according to soil test results for a 2 bale/A (lint) yield goal. In-season plant measurements included stand counts, plant height, nodes to first fruiting branch, and total nodes. Lint yield was determined and samples sent to Cotton Inc. for HVI (quality) analysis.

There was some variation in height and total nodes between differing amounts of K applied, but the biggest visual differences between treatments was in K deficiency symptoms in leaves, with higher rates of K (especially banded) showing fewer symptoms. There was yield response to K application at both locations. Overall, band-applied K treatments performed better than did the broadcast application. Average yield increases for broadcast application were 101 and 80 lb lint/A and for banded application were 296 and 332 lb lint/A in the Blacklands and Gulf Coast region sites, respectively. The highest rates of K application tended to produce the highest yields. The calculated return on investment, which takes into account lint quality parameters, was highest with band applications, and was maximum in the Blacklands and Gulf Coast regions at $166/A (40 lb banded rate) and $221 (120 lb banded rate), respectively. This project will continue in 2014.

*IPNI-2013-USA-TX56*
Arkansas

_Biomass and Macronutrient Accumulation and Losses in Switchgrass During and After the Growing Season_

Project Leader: Charles West, University of Arkansas, Crop, Soil and Environmental Sciences, Fayetteville, AR.
Email: cwest@uark.edu

Current fertilizer recommendations for cellulosic fuel crops in Arkansas are based on native warm-season grasses used as forages. These crops are normally harvested as hay in early to mid-summer when N, P and K removal rates are typically much greater than when harvested in the fall after the crop senesces and dries down. Fall harvest of a grass crop for bioenergy returns a large fraction of the plant macronutrients back to the soil or to the roots and crowns for recycling back into subsequent year’s regrowth. This phenomenon probably would result in P and K fertilizer recommendations that are lower than when the same grasses are utilized as forages. Studies are being conducted in Northwest Arkansas to evaluate the effect of N, P and K fertilization on switchgrass production when grown as a fuel crop.

There were no significant differences in biomass yield due to P or K fertilization in 2013. The biomass yields in the P fertilization trial ranged from 12.3 to 13.3 t/ha, but yields were not significantly different among the P fertilizer application rates (0 to 120 kg/ha). The yields in the K fertilization trial ranged from 12.9 to 13.6 t/ha among the K fertilizer rates (0 to 240 kg/ha), but yield differences were not significantly different. The yields in the N fertilization trial ranged from 9.3 to 20.8 t/ha, which represented a significant yield boost with increasing N application rates. These studies will be continued in 2014. _IPNI-2008-USA-AR33_

Florida

_Potassium and Phosphorus Fertilization of Grass Pastures_

Project Leader: Maria Silveira, University of Florida, Range Cattle Research & Education Center, Ona, Florida.
Email: mlas@ufl.edu

Pasture fertilization plays a vital role in the success of modern forage-based livestock production systems. Despite the University of Florida recommendations for K and P fertilization of highly productive hayfields and pastures, many forage producers do not supply adequate amounts of K and P to replace the exported nutrients in harvested forage. The relatively large K removal associated with the sandy-textured soils with low K-buffering capacity can lead to severe K deficiency symptoms, particularly in mechanically harvested forage production systems. The objective of this study was to evaluate the response of Jiggs bermudagrass ( _Cynodon dactylon_ (L.) Pers.) and limpograss ( _Hemarthria altissima_ Stapf. and Hubbard) to K and P fertilization. The study was conducted at the University of Florida Range Cattle Research and Education Center, Ona, Florida and treatments consisted of minimum fertilization regimens that could maintain optimum forage yield, nutritive value, and stand persistence. Because limpograss is often conserved as a stockpile grass, this study also investigated the effect of harvest frequency (4- vs. 2-times per year) on limpograss responses to K and P fertilization. Potassium and P were applied in 2012 and 2013 at rates of 0, 40, and 80 K₂O/A and 0, 20, and 40 lb P₂O₅/A per year.

Cumulative dry matter yields (DMY) of Jiggs bermudagrass increased linearly (~121 to 170%) as K fertilization increased. Similarly, K fertilization increased limpograss DMY by as much as 38% relative to the zero K control treatments. Despite the positive effect of K fertilization, the 2013 DMY of both Jiggs bermudagrass and limpograss were significantly lower than those obtained in 2012. Although the amounts of K exported via above-ground biomass harvest were similar or less than those applied as fertilizer, K fertilization at the levels tested in this study was not sufficient to sustain the same level of production during
the 2-yr study. There was considerable stand losses and concomitant weed infestation by the end of the study. No significant benefit from P fertilization on DMY was observed. Although K and P fertilization showed no effect on soil chemical properties in the limpograss study, soil pH and extractable P and K concentrations were affected by fertility treatments in the Jiggs study. Our data indicated that continuous above-ground removal without proper K fertilization results in poor forage performance, stand loss, and weed infestation. Adequate K supply is essential to sustain Jiggs bermudagrass and limpograss productivity and long-term persistence. *IPNI-2012-USA-FL31*

**Georgia**

*Loblolly Pine Stand Fertilization at Mid-rotation to Increase Small and Large Sawtimber Volume*

**Project Leader:** E. David Dickens, University of Georgia, Warnell School of Forest Resources, Statesboro GA.  
**Email:** ddickens@arches.uga.edu  
**Project Cooperator:** David Moorhead

There are over 500,000 family forest landowners in Georgia who own approximately 67% (24.3 million acres) of the state's 36 million acres of forested land. The family forest landowners in the southeastern United States own from 49% to 67% of the forestland. Real Estate Investment Trusts and Timber Investment Management Organizations, which currently own mostly former forest industry lands, have been fertilizing between 600,000 and 1 million of primarily loblolly pine stand acres annually in the southeastern U.S. over the last decade. Fertilization on family forest landowners' acreage is well below that of larger landowners. Yet numerous loblolly pine family forest landowners' stands are candidates for fertilization based on diagnostic tool use (leaf area index estimates or LAI, soil test-P, crown visual symptoms, and foliar nutrient concentrations). Financial returns ranging from 5 to 12% over an eight-year period can be realized with proper fertilizer applications.

Twenty-one 1/6 A permanent measurement plots were located and established in September and October 2013 in a 1988 planted loblolly pine stand that was thinned approximately 5 years ago on former Weyerhaeuser lands, now part of Charlane Plantation in Georgia. The gross treated plots are ¼-acre and there are 30 feet on untreated buffer between each plot. Herbicide plots were treated with 3 quarts of Razor Pro/A at 25 gallons per acre (gpa) on September 9 to October 2. All living loblolly pine trees greater than 4.5" diameter at breast height (dbh) in each plot were aluminum tree tagged, numbered, measured for dbh, total height and height to base of live crown on February 3 to 5, 2014. Soil and foliage sampling will be done on February 13, 2014. Randomly assigned to each plot will be the following treatments: (1) control (no herbicide, no fertilizer), (2) herbicide only, (3) herbicide + a full dose of NP (342 urea +125 DAP/A), (4) herbicide + NPK (342 urea + 125 DAP + 100 KCl), (5) herbicide and a ½+ ½ dose of NP (171 urea + 63 DAP), (6) herbicide and a ½+ ½ dose of NPK (171 urea + 63 DAP + 50 MOP) to be applied in February 2014 and again in February 2017, and (7) no herbicide + full NPK. Cumulative fertilizer application rates are 180 lb N/A + 25 lb elemental-P for the NP treatments and the same for NP+ 50 lb elemental-K for the NPK treatments and are planned for first application in later part of February 2014. *IPNI-2004-USA-GA26*

**Tennessee**

*Improved Plant Response to Potash Fertilization Through Control of Seedling Diseases*

**Project Leader:** Craig Canaday, University of Tennessee West Tennessee Research & Education Center, Jackson, Tennessee.  
**Email:** ccanaday@utk.edu  
**Project Cooperator:** Angela McClure

Research at The University of Tennessee’s West Tennessee Research and Education Center evaluated the effects of potash application, four seed treatment supplements, and in-furrow applications of liquid calcium nitrate (CAN) fertilizer on snap bean diseases, seedling emergence, plant stand, plant growth, and yield in two experiments in a field naturally infested with several soil-borne plant pathogens. In a test planted April 23, seedling emergence 15 days after planting was greatest when a standard seed treatment (thiamethoxam + mefenoxam + fludioxonil) received a calcium-containing supplement (Treatment A).

The number of healthy plants per row was highest when the standard seed treatment was supplemented with Treatment A, particularly in plots receiving KCl. Pathogens isolated from diseased seedlings during this experiment were tentatively identified as *Fusarium* spp. (60%), *Macrophomina phaseolina* (17%), *Sclerotinia sclerotiorum* (6%), and *Rhizoctonia solani* (5%). Snap bean yield was highest when the standard seed treatment was supplemented with Treatment A. The seed treatment supplements had no effects on seedling
vigor, plant height, or plant flowering. In a snap bean test planted August 2, seedling emergence 5 and 7 days after planting was significantly delayed with the application of KCl at 100 lb K₂O/A. Four calcium-containing seed treatment supplements had no effect on seedling emergence. Supplementing the standard snap bean seed treatment with a high rate of another experimental treatment (Treatment E) increased the number of healthy plants per row two weeks after planting, while a lower rate increased the number of healthy plants five weeks after planting. Potash application increased the number of plants lost to seedling diseases by over 56%, decreased plant height by 5% and decreased snap bean yield by 45%. The seed treatment supplements failed to significantly affect plant height or snap bean yield. *Macrophomina phaseolina* was isolated from 96% of the diseased plants.

In a separate soybean field experiment, four application rates of an in-furrow calcium nitrate spray (0, 1, 2, and 3 lb N/A) were evaluated with and without KCl to examine their effects on soybean seedling diseases, plant growth, and yield of untreated soybean seed. Soybean yield was lowest in plots that received the 1 lb N/A in-furrow spray plus potash fertilization. *IPNI-2012-USA-TN21*
Documenting Nutrient Deficiency and Accumulation Rate in Vegetables

Project Leader: Dharma Pitchay, Tennessee State University, Nashville, Tennessee. Email: dpitchay@tnstate.edu

Whenever crops are supplied with sub- or supra-optimal rates of macro and micronutrients, the impact on the yield can be drastic. The measurement of days needed to develop visual deficiency or toxicity symptoms indicates the sensitivity of the crop to a particular nutrient. Information generated in this on-going greenhouse project provides a unique and invaluable tool for technical personnel and growers to visually diagnose plant nutrition problems. Consequently, better nutrient management can increase the efficient use of fertilizer to increase the yield and quality of fruits and vegetables. The findings of this study provide the necessary information to develop guidelines for more precise nutrient management for these frequently overlooked crops. The entire study is conducted in the greenhouse by growing plants with a carefully controlled hydroponic system. The treatments are made with specially formulated nutrient solution using reagent grade chemicals and 18 megaohms purity water to eliminate any confounding errors. To date, we have documented and photographed nutrient deficiency symptoms as the symptoms appear for blueberry, coffee, cucumber, romaine lettuce, okra, eggplant, squash, and papaya at the vegetative stage.

The documentation of nutrient deficiency and toxicity symptoms for coffee, an important beverage plant consumed globally, was recently completed. With the world’s growing demand for coffee, there are initiatives to address the specific nutrient need for coffee production by small-sized farms. In coffee, unlike most species, the visual N deficiency symptoms developed first on the young leaves and not on older leaves. In blueberry, the mature leaves developed unique visual symptoms of blackened veins as a result of NH₃ toxicity under high alkalinity. There is special interest in the blueberry research since the acreage of this crop is rapidly expanding across North and South America. The results of the blueberry study have been presented at various regional conferences. On-going work involves studying the impact of macro and micronutrient at sub- and supra-optimal levels at fruiting stage for squash, eggplant, cucumber and okra. This work is a continuation of previous collaboration to document nutrient deficiency symptoms of the often overlooked vegetable and fruit crops. The photographs are added to the IPNI Deficiency Symptom collection.

IPNI-2012-USA-TN20

Nitrous Oxide Emissions from the Application of Fertilizers: Source Partitioning

Project Leaders: Johan Six, Formerly with The University of California. Email: jsix@ethz.ch

Project Cooperators: Charlotte Decock and Clifford Snyder

Nitrous oxide (N₂O) emissions account for 7% of total U.S. greenhouse gas emissions and have been identified as the dominant driver of stratospheric ozone depletion in the 21st century. In the U.S., agriculture accounts for 75% of total N₂O emissions, of which 92% is attributable to soil management practices such as fertilizer N and manure application. N₂O emissions from soil are mainly mediated by nitrifying and denitrifying microorganisms and are controlled by C and N availability, O₂ availability (often approximated by soil moisture content), and soil pH. The objective of the current study is to expose data availability and then quantitatively summarize effects of a suite of agronomic management practices on N₂O emissions in corn cropping systems in the Midwestern U.S. and southeastern Canada through meta-analysis. This approach explores the potential of alternative agronomic management practices to mitigate N₂O emissions from corn cropping systems in major corn producing regions in the U.S. and Canada, by synthesizing available data from peer-reviewed literature. Corn was selected as a focus crop, because it covers the greatest proportion of U.S. crop land and receives more N than any other major U.S. crop. The geographic area of interest confines...
a large corn-growing region with relatively comparable climate, environmental conditions, and agronomic management.

The use of the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) in combination with the nitrification inhibitor dicyandiamide (DCD) was the only management strategy that consistently reduced N₂O emissions. Manure application caused higher N₂O emissions compared to the use of synthetic fertilizer N. This warrants further investigation in appropriate manure N management, particularly in the Lake States, where often over 30% of corn crop land receives manure. The N₂O response to increasing N rate varied by region, indicating the importance of region-specific approaches for quantifying N₂O emissions and mitigation potential. In general, more data collection on side-by-side comparisons of common and alternative management practices, especially those pertaining to N placement, N timing and N source, in combination with biogeochemical model simulations, will be needed to further develop and improve N₂O mitigation strategies for corn cropping systems in the major corn producing regions in the U.S. *IPNI-2011-USA-CA32*

**Effect of Nitrogen Fertilization Practices on Spring Wheat Yield, Protein Content**

Project Leader: Steve Wright, UCCE Tulare County, Farm Advisor, Tulare, California. Email: sdwright@ucdavis.edu

Project Cooperators: Robert Hutmacher, Steve Orloff, Geoff Shulz, and Nathan Heeringa

The goal of this study is to evaluate the timing and rate of N fertilizer application to optimize wheat grain yield and protein content, while minimizing the potential for nitrate leaching. Since high yields are often accompanied by low protein content, it can be difficult to simultaneously achieve both goals.

Field research to assess the response to N fertilizer management began during 2013 in the major durum, hard red, and hard white wheat-growing regions of California. Soil samples are collected to a depth of eight feet prior to planting and following grain harvest. Fertilizer application rates range from zero to 300 lb N/A, with adjustments for preplant soil nitrate concentrations. Nitrogen fertilizer is applied at a variety of times during the growing season (preplant, tillering, boot stage, and flowering stage) to determine how to maximize recovery. Various forms of N are being used to assess the right source to improve N uptake (including controlled-release N and various inhibitors). Plant tissue samples are monitored for various N parameters to improve the diagnostic techniques to make accurate fertilizer recommendations. This study will continue for several years to develop reliable N management strategies for wheat growers in this region. *IPNI-2012-USA-CA34*

**Utah**

**Mineral Nutrition of Leafy Lettuce and the Impact on Verticillium Severity**

Project Leader: Brad Geary, Brigham Young University, Provo, Utah. Email: brad_geary@byu.edu

The Salinas Valley of California has had a serious problem with Verticillium wilt on lettuce since 1995. There is evidence that the supply of mineral nutrients can influence the severity of Verticillium outbreaks. A greenhouse study is examining the effect of N, P and K nutrition on disease severity using a hydroponic growth system. The purpose of evaluating lettuce nutrition and Verticillium in a hydroponic setting is that nutrient concentrations and growth conditions can be carefully and rigorously controlled to minimize confounding and varying effects. Certified disease-free lettuce seed are sprouted and grown in a hydroponic system containing balanced levels of all elements until the plantlets are 2 in. tall. The hydroponic solutions are then changed and varying concentrations of K, Ca, Mg, Mn, and Al are added according deficient, optimum, and excessive levels. This first phase of the experiment has been to identify the optimal concentrations of N, P, and K in the nutrient solutions for lettuce growth. This recently completed research will now allow us to establish treatments ranging from deficient to toxic nutrient concentrations while examining Verticillium infection on lettuce.

In the upcoming phase, Verticillium inoculum will be added one week following the nutrient solution change at a rate of 20 ml (2,000,000 spores/ml) of *V. dahliae*. Four weeks following the addition of inoculum, eight plants will be removed from solution and the roots separated from above-ground foliage. Randomly selected roots will be freeze-dried and prepared for quantification by PCR. Since the lettuce plants will be around 6 in. tall, randomly selected plants will be air-dried and the roots and foliage will be analyzed for nutrient content through tissue analysis. Measuring the interaction between varying concentrations of N, P and K (ranging from deficient to toxic) and Verticillium infection will provide valuable guidance on using proper plant nutrition to counteract a serious challenge to lettuce production. *IPNI-2011-USA-UT8*
**Oregon**

**Improved Nitrogen Fertilizer Practices for Highbush Blueberry**

Project Leaders: David Bryla, USDA-ARS. Corvallis, OR. Email: david.bryla@ars.usda.gov

Project Cooperator: Oscar Vargas

More than 77,000 ha of cultivated blueberry are grown worldwide, and production will increase another 46% over the next five years. Nearly 90% of the crop is produced in North America and South America. Annual total global production is predicted to reach 635,000 t by 2015. Blueberry is a long-lived perennial crop (30+ years), adapted to acidic soil conditions. Blueberries primarily acquire their N in the form of NH₄⁺ and tolerate relatively low levels of P, K, Ca, and Mg in the soil and high concentrations of Mn and Al. Nutrient management guidelines for highbush blueberry are currently based on granular fertilizers. However, most new plantings are fertigated through drip systems, which based on 4R principles, may have very different nutrient requirements. Three field trials were initiated in Oregon to evaluate new N fertilizer practices for establishment of highbush blueberry.

The first trial compared the effects of N fertigation to conventional granular fertilizer. Fertigation produced more growth and less salt injury in young plants than granular fertilizers, but fertigation required more N to reach maximum plant growth potential. More N was needed by fertigation because NH₄⁺ is immobile in soil. Unlike granular fertilizer, which was applied by hand around the base of the plants, much of the injected fertilizer wound up between the young plants and unavailable for plant uptake. In the second trial the effects of fertigation using three different methods of water placement in six cultivars was studied. Use of two irrigation laterals of drip (now a common practice) was worse than a single irrigation line. Drip emitters with two lines placed the NH₄⁺ fertilizer too far from the roots of the young plants. The third trial was planted to identify practices that increase N uptake and plant productivity during establishment, including organic acids, controlled-release fertilizers, and small amounts of granular fertilizer applied shortly after planting. After one year, importance of the dripper placement was confirmed. Fertigation with organic acid fertilizer or urea sulfurous acid also produced more growth than liquid urea alone. It is now recommended to use two lines of drip per row, but locating the lines near the base of the plants during few years after planting, and then later moving the lines away from the plant. Fertigation is also now recommended over the use of granular N fertilizers when possible, and using urea sulfurous acid or organic acids in high pH soils. Fertigation with liquid ammonium sulfate is also well suited to blueberry. *IPNI-2012-USA-OR16*

**Idaho**

**Root Scans to Document Fertilizer Response**

Project Leaders: Jared Williams, Brigham Young University, Ag Bus, Plant & Animal Sci, Rexburg, Idaho.

Email: williamsj@byui.edu

Project Cooperators: Kevin Anderson and Blake Willis

A growth chamber rhizotron project was designed to demonstrate the influence of plant nutrients on root growth using time-lapse videos. A secondary goal was to develop a teaching tool that could be shared with other educational institutions for classroom demonstration of root development. The rhizotron project continues to be a laboratory experience for a crop physiology class and is currently in its 7th semester (approx. 100 students have been involved). In between semesters, the rhizotrons have been used to conduct undergraduate research projects. In 2013, two student projects were conducted: 1) manure placement on seed emergence and root growth and 2) the effect of various fertilizers and their placement on wheat germination.

The rhizotron project has been a valuable teaching, learning, and research tool for the students. As part of the crop physiology class, students design their own research project using the rhizotrons. Student projects have included a wide variety of crops (alfalfa, wheat, barley, corn, soybeans, and potatoes) and fertilizer treatments (rates, placements, N and P combinations and compost). The rhizotron has been a motivating teaching tool and has facilitated student understanding of root growth and fertilizer response.

In 2013, we began collaboration with the university communication service to create time-lapse videos of root growth. The videographer students are assisting agronomy students in setting up the rhizotrons. Fertilizer treatments consisted of type, amount and placement of fertilizer. Each rhizotron was programmed to take a root scan every 15 minutes for 10 days. The scans were used to create time-lapse videos that have been posted to YouTube. The videos are used in classrooms to demonstrate root response to fertilizer. *IPNI-2010-USA-ID11*
A study was conducted from 2009 to 2011 where nutrient deficiencies were imposed on replicated red and white wine grape plants grown in pots. Deficiencies of N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, and Zn were imposed on 10 replications of Cabernet Sauvignon and of Semillion plants. In addition, 30 control (full nutrition) Cabernet Sauvignon and Semillion plants were also grown for comparison. In 2010, just prior to commercial harvest, three plants for each cultivar and nutrient treatment and three control plants were destructively harvested. The plants parts were divided into components (roots, trunk, shoots, petioles, leaves, and, if present, fruit and rachis). The components were dried, weighed, ground, and analyzed for nutrient concentration. The remaining plants were over-wintered in a cold storage area, and in 2011 the treatments were continued, with weekly photographs of the developing nutrient deficiency symptoms. At bloom, another three plants of each cultivar/nutrient combination were destructively harvested and in later September, at commercial harvest, all remaining plants were destructively harvested and handled as described above.

Nutrient deficiency symptom images are being processed and will soon be made available for viewing on the IPNI website. While all photographs were taken early in the morning, and a large umbrella was used for shading, there was still variation in the plant color in the photographs due to light interception created by the changes in the sun’s position as well as plants being photographed from an eastern or western exposure depending on their position. All photographs were taken with the plant placed in front of a black background to use for color adjustment. This project resulted in over 5,000 photographs. Using the program Adobe Lightroom, each photo was adjusted to a uniform “exposure” using the black background as the constant for adjusting the image. Additionally, photos were cropped to remove any edges beyond the black background and to strive for fairly uniform sizing. As the image processing is completed, the photographs will be added to the IPNI nutrient deficiency gallery for public viewing. IPNI-2013-USA-WA15
Nutrient Demand of Oil Palm Hybrids in Tropical America

The aim in the second phase of this study is to estimate the effect of five application rates of N, P, K, and B in the growth and yield of two crosses of *Elaeis oleifera* with *Elaeis guineensis* (“OxG” hybrids) by using a factorial experiment arranged in a central composite design. The study was replicated at three locations—the Casanare, Meta and Tumaco Departments of Colombia—with all of them being important oil palm areas and having the presence of bud rot disease. The soils at these locations are acidic (pH from 4.3 to 4.8) with very low to intermediate P concentrations (3 to 18 ppm), and variable exchangeable Al (30 to 70%). Two OxG hybrids were evaluated: “M1” from La Cabaña (Coarix LaMé) and “M2” from Unipalma (Oleifera of uncertain origin x Mongona). The plants were transplanted from nursery in the second half of 2011. In 2013, we had a second year of measurement of vegetative growth, i.e., plant height (H), leaf area of leaf number nine (LA9), dry mass of leaf number nine (DM9), rate of leaf production (RLP) and transversal petiole section area at the leaf base (TPS). Also, chemical analysis of leaf tissue was carried out on samples taken from leaf number nine (the commonly used leaf seventeen is not recommended for young plants).

Contrary to the initial effects observed in the nursery phase of the study, we did not detect a strong isolated effect of N on all vegetative growth parameters. On the other hand, several interactions among nutrients were observed: P and N showed a relatively small effect in the M1 hybrid with increases in H and RLP, while there was a highly significant interaction of K with N in both M1 and M2 hybrids. As an example, the highest RLP was found for M2 with the highest values of K and low or intermediates values of N (27 leaves per yr), while low values of N and K produced around 7 leaves less per year (i.e., 20). In summary, K appeared to be a very important nutrient in the growth of the OxG hybrids, even more than N in this second year of growth, but the largest effect of K occurs when N is not deficient. Boron showed a net negative effect on all the vegetative growth parameters, especially with M1. We feel that B is not a fundamental nutrient in the initial phases of the OxG hybrid, and actually has a detrimental effect, especially, with high application rates. The nutrient content of LA9 followed different patterns in both hybrids indicating that each plant genetic material should have its own reference diagnostic tables.
Americas and Oceania Group

Mexico and Central America Program

Dr. Armando Tasistro

Response of Two Maize Cultivars to Potassium in Cintalapa

Project Leader: Rodolfo Vitchis Ramos, INCA Rural, A.C. Email: vilang8@hotmail.com

The objective of this study is to determine the responses of an open pollinated variety and a hybrid of maize to K fertilizer applied using two sources and at four rates. The study was conducted in a farmer’s field in Cintalapa, Chiapas, Mexico on a sandy clay loam soil (pH 5.5, 2.4% organic matter, 51 ppm Bray 1-P, 48 ppm available K, 1,214 ppm Ca, 213 ppm Mg, 18 ppm Na, 0.7 ppm Zn, 32 ppm Mn, 2 ppm Cu, and 0.2 ppm B). The effective cation exchange capacity of the experimental soil was 8 cmol/kg. Treatments included two cultivars (variety ‘V 424’ and hybrid ‘P4063W’), two K sources (KCl and K$_2$SO$_4$) and four K rates (0, 60, 120, and 180 kg K$_2$O/ha). The resulting 16 treatments with 2 replications were arranged in an experimental design with split-split-plots, where the cultivars were assigned to main plots, sub-plots had K sources and sub-sub-plots had K rates.

Maize grain yield averaged 2.6 t/ha (14% moisture) because of the drought that affected the location. No significant effects (p=0.05) could be detected for any treatment. Average yield for the hybrid (3.5 t/ha) was almost twice as high as that of the open-pollinated variety (1.8 t/ha), which could be due to several factors including open-pollinated variety’s lower tolerance to drought and more severe damage by fall armyworm in the season.

Effects of AGARRE on the Response of Maize to Potassium in Villaflorres

Project Leader: Santiago Mendoza Pérez, Universidad Autonoma de Chiapas. Email: chachiago@yahoo.com.mx

The objective of the study was to determine the influence of a commercial seed treatment (AGARRE) that contains micronutrients and hormones on the response of maize to K supplied using two fertilizer sources at four application rates. The study was conducted at the experimental station of the University of Chiapas in Villaflorres, Chiapas, Mexico. The field had a sandy loam soil (pH 4.8, 2.3% organic matter, 10 ppm Bray-1 P, 102 ppm available K, 508 ppm Ca, 98 ppm Mg, 17 ppm Na, 2 ppm Zn, 49 ppm Mn, 0.6 ppm Cu, and 0.4 ppm B). The effective cation exchange capacity of the experimental soil was 4 cmol/kg, with an exchangeable Al saturation of 8%. Treatments included AGARRE (0 and 250 mL/ha), K sources (KCl and K$_2$SO$_4$) and K rates (0, 60, 120, and 180 kg K$_2$O/ha). The resulting 16 treatments with two replications were arranged in an experimental design with split-split-plots, where the main plots had the application of AGARRE, the sub-plots had different K sources and the sub-sub-plots had K rates.

Due to the occurrence of extreme spatial variation in plant growth, grain was not harvested. The average plant height of tall, apparently normal plants was 216 cm, which was 27% greater than that of stunted plants (170 cm). Although apparently normal plants tended to be taller as the K rate increased, the effects were not statistically significant (p < 0.05). However, plant height decreased markedly when Mn concentration in leaves exceeded 90 mg/kg. The trial site had conditions conducive to Mn toxicity: low pH and reducing conditions due to water logging (caused by subsoil compaction) and abundance of organic residues from the previous crop.
**Effects of Liming on the Response of Maize to Potassium in Jiquipilas**

Project Leader: Carlos Eduardo Cabrera Escobar. Email: carlos9.88@hotmail.com

The objective of this study was to determine the influence of liming on the response of maize to K added as two fertilizer sources and at four application rates. The study was conducted in a farmers field in Jiquipilas, Chiapas. The field had a sandy loam soil with pH 5.2, 2.3% organic matter, 48 ppm Bray-1 P, 72 ppm available K, 411 ppm Ca, 31 ppm Mg, 17 ppm Na, 0.3 ppm Zn, 22 ppm Mn, 0.3 ppm Cu, and 0.2 ppm B. The effective cation exchange capacity (CEC) of the experimental soil was 3 cmol/kg, and exchangeable Al saturation was 4%. Treatments included liming (0 or 1 t/ha of dolomitic limestone), K fertilizer sources (KCl or K$_2$SO$_4$) and K application rates (0, 60, 120, and 180 kg K$_2$O/ha). The resulting 16 treatments with two replications were arranged in an experimental design with split-split-plots, where main plots received limestone application, sub-plots had different K sources and sub-sub-plots had different K rates.

Grain yield (14% moisture) averaged 6.4 t/ha, and no significant effects ($p > 0.05$) could be detected for any treatment, possibly because of the very large variation (CV 22%) observed in the study. Average yield when lime was applied at 6.9 t/ha was 18% higher than when no lime was applied (5.8 t/ha). Also, yields decreased as foliar Mn concentrations increased. *IPNI-2013-MEX-55*

**Response of Peanuts to Gypsum in Cintalapa**

Project Leader: Rodolfo Vilchis Ramos. Email: vilang8@hotmail.com

Cintalapa—situated in the Northwest of the State of Chiapas, Mexico—is an important peanut-growing area, mainly because this crop provides some income under the erratic rains and the extremely degraded soils that prevail. No nutrients are supplied to the crop, other than the N coming from symbiotic fixation. This exploratory study was started after the crop had been sown, and was therefore restricted to the application of gypsum (0, 500, 1,000, 1,500, and 2,000 kg/ha), mostly as a source of Ca for the developing pods. The leaf analyses data for different nutrients at the six locations chosen for this experiment showed quite a variation and lower nutrient concentrations compared with the adequate values needed for maximum production.

Only three locations could be harvested. Peanuts yields, both as pods or grain, trended higher with gypsum application in locations Juan V. and Heberto M., although the effects were not statistically significant ($p > 0.05$). Low yields at the Juan V. location are consistent with the very low nutrient contents found in peanut leaves at this location. *IPNI-2013-MEX-56*
Nutrient Management and Optimized Fertilization on Maize in Heilongjiang Province

Project Leader: Li Yuying, Heilongjiang Academy of Agricultural Sciences, Soil and Fertilizer Institute, Harbin, Heilongjiang. Email: yyli@ppi.caas.ac.cn

Project Cooperator: Liu Shuangquan

Nutrient Expert® (NE) is a computer-based decision support tool developed to assist local experts to formulate fertilizer guidelines for maize. It is based on the principles of site-specific nutrient management (SSNM). The tool is especially useful when soil testing facilities are not easily accessible, which makes timely fertilizer recommendation difficult. This study was continued in 2013 to validate NE-based fertilizer recommendations for spring maize in farmer fields and compare them with farmer fertilizer practice (FFP). For this project, 12 on-farm experiments were conducted in five different counties in Heilongjiang Province. Each individual site had a site-specific rate applied; the NE-based plots received 178 kg N, 82 kg P₂O₅ and 80 kg K₂O/ha on average, while the FFP plots received an average of 172 kg N, 65 kg P₂O₅ and 53 K₂O/ha. Grain yield (11.5 t/ha) and profit (US$3,424/ha) were higher in NE-based treatment plots than in the FFP plots, where corresponding values were 10.6 t/ha and US$3,185/ha. Also, higher agronomic (20.3 kg/kg) and recovery efficiencies (34%) of N were obtained using NE-based fertilizer recommendations versus FFP, where corresponding values were 15.5 kg/kg and 25%. This was likely due to the fact that there was more balanced application of N, P and K fertilizers in the NE-based treatment vis-a-vis in the FFP treatment.

IPNI-2006-CHN-HG8

Nutrient Management and Optimized Fertilization on Wheat and Maize in Henan Province

Project Leader: Jinfang Tan, Henen Agricultural University, College of Resources and Environment, Zhengzhou, Henan. Email: wangyilunrl@163.com

Project Cooperator: Yilun Wang

This study was conducted to validate Nutrient Expert® (NE)-based fertilizer recommendation for winter wheat and summer maize in farmer fields and compare them with farmer fertilizer practice (FFP). For this project, nine on-farm wheat and three on-farm maize experiments were conducted in Hebi and Zhengzhou, in Henan Province. The NE-based fertilizer recommendation plots received on average 174-92-78 kg N-P₂O₅-K₂O/ha for wheat and 182-79-90 N-P₂O₅-K₂O/ha for maize, respectively, while FFP plots received 161-112-90 N-P₂O₅-K₂O/ha for wheat and 249-48-42 N-P₂O₅-K₂O/ha for maize.

Results from the study in 2013 showed that grain yields in NE plots were 7.5 t/ha and 10.6 t/ha for wheat and maize, respectively; while respective profits were US$2,894/ha and US$3,346. In FFP plots, the corresponding values were 7.4 and 10.6 t/ha and profits were US$2,846 and US$3,389/ha. However, higher agronomic efficiency of N (8.5 kg/kg for wheat and 9.4 kg/kg for maize), N recovery efficiency (32% for wheat and 41% for maize) and partial factor productivity of N (43.7 kg/kg for wheat and 58.5 kg/kg for maize) were obtained using NE-based fertilizer recommendations compared to FFP, where the corresponding values were 8.1 and 6.7 kg/kg, 26.4 and 24.7%, and 46.3 and 42.5 kg/kg for wheat and maize, respectively.

IPNI-2006-CHN-HN6

Nutrient Management and Balanced Fertilization on Major Crops in Jilin Province

Project Leader: Zhang Kuan, Jilin Academy of Agricultural Sciences, Soil and Fertilizer Institute, Changchun, Jilin. Email: jgxie@ppi.caas.ac.cn

Project Cooperators: Xie Jiagui and Wang Xiufang

This study was conducted to validate Nutrient Expert® (NE)-based fertilizer recommendation for spring maize in farmer fields and compare them with farmer fertilizer practice (FFP). For this project, 15 on-farm
Experiments were conducted in three different counties in Gongzhuling, Jilin Province. Nutrient Expert®-based fertilizer recommendation plots received an average of 156-82-94 kg N-P₂O₅-K₂O/ha, while FFP plots received 243-119-94 kg N-P₂O₅-K₂O/ha, respectively.

Results in 2013 showed that grain yield (11.1 t/ha) and profit (US$3,592/ha) obtained in NE-based treatment were similar to those obtained in the FFP treatment (10.7 t/ha and US$3,316/ha). However, a significantly higher agronomic efficiency of N (17.3 kg/kg) and partial factor productivity of N (70.5 kg/kg) were obtained using NE-based fertilizer recommendations than when using FFP, where the corresponding values were 9.3 and 43.6 kg/kg, respectively. Also, 35.8% less fertilizer N was used in the NE-based treatment than that used in the FFP. The results of this study demonstrated the potential of NE as a viable alternative to soil testing for making improved fertilizer recommendations. IPNI-2006-CHN-JL7

Nutrient Management and Optimized Fertilization on Wheat and Maize in Hebei Province

Project Leader: Mengchao Liu, Hebei Academy of Agricultural and Forestry Sciences, Institute of Agricultural Resources and Environment, Shijiazhuang, Hebei. Email: lmchao1758@126.com

Project Cooperators: Jia Liangliang, Xing Suli, and Han Baowen

This study was conducted to validate Nutrient Expert® (NE)-based fertilizer recommendations for winter wheat and summer maize in farmer fields and compare them with farmer fertilizer practice (FFP). For this study, 18 on-farm experiments were conducted in Xinji and Zhending cities in Hebei Province. NE-based fertilizer recommendation plots received an average of 182 kg N, 104 kg P₂O₅ and 83 kg K₂O/ha for winter wheat and 182 kg N, 73 kg P₂O₅ and 77 kg K₂O/ha for summer maize, while FFP plots received an average of 342 kg N, 177 kg P₂O₅ and 40 kg K₂O/ha for winter wheat and 295 kg N, 40 kg P₂O₅ and 50 kg K₂O/ha for summer maize.

Results showed that the NE treatment led to significantly higher wheat grain yields (6.9 t/ha), profits (US$2,164/ha), agronomic efficiency of N (AEN, 5.8 kg/kg) and partial factor productivity of N (PFPN, 7.9 kg/kg) vis-a-vis the FFP treatment (6.3 t/ha, US$1,789/ha, 1.7 kg/kg and 18.4 kg/kg, respectively). For maize, the NE treatment had almost similar grain yields (8.7 t/ha) and profits (US$2,999/ha) as the FFP treatment (8.4 t/ha and US$2,886/ha, respectively), but had significantly higher AEN (6.6 kg/kg vs. 3.2 kg/kg) and PFPN (47.7 kg/kg vs. 28.3 kg/kg) compared to FFP. The study demonstrated that NE was an effective fertilizer recommendation method for wheat and maize crops in Hebei. IPNI-2009-CHN-HE6

Nutrient Management and Optimized Fertilization on Wheat and Maize in Shanxi Province

Project Leader: Hongting Wang, Shanxi Academy of Agricultural Sciences, Institute of Agricultural Environment and Resources, Taiyuan, Shanxi. Email: ting_tfs@163.com; htwang@ipni.ac.cn; htwangwb@public.ty.sx.cn

Project Cooperators: Wang Bin

This study was conducted to validate Nutrient Expert® (NE)-based fertilizer recommendations for winter wheat and summer maize in farmer fields and compare them with current farmer fertilizer practices (FFP). Seven on-farm experiments each for winter wheat and summer maize were conducted in Linfen, Shanxi Province. NE-based fertilizer recommendation plots received on average 174-86-65 kg N-P₂O₅-K₂O/ha for wheat and 148-60-61 kg N-P₂O₅-K₂O/ha for maize, while the FFP plots received an average of 258-91-26 kg N-P₂O₅-K₂O/ha for wheat and 277-30-19 kg P₂O₅-K₂O/ha for maize.

Results of the study showed that grain yields and profits were 7.7 t/ha and US$2,500/ha for wheat and 9.6 t/ha and $3,207/ha for maize under the NE treatments; and 7.9 t/ha and $2,556/ha for wheat and 9.1 t/ha and $3,207/ha for maize under the FFP treatments. These were statistically similar results. The agronomic efficiency of N (4.9 kg/kg for wheat and maize) obtained with NE was equal to FFP. However, significantly higher N recovery efficiency (18.5% for wheat and 23% for maize), and partial factor productivity of N (43.8 kg/kg for wheat and 73.9 kg/kg for maize) were obtained using NE-based fertilizer recommendations than using FFP, where the corresponding values were 13 and 16%, and 37 and 36 kg/kg for wheat and maize, respectively. When following the recommendations made with NE, 32 and 47% less fertilizer N was used compared to FFP for wheat and maize, respectively. The study demonstrated that NE was an effective fertilizer recommendation method in Shanxi. IPNI-2006-CHN-SH4
Asia and Africa Group

China Program

Northwest Region:
Dr. Shutian Li, Deputy Director

Potassium Management in Apple Production in North China

Project Leaders: Yan’an Tong, University of China, Yangling, Shaanxi. Email: tongyanan@nwsuaf.edu.cn; Rongzong Cui, Shandong Academy of Agricultural Sciences, Jinan City, Shandong Province. Email: rzcui@ipni.ac.cn; Ren Wang, Liaoning Academy of Agricultural Sciences, Shenyang, Liaoning. Email: lntfswr@yahoo.com.cn

Project Cooperators: Yan’an Tong, Yimin Gao, Rongzong Cui, Xianlin Wei, Ren Wang, and Yuehua Xing

Field trials were conducted in Shaanxi, Shandong and Liaoning Provinces to investigate fertilizer use in apple orchards and to study the effect of source, rate and time of potash application on apple yield and quality. The orchard sites in Shandong and Liaoning had low soil organic matter content. The average mineral N, Olsen-P and exchangeable K concentrations in the surface soil (0 to 20 cm depth) were 78, 76 and 238 mg/kg in Shandong and 81, 87 and 103 mg/kg in Liaoning. All these nutrient concentrations decreased with greater depth down the soil profile. Shandong orchard farmers mainly applied chemical fertilizers as the nutrient source (a mean of 667 N/ha, 301 kg P$_2$O$_5$/ha and 542 kg K$_2$O/ha, with no animal manure application. However, apple farmers in Liaoning applied nearly half of the total nutrients using manures. A positive K balance existed in all the soil of all the orchards studied in both provinces.

Apple fruit yield and economic returns significantly increased with K application at all the three locations. Fruit quality was also improved by K application. Application 0.3 kg of K$_2$O/tree (as KCl) produced similar fruit yield and quality to K$_2$SO$_4$, but had better economic benefit. The high application rate of K fertilization reduced the Ca and Mg contents in apple fruit, suggesting that overuse of K could cause issues related to Ca or Mg deficiency. All the treatments with K application showed positive K balances at all the experimental locations. Application of 50% of the recommended K at later crop growth stages such as flowering and fruit expending could be beneficial for fruit yield and quality as well as increase farmer’s income. In summary, the best K management practice was to apply KCl at 0.3 to 0.45 kg K$_2$O/tree, but apply 50% of the K as basal (at flowering) and the additional half of the K during the fruiting stage. IPNI-2011-CHN-C16

Best Management Practice for Potassium Application in Potato in Northwest China

Project Leaders: Yu Duan, Institute of Plant Nutrition and Analysis, Inner Mongolia Academy of Agricultural Sciences, Inner Mongolia, Gansu. Email: duanyu63@yahoo.com.cn; Tianwen Guo, Institute of dryland Crops, Gansu Academy of Agricultural Sciences, Anning District, Lanzhou City. Email: guotw11@sohu.com

Project Cooperators: Debao Tuo, Yu Duan, Tianwen Guo, and Pingliang Zhang

During 2012 to 2013, 30 field trials with two treatments (OPT and OPT-K) were conducted in randomly selected rainfed and irrigated farmers’ potato fields in Inner Mongolia and Gansu Provinces. The objective was to study tuber yield response and agronomic efficiency of K, soil indigenous K supply and productivity for K recommendation. The effect of K fertilizer source and time of application on potato tuber yield and quality were also studied in the two provinces. The average soil exchangeable K was 97 and 164 mg/kg in rainfed fields and 171 and 198 mg/kg in irrigated fields in Inner Mongolia and Gansu, respectively. The relationship between soil exchangeable K and relative yield (yield with no K/yield with K ×100%) showed that the critical level of soil exchangeable K at 90% relative yield was 99 mg K/kg for rainfed potato and 137 mg K/kg for irrigated potato.

In Inner Mongolia, K application increased potato tuber yield by an average of 1.7 t/ha (11%) and 2.2 t/ha (8%) and starch content by 0.7 and 0.6%, while it decreased reducing sugars by 0.3 and 0.25% for rainfed and irrigated potato, respectively. In Gansu, K fertilizer application significantly increased tuber yield by an average of 2.0 t/ha (8%) and 2.7 t/ha (8%) and starch content by 0.8 and 0.2%, while it decreased reducing sugars by 0.04% for rainfed and irrigated potato, respectively. The average agronomic efficiency (AE) of K fertilizer was 26.5 kg tuber/kg K$_2$O and 15.7 kg tuber/kg K$_2$O for rainfed and irrigated potato, respectively,
in Inner Mongolia. These AE values in Gansu were 31 kg tuber/kg K\(_2\)O and 41 kg tuber/kg K\(_2\)O, respectively. In Inner Mongolia, the average indigenous K supply and tuber productivity were 52.7 kg/ha and 13.9 t/ha for rainfed potato and 118 kg/ha and 25 t/ha for irrigated potato, respectively. In Gansu, the mean indigenous K supply and tuber productivity were 172 kg/ha and 23.5 t/ha for rainfed potato, 246 kg/ha and 30 t/ha for irrigated potato, respectively. Tuber yield of rainfed potato was not related with soil exchangeable K, but the tuber yield of irrigated potato increased with the increase of exchangeable K in the soil. Potassium fertilizer application rates could be recommended based on AE (kg tuber/kg K\(_2\)O), target yield (Yt, t/ha), and no K yield (Y0, t/ha); i.e. recommended K (kg K\(_2\)O/ha) = (Yt – Y0) \times 1000/AE. In rainfed and irrigated conditions, K fertilizer sources did not significantly affect tuber yield and quality, except that MOP significantly lowered the reducing sugar content. The best management practice for K fertilizer application in potato production of this region was to apply 100% KCl as basal or 50% as basal and 50% as topdressing either in rainfed or irrigated conditions. 

**Effect of Potassium Management on Lint Yield and Fibre Quality of Cotton in North China**

Project Leaders: Yan Zhang, Xinjiang Academy of Agricultural Sciences, Urumqi, Xinjiang. Email: yanzhangyz@sohu.com; Rongzong Cui, Shandong Academy of Agricultural Sciences, Jinan City, Shandong Province. Email: rzcui@ipni.ac.cn; Kegang Sun, Henan Academy of Agricultural Sciences, Zhengzhou City, Henan. Email: kgsun@ipni.ac.cn; Suli Xing, Hebei Academy of Agricultural and Forest Sciences, Shijiazhuang, Hebei. Email: 834591172@qq.com

Project Cooperators: Yan Zhang, Qingjun Li, and Wei Hu

During 2012 and 2013, 60 cotton fields were randomly selected to investigate the relationship between soil K supply and cotton yield/fibre quality in Hebei, Henan, Shandong, and Xinjiang Provinces. The effects of application rate and time of K fertilization on cotton yield and fiber quality were also studied in each province. Exchangeable K values in the soil of Shandong (mean=232 mg/kg) and Xinjiang (217 mg/kg) cotton fields were higher than that in Henan (128 mg/kg) and Hebei (133 mg/kg) cotton fields. In Henan, Shandong and Xinjiang, soil exchangeable K, total plant K uptake, seed cotton or lint uptake K were significantly and positively correlated with seed cotton and lint yield. The relationships between soil exchangeable K and fiber quality indices (length of fiber, fiber length uniformity, linter index, fiber strength, fiber elongation, macronaire value, fiber maturity ratio) were variable, but significantly and positively correlated with macronaire value.

Application of fertilizer K increased lint yield by 1 to 9% (Hebei), 14 to 68% (Henan), 5 to 14% (Shangdong), and 8.5 to 27% (Xinjiang). The agronomic efficiency of K was <1.2 kg lint/kg K\(_2\)O, 0.7 to 2.0 kg lint/kg K\(_2\)O, 0.7 to 2.1 kg lint/kg K\(_2\)O, and 2.7 to 9.8 kg lint/kg K\(_2\)O for the four provinces, respectively. Also, the economic benefit from K application was US$220 to 540, $420 to 2,130, $285 to 680, and $608 to 1,885/ha for the four provinces, respectively. Application of K increased length of fiber, fiber length uniformity and fiber strength. Application of K also decreased macronaire values, but did not affect fiber elongation in Hebei. Length of fiber, fiber strength and fiber elongation increased with K application in Henan, while fertilizer K application did not significantly affect various fiber quality indices in Shandong and Xinjiang. The appropriate application rates of K fertilizer in cotton at Hebei, Henan, Shandong, and Xinjiang were 150, 240, 180, and 150 kg K\(_2\)O/ha, respectively. The right time of K application in Hebei, Henan and Xinjiang was determined as 50% K at bud stage plus 50% K at boll stage, while in Shandong, 50% K is applied as basal preparation and the remaining 50% K at flowering. 

**Potassium Management for Improving Processing Tomato Yield and Quality in Xinjiang**

Project Leaders: Yan Zhang, Institute of Soil and Fertilizer, Xinjiang Academy of Agricultural Sciences, Urumqi, Xinjiang. Email: yanzhangyz@sohu.com

Project Cooperators: Yan Zhang, Qingjun Li, and Wei Hu

Two experiments on K application rate and proper time of fertilization and two trials on K nutrient sources were conducted in Changji City of Xinjiang Province using two tomato varieties (HYH-01 and Tunhe-No.8). Plant uptake of K in later stages of crop growth (i.e., after 48 days of transplanting) was mainly transported to the fruit, so sufficient K supply in later stages is important for K nutrition of processing tomato. Application of K at 120 kg K\(_2\)O/ha for variety Tunhe-No.8 and 180 kg K\(_2\)O/ha for HYH-01 produced more dry matter than other rates. Application of K produced 24 to 37% (HYH-01) and 11 to 24% (Tunhe-No.8) more fruit yield compared with the control without K. The agronomic efficiency (AE) of K was 134 to 402 kg fruit/kg K\(_2\)O for HYH-01 and 49 to 238 kg fruit/kg K\(_2\)O for Tunhe-No.8 and decreased with the increase in K application rates. The economic benefit of K application over the control without K fertilizer was US$1,634 to 2,505/ha and US$506 to 1,262/ha for HYH-01 and Tunhe-No. 8, respectively. The average of the two tomato varieties indicated that 50% K applied at flowering and 50% K applied at fruiting with a total rate of 120 kg K\(_2\)O/ha produced the highest fruit yield and benefit. An application of 120 kg K\(_2\)O/ha as KCl resulted in similar or more fruit yield and economic benefit than K\(_2\)SO\(_4\) and KNO\(_3\), but the different sources of K had no significant effect on fruit quality indexes.
**Research in Herbosa Succession Process Based on Soil Fertility Evolution**

Project Leader: Wan Kaiyuan, Chinese Academy of Sciences, Wuhan Botanical Garden, Hongshan District, Wuhan, Hubei. Email: wankaiyuan@126.com

Project Cooperators: Tao Yong and Chen Shusen

Weeds compete with crops for abiotic factors affecting growth, and this competition can result in drastic declines in crop yield and quality. These factors also play an important role in nutrient cycling, soil preservation and other ecosystem functions. Fertilization can not only affect crop growth, but also impact selection pressures on weeds. Therefore fertilization is regarded as an important component of integrated weed management program. Previous studies have demonstrated that fertilization greatly affected weed species composition, abundance, density and diversity. Study of the effect of nutrient management on weed communities is important for making better nutrient management strategies in an integrated farmland ecological system.

Based on an 11-year field experiment, Wuhan Botanical Garden of the Chinese Academy of Science studied the cumulative effects of different fertilizing patterns on the floristic composition and species diversity of farmland weeds in a wheat-soybean rotation. The field trial included five fertilizing patterns with different combinations of N, P and K fertilizers. Species composition and diversity of weed communities, plant biomass and nutrient accumulation as well as light penetration were measured. There were four dominant weeds that accounted for 90% of the total weeds. Residual weed community assembly was influenced by the topsoil-available nutrients in the order P > N > K. Competition for nutrients and solar radiation between crops and weeds constitute indirect effects on the changes in weed community composition and species diversity. The species diversity indices (species richness, Shannon-Winner Index, Pielou Index and Simpson Index) showed quadratic function relationship with light transmittance. Balanced fertilization showed an efficient inhibiting effect on weeds. The authors believe that balanced fertilization has a beneficial effect on farmland environment because it can better support crop yield and suppress competition from diverse weed species.

*IPNI-2009-CHN-HB34*

**Study on the Fertilization Effect and Nutrient Management for Direct Seeding Rapeseed in China**

Project Leader: Jianwei Lu, Huazhong Agricultural University, Resources and Environment College, Hongshan District, Wuhan, Hubei. Email: lujianwei@mail.hzau.edu.cn

Project Cooperator: Xiaokun Li

A 10-year study conducted with the support of IPNI China Program, Huazhong Agricultural University demonstrated the positive impact of nutrient management on the productivity of oilseed rape in China. The results of soil investigation showed that soil pH that decreased slightly from 6.6 to 6.4, while the soil organic matter (SOM) and available N, P, K, and B contents in the main winter oilseed rape-planting regions of China were increased over the last four decades. The amount of crop stubble that annually remains in soil increased with the increase in seed yield, and at present it could reach 4 t/ha for some top farmers. This is one of the main reasons for the increase in SOM. Boron fertilization has become a common practice and it directly increased soil available B concentration.

Although compared with 1960s and 1980s, the soil fertility of oilseed rape farms in the Yangtze River Valley in 2004-2006 improved, deficiencies of N, P, K, and B in soil can still be found. This is mainly due to unbalanced fertilization and the fact that the critical soil nutrient concentrations have been revised upwards in the last few decades. The results from field trials indicate that if we measure the soil nutrient concentration when 90% of relative yield was achieved, then we can suggest that 160 mg N/kg, 25 mg P/kg, 135 mg K/kg,
and 0.6 mg B/kg could be used as soil critical values. With the new values, the relative soil N, P, K, and B nutrient deficiency areas have reached 95, 89, 79, and 87% in Yangtze River valley, respectively.

Better nutrient management is one of the key factors for increasing not only seed yields, but also seed quality. This investigation shows that about 55% of the seed yield increase was contributed by balanced fertilization in recent years. The agronomy efficiency of N, P, K, and B in 2004-2006 reached their peak values. Therefore, China’s winter oilseed rape planting has benefited from soil fertility improvement and greatly increased the rational application rates of commercial fertilizers in the last four decades.

**IPNI-2010-CHN-HB39**

**Study on Nutrient Management Technology for Vegetables in Wuhan**

**Project Leader:** Gang Chen, Wuhan Academy of Agricultural Science, Agricultural Research Institute, Dongxihu District; Wuhan, Hubei. Email: gangch2006@yahoo.com.cn

**Project Cooperators:** Juan Hong, Xiang Huang, Mihong Ge and Lihong Zhang

Red flower stalk is one of the main vegetables in Wuhan region. However, unbalanced fertilization frequently limits its yield and quality. This project was started in 2011 to study the benefit of proper nutrient management practices for improving red flower stalk yields and quality. Treatments include five application rates each of N (0, 300, 600, 900, and 1,200 kg N/ha), P (0, 150, 300, 450, and 600 kg P₂O₅/ha) and K (0, 225, 450, 675, and 900 kg K₂O/ha).

Results showed that the number of green leaf flowing stalks had no significant relationship with application rates of N, P and K fertilizers at the beginning of growing season, but increased with the increase in N application rates in the middle and late growth periods. Similarly, the green leaf number increased with P and K application rates in middle and late periods. Nitrogen fertilization improved the yield of flowering stalk. Relationship between yield (Y) and N application rate (X) followed the quadratic equation: Y=-0.0154X²+14.380X+12181 (R²=0.929). When N fertilization rate reached 467 kg/ha, the yield of flowering stalk increased to 15,538 kg/ha. Nitrogen application increased the concentration of nitrate in the stalk. N, P and K fertilization also affected the content of vitamin C in the plant. **IPNI-2010-CHN-HB40**

**Improvement Method and Classification System for Evaluating Available Soil Potassium and Plant Potassium Status for Potassium Fertilization of Rice and Winter Wheat**

**Project Leader:** Huoyan Wang, Chinese Academy of Sciences, Nanjing Institute of Soil, Nanjing, Jiangsu. Email: hywang@issas.ac.cn

**Project Cooperator:** Xiaqin Chen

The scarcity of K fertilizer and underfertilization of K in China has resulted in a widespread exhaustion of K reserves in farmland soils in recent decades. The most common soil K fertility index used is soil available K, measured using the 1 mol/L ammonium acetate (NH₄OAc) extractant. However, the NH₄OAc method is only suitable for evaluating K availability in soils with similar K buffering capacity, but not in soils with variable K buffering capacity or where the non-exchangeable K contributes greatly to plant K uptake. Developing a better method to test real K availability to plants in various soils to create better and precise diagnostic indices, estimating plant K uptake potential and making stable and uniform fertilization recommendation are important for improving K use efficiency. The Nanjing Soil Research Institute of Chinese Academy of Science conducted a study on the diagnostic indicator system of K soil test measurements under field conditions in a rice-wheat rotation in Wuhu and 16 locations around the Taihu Lake regions. Soil samples were collected one week after fertilization. Rice and wheat plants were sampled at tillering and at different maturity stages. The NH₄OAc extraction method was compared with nine other laboratory methods and correlated with plant parameters.

Results indicated that two methods, one using 2 mol/L of NaBPh₄ (Sodium tetraphenylboron) and extracting for 30 minutes, and the other method using 0.5 mol/L of HNO₃ and extracting for 30 min, to determine available soil K could better evaluate the available soil K than traditional laboratory evaluations. Both methods showed a significant correlation between K uptake by rice and wheat plants and other indicators. Taking into account the operational efficiency and ease of methods, as well as the environmental and economic effects, 0.5 mol/L of HNO₃ was more suitable for the determination of plant-available K content in the soil. As a result of this determination, laboratories can now timely and accurately predict the abundance or shortage of soil K for rice and wheat, which plays an important role in improving grain yields and quality. This improvement will give guidance for recommendations that will include balanced fertilizer use to increase efficiency and soil fertility. **IPNI-2010-CHN-NJ12**
Study and Demonstration of Soil Nutrient Management and Balanced Fertilizer Technology for Cotton in Anhui

Project Leader: Zhou Kejin, Anhui Agricultural University, Resource and Environment College, Hefei, Anhui.
Email: zhoukejin@163.com

Project Cooperators: Ma Cheng-ze, Zhang Li-gan, He Fang, and Tang Xiao-qiang

Anhui Province is one of the major cotton production provinces in China with an annual planting area of 344,000 ha in 2010. However, cotton is planted in the region along the Yangtze River valley on mainly gray sandy soils that are (a) low in native soil fertility (organic matter 0.95%, 32 mg nitrate-N/kg, 16 mg available P/kg, 86 mg available K/kg, 35 mg available S/kg and 0.8 mg available B/kg) and (b) not fertilized in a balanced way. Therefore, this study on balanced fertilization in cotton is being conducted along the Yangtze river valley since 2011. Treatments include recommended fertilizer application of 225-150-225 kg N-P₂O₅-K₂O/ha and farmer’s common practice (i.e., average application rates of 270-150-150 kg N-P₂O₅-K₂O/ha).

Results showed that the recommended fertilization treatment led to highest seed cotton yield of 4,350 kg/ha with an income of US$2,085/ha. This represented an increase in yield by 356 kg/ha (8.9%) and net income by US$145/ha (7.5%) over the farmer’s practice. Demonstration plots in other nearby fields also showed similar results. Thus, with similar but more balanced fertilizer input, the recommended fertilization technology not only increased cotton yield and income, but also reduced the risk of fertilizer N loss to environment.

Studies and Demonstration on Environmentally Sound Fertilization Technology for Vegetables and Banana

Project Leader: Zhang Mingqin, Fujian Academy of Agricultural Sciences, Soil and Fertilizer Institute, Fuzhou, Fujian.
Email: Zhangmq2001@163.com

Project Cooperators: Li Juan, Kong Qingbo, and Chen Yanhua

Vegetables and banana are major crops in Fujian Province, and these crops need much more fertilizer than grain crops. Therefore, these two crops have a great impact on local fertilization efficiency, economics and the environment. To increase banana and vegetables yields and fertilization efficiency, the Soil and Fertilizer Institute of Fujian Academy of Agricultural Science carried out 11 field fertilization trials for banana and vegetables in nine counties, including a long-term site-specific field experiment with vegetable-rice rotation in 2013. Six treatments were used in the experiment, viz., OPT (optimum fertilization), OPT-N, OPT-P, OPT-K, FP (farmer practice) and CK (no fertilization). The N, P and K fertilizer application rates for different vegetable species and banana varied greatly.

Results showed that average nitrate-N concentration in the top soil layer of the vegetable fields was 47 mg/kg and the Olsen-P concentration was 62 mg/kg. The optimum N-P₂O₅-K₂O application rates were determined as 180-90-135 kg/ha for cucumber (yield 53.3 t/ha) and 315-180-180 kg/ha for courgette (yield 44.7 t/ha) with significant economic benefit over FP. Double Speed Turning Point model were used to estimate N and P leaching potential in the vegetable soils. According to the 121 leaf sample analysis, the recommend nutrient diagnosis indices of banana leaf for local diagnoses were 3.15 to 3.30% for N, 0.23 to 0.35% for P, 3.85 to 4.0% for K, 0.5 to 1.2% for Ca, 0.28 to 0.40% for Mg, 0.23 to 0.27% for S, and 10.0 to 21.0 mg/kg for B. The optimum rate of N-P₂O₅-K₂O fertilization was 675-90-1,050 for banana for a yield 59.7 t/ha. This optimum rate increased banana yield by 7 to 14% and net income by 6 to 14% over FP.

Study and Application of Nutrient Management Expert System in a Summer Maize-Winter Wheat Rotation

Project Leader: Lujiu Li, Soil and Fertilizer Institute, Anhui Academy of Agricultural Science.
E-mail: lilujiu@yahoo.com.cn.

Anhui Province is one of the most important maize-producing provinces in China with an annual planting area of 761 million ha in 2010. Some of the major issues regarding maize production in the region are low yield and poor nutrient management. In 2010, the average maize yield of Anhui was 4.1 t/ha, which was 24.7% lower than the average maize yield (5.4 t/ha) in the country. This project was started in 2013 to study and demonstrate the Nutrient Expert® (NE) in summer maize-winter wheat rotation in the province to improve farmer’s nutrient management practices as well as maize yields. Six treatments, viz., OPT (optimum fertilization based on NE), OPT-N, OPT-P, OPT-K, FP (farmer practice), CK (no fertilization) were used for the study. The OPT treatment had 210-90-120 kg N-P₂O₅-K₂O/ha.

Maize yields increased from 7.5 t/ha in the FP treatment to 8.35 t/ha in NE treatment (a 11% increase) along with an increase in net income by US$262/ha. At the same time, NE reduced the cost of N and P fertilizers by US$87/ha. Therefore, the NE system showed great potential for improving maize yields and farmer fertilization practices in this region. IPNI-2013-CHN-AH20
Effects of Nitrogen on Oxalate Accumulation Mechanisms in Different Spinach Genotypes

Project Leader: Xianyong Lin, Zhejiang University. E-mail: xylin@zju.edu.cn

From the agricultural and nutritional point of view, oxalate is regarded as a naturally occurring toxin and anti-nutritional factor. Intake of oxalate-rich vegetables may increase the risk of kidney stone production by inducing a significant increase in urinary oxalate excretion. It is commonly accepted that N nutrition is one of the most important factors affecting oxalate accumulation in vegetable production. In this research, two spinach genotypes differing in oxalate accumulation capacity are employed to study the genotypic difference in oxalate accumulation in spinach as affected by N application rates and N fertilizer source. We also focused on the relationships between N uptake, metabolism and oxalate metabolism in the two genotypes by using N uptake kinetics, precursors of oxalate biosynthesis, inhibitors of N uptake and reduction, and inhibitors of photosynthesis. The aim of this study is to elucidate the mechanisms of N affecting oxalate metabolism, which could provide the scientific basis for producing nutritional, low oxalate-accumulating spinach by using the combined measures of genetic breeding and nutrient management.

At a N supply concentration of 18 mmol/L, total oxalate and soluble oxalate contents in leaves of 31 spinach cultivars ranged from 9.86 to 21.41 mg/g FW and 9.62 to 13.45 mg/g FW, respectively. Oxalate content in spinach increased with increasing N levels. For instance, when N supply levels increased from 2 to 8 mmol/L, the total oxalate in leaves increased by 8 to 23%. When nitrate supply increased from 2 to 8 mmol/L, total oxalate contents in leaves of spinach increased by 56 to 60%. When the plants were treated with a mixed solution of nitrate/ammonium in 1:1 ratio, total and soluble oxalate content again increased. The oxalate content was positively correlated with nitrate uptake rate, but not ammonium uptake rate.

Addition of plasma membrane H+-ATPase-inhibitor sodium vanadate (NaVO_3) to the solutions of oxalate at concentrations ranging from 0.01 to 1.0 mmol/L, total and soluble oxalate contents in leaves of 31 spinach cultivars increased by 56 to 60%. When the plants were treated with 8 mmol/L, the total oxalate in leaves increased by 8 to 23%. When nitrate supply increased from 2 to 8 mmol/L, total oxalate and soluble oxalate contents in leaves of 31 spinach cultivars ranged from 9.86 to 21.41 mg/g FW and 9.62 to 13.45 mg/g FW, respectively. Oxalate content in spinach increased with increasing N levels. For instance, when N supply levels increased from 2 to 8 mmol/L, the total oxalate in leaves increased by 8 to 23%. When nitrate supply increased from 2 to 8 mmol/L, total oxalate contents in leaves of spinach increased by 56 to 60%. When the plants were treated with a mixed solution of nitrate/ammonium in 1:1 ratio, total and soluble oxalate content again increased. The oxalate content was positively correlated with nitrate uptake rate, but not ammonium uptake rate.

Addition of plasma membrane H+-ATPase-inhibitor sodium vanadate (NaVO_3) significantly decreased (17 to 29%) oxalate accumulation in spinach leaves. Treatments of NaVO_3 also resulted in a substantial inhibition of nitrate uptake, nitrate reductase and glutamine synthetase activity. Results confirmed that oxalate accumulation in different spinach genotypes is positively related with not only root uptake of nitrate, but also its reduction and assimilation within the plants, probably through glycolate metabolic pathway, rather than ascorbic acid metabolic pathway. *IPNI-2013-CHN-ZJ26*

Highly Efficient Nutrient Management Strategy for Modern Rice Planting in China

Project Leader: Li Zhuzhang, Jiangxi Academy of Agricultural Sciences, Soil and Fertilizer Institute, Nanchang, Jiangxi. Email: lgrtfs@sina.com

Project Cooperators: Fusheng Yuan, Zuzhang Li, Qixiang Luo, Gang Sun, Changxu Xu, Duogen Xiong, and Wenxue Zhang

As a major source of nutritional calories, over 60% population of China eats rice. With the reduction in planting area and the increase in population, food security and safety has become a prominent issue in the country. In rice production, the issues of maintaining the delicate balance between yield and quality, yield and efficiency, yield and ecological environment are becoming important. Therefore, this study is being conducted on the technology of efficient nutrient management for improving fertilizer use efficiency in China. This project includes the main rice production provinces (Jiangxi, Hubei, Hunan, Guangxi, Fujian, Yunnan, Heilongjiang, Zhejiang) in the country. All the provinces involved in the project collect data from rice field experiments following a uniform experimental design.

Both nutrient use efficiency and agronomic efficiency of commercial fertilizer application have decreased with an increase in fertilization rates in the last decade. In Jiangxi, the contribution of fertilization and fertilizer N, P and K to rice yield increases were 41, 32, 10, and 11%, respectively. Researchers recommend that 40% of N and K fertilizers should be basally applied in early rice, and 50% of N and K fertilizers should be basally applied in late rice. In Fujian, the contributions of fertilizer N, P and K to rice yield increases were 40, 15 and 39%, respectively. The recommended N fertilization rate for early and late rice was 162 kg N/ha with a ratio of N:P:K as 1:0.4:0.8. The recommended N fertilization rate for early and late rice was 162 kg N/ha with a ratio of N:P:K as 1:0.4:0.65; while for middle rice, it was 206 kg N/ha with a ratio of 1:0.4:0.8. The most appropriate N fertilization timing during the rice-growing season at the base:tillering:panicle:granular stages was 30:20:30:20 for early rice and 40:20:20:20 for late rice. The basal:topdressing proportion of K fertilizer was 50:50. In Hubei, rice production is mainly middle rice with an average yield of 7.9 t/ha and average fertilization rate of 185 kg N/ha with a ratio of N:P:K as 1:0.35:0.30. The recommended fertilization rates for rice in Hubei were 165 to 210 kg N/ha, 60 to 90 kg P_2O_5/ha and 75 to 120 kg K_2O/ha. The optimum N fertilization ratio during the rice growing season was determined at base:tillering:panicle stages was 40:30:30, and the basal:topdressing proportion of K fertilizer was 50:50. Results from other provinces showed a similar pattern. *IPNI-2012-CHN-JX30*
**Effects of N and K Rates on Yield of Summer Chinese Cabbage**

Project Leader: Zhengyin Wang, Southwest University, Beibei District, Chongqing, Chongqing.
Email: wang_zhengyin@163.com

Chinese cabbage is one of the most widely grown leafy vegetables in China, a crop which can be grown year round. Nutrient management studies conducted in the past on Chinese cabbage were mostly targeted toward winter varieties. This project was started to determine the optimal K rates for some summer varieties of Chinese cabbage in Chongqing. The experiment consisted of six treatments including two N rates (300 and 375 kg N/ha), one P rate (90 kg/ha) and four K rates (0, 75, 150 and 225 kg K$_2$O/ha) replicated three times. Fertilizer sources used for N, P and K were urea (46% N), diammonium phosphate or DAP (11% N and 44% P$_2$O$_5$) and potassium chloride or KCl (60% K$_2$O). Nitrogen and K fertilizers were split applied at three times, viz., basal application at seeding and two top dressings at seedling and russet stages in a 30:30:40 ratio. Fertilizer P was applied only once basally.

Results showed that for each N rate, cabbage yield increased significantly with an increase in K rates without leveling-off. At 225 kg K$_2$O/ha, cabbage yields reached 41 t/ha at 300 kg N/ha and the highest yield of 42 t/ha was obtained at 375 kg N/ha. These yields were 4.7 t (13%) and 5.9 t (16%) higher than the yields obtained with K omission treatment. In terms of cabbage quality, the treatment with low N and low K obtained high contents of vitamin C, amino acids and soluble sugars, indicating that high quality does not always follow high vegetable yields. The treatment with high N rate and medium K rate achieved the highest N agronomic efficiency and N recovery. Minimum N content in leaves was observed six days after top dressing N. This indicated that a week after topdressing N might be the best time to apply the next dose of fertilizer N, especially during the fast growing period of summer Chinese cabbage in the region.

**Nutrient Management for New Banana Varieties in Guangdong**

Project Leader: Lixian Yao, Guangdong Academy of Agricultural Sciences, Soil and Fertilizer Institute, Guangzhou, Guangdong. Email: lyaolx@yahoo.com.cn

Project Cooperators: Guoliang Li and Baomei Yang

This project was initiated in 2012 to test the effects of different N and K rates and their combinations on growth, photosynthesis, budding time, yield and quality of a banana cultivar - Pisang awak (Musa ABB Pisang Awak) - in Guangdong. Eight treatment combinations with four N rates (0, 731, 975 and 1,219 kg/ha), four K rates (0, 1,097, 1,463 and 1,828 kg K$_2$O/ha) and one P rate (375 kg P$_2$O$_5$/ha) were used and replicated three times. All treatments included (per ha) 15 kg of borax and 1.5 kg of ammonium molybdate. Fertilizer sources used for N, P and K were urea (46% N), diammonium phosphate or DAP (11% N and 44% P$_2$O$_5$) and potassium chloride or KCl (60% K$_2$O). Fertilizers were split applied at seven times, viz., twice at seedling stage, twice from flower initiation to budding stage and three times from budding stage to maturity. The proportions of nutrients applied at the seedling stage before and after budding stage were 20:45:35 for N, 50:30:20 for P and 18:50:32 for K to meet nutrient demand at different crop growth stages. These nutrients were banded before budding stage and used in hoe-dug hills with irrigation after the budding stage. Borax and ammonium molybdate were applied after thoroughly mixing with urea.

Results showed that the growth of banana was significantly affected by different fertilizer treatments. The treatment with optimal rates of N and K had the highest plant height, stem girth, rate of photosynthesis and budding rates, and produced highest banana yield (52 t/ha) and profit (US$32,747/ha). These values were 4.4 t/ha (9.3%) and US$3,160 (7%) more than the omission N treatment and 7.28 t/ha (16%) and US$5,057 (18%) more than the yield and profit obtained with omission K treatment. Furthermore, this treatment also yielded higher contents of vitamin C, soluble sugar and edible portions in fruit. Preliminary results indicate that to produce 50 t/ha of banana fruit yield, the optimal fertilizer rates are 770-850 kg N, and 375 kg P$_2$O$_5$ and 1,000 to 1,120 kg K$_2$O/ha with a N/K$_2$O ratio of 1:1.30. IPNI-2010-CHN-GD14
Nutrient Management on Dragon Fruit

Project Leader: Hongwei Tan, Guangxi Academy of Agricultural Sciences, Soil and Fertilizer Institute, Nanning, Guangxi. Email: hwtan@public.nn.gx.cn
Project Cooperators: Zhou Liuqiang and Xie Rulin

This project was initiated in 2011 to refine the fertilizer recommendations for red dragon fruit production in Guangxi Province. The initial experiment consisted of eight treatments replicated three times. Treatments included an optimal treatment (OPT) with fertilizer application rates of 411-188-675-150-1.3 kg N-P₂O₅-K₂O-MgO-B/ha, OPT-N, OPT-P, OPT-K, OPT-1/2K, OPT+1/2K, OPT-Mg, and OPT-B. In 2013, P rate was slightly increased and the range of K rates between low and high was narrowed based on previous year results. However, fertilizer sources, application timing and methods remained the same.

Red dragon fruit yields were much higher in 2013 than in 2012 due to more favorable weather conditions. But similar to 2012, the OPT treatment significantly increased red dragon fruit yield compared to the yields obtained in omission treatments. For example, omitting N, P, K, Mg, and B led to yield reductions of 11.1 t/ha (-50%), 6.2 t/ha (-28%), 6.4 t/ha (-29%), 1.8 t/ha (-8%), and 0.95 t/ha (-3%), respectively, compared to the OPT treatment. Except for Mg, continued omission of the other four nutrients further expanded the yield gap between OPT and omission treatments from 2012 to 2013. Unlike in 2012, cutting K fertilizer by half in the OPT treatment decreased the fruit yield by 2 t/ha (-9%), while increasing K fertilizer by half increased the fruit yield by 0.6 t/ha (2.5%) compared with OPT. This supports the high K demand of red dragon fruit - a fact also reflected in the fruit K content measured during the past two years. The K content was more than double the N content in fruits. We propose the optimal fertilizer rates for red dragon fruit production in the region as 420-230-650-140-1.3 kg N-P₂O₅-K₂O-MgO-B/ha, respectively. IPNI-2010-CHN-GX13

Nutrient Management for Sorghum

Project Leader: Wei Li, Chongqing Agricultural Techniques Extension Center. Ag-Tech Building 186, No 186 E Huangshan Ave., North New District, Chongqing, China. Email: dongjiangliwei@163.com

Sorghum is a key ingredient in Chinese liquor production. In recent years, as the demand for liquor has increased, the area planted to sorghum has also increased. The aim of this experiment was to determine the best nutrient management guides for sorghum in Chongqing. The experiment consisted of ten treatments, including four application rates of N (0, 110, 220, 330 kg N/ha), four rates of P (0, 60, 120, 180 kg P₂O₅/ha) and four rates of K (0, 65, 130, 195 kg K₂O/ha). Nitrogen was used as urea (N 46%), P as single superphosphate (SSP - 12% P₂O₅) and K as (KCl - 60% K₂O). All P, 40% of N and 50% of K were applied as basal fertilizers at seeding, and the rest of the N and K fertilizers were topdressed at elongation stage.

Sorghum yields were significantly boosted with an increase in the application rates of N, P and K, reaching the highest yields of 7,817 kg/ha at the set-optimal rates of 220-120-130 kg N-P₂O₅-K₂O/ha. This implies that the set-optimal rates can be used in the region before any adjustment is made through future field experiments. Yield increases with nutrient application followed the order: N (18%) > P (12%) > K (9%). The agronomic efficiency of N fertilizer was highest at the set-optimal rate, while those for P and K decreased with an increase in fertilizer rates. The net income was also the highest (US$3,418/ha) for the set-optimal fertilizer rates, which was 26, 24 and 10% higher than the treatments omitting N, P and K, respectively. The ratios of nutrient partitioning in grain to straw decreased with an increase in N and P rates, but remained relatively constant for K rates. This indicated strong K-absorption ability of sorghum even at high grain yields. IPNI-2013-CHN-CG8

Response of Sugarcane to Controlled-release Urea

Project Leader: Hongwei Tan, Guangxi Academy of Agricultural Sciences. Daxue Road 174, Nanning, China.
Email: hongwei_tan@163.com

Sugarcane is considered to be an ideal crop to use controlled-release urea (CRU) because of its long growing season, high biomass production, and dense population that makes it difficult to fertilize, especially at mid to late growth stages. A field experiment tested different fertilization rates and timings of CRU application on sugarcane yields in Guangxi, the number one sugarcane-producing province in China. The experiment consisted of nine treatments including one check (CK, omitting N), two urea treatments (100% N rate (670 kg N/ha) applied in two splits and another in three splits), three CRU treatments (70, 80 and 100% N rates all applied in two splits), two treatments with different CRU and urea blends (CRU 60% + urea 40% and CRU 80%+urea 20%) applied in two splits, and one 80% N rate with CRU 60%+RU 40% blends. Except the CK and one urea treatment, N fertilizers in the other eight treatments were applied as basal at seeding and side-dressings at seedling stage in proportions of 40:60. In one of the 100% urea treatments, N was used at seeding, seedling and elongation stages in proportions of 30:30:40. Phosphate was applied as SSP (18% P₂O₅) at 175 kg P₂O₅/ha and K as KCl (60% K₂O) at 880 kg K₂O/ha.
Validation Studies for Fertilizer Recommendations Made by Nutrient Expert in Yunnan

Project Leader: Lifang Hong, Yunnan Academy of Agricultural Sciences, Soil and Fertilizer Institute, North Suburb, Kunming. Email: gredbean@163.com

Project Cooperator: Yin Mei

Three field experiments were carried out to validate Nutrient Expert (NE)-based fertilizer recommendations for maize in Yunnan Province. The experiments were conducted at three locations with different soil fertility levels ranging from low to high. The experiments consisted of seven treatments, viz., optimal treatment (OPT) generated by NE, omitting N (OPT-N), omitting P (OPT-P), omitting K (OPT-K), check (no fertilizer), farmers' practice (FP) and soil test-based recommendation (OPTS). The N-P2O5-K2O fertilization rates in OPT at the three locations were 175-83-118 kg/ha for the high, 180-64-96 kg/ha for the medium, 225-94-140 kg/ha for the low fertility soils. The N rates in the FP and the OPTS were more than doubled compared to the OPT. Nitrogen was supplied using urea, P as single superphosphate (SSP) and K as KCl. Phosphate was applied as basal application at seeding. N was split into one basal application at seeding and two side-dressings at 45 days after seeding (DAS) and 60 DAS in proportions of 21:31:48, respectively, and K was split into one basal application plus one side-dressing 45 DAS in proportions of 30:70, respectively.

Results showed that different fertilizer treatments significantly affected maize growth and kernel yields at all three locations. In the low fertility soil, the OPT treatment produced the highest maize yield followed by the FP and the OPTS. In the medium fertility soil, however, the OPTS produced the highest maize yield followed by the FP and the OPT. There were not much yield differences in the high fertility soil. At all the three experimental locations, the CK treatment produced the lowest maize yield followed by OPT-N, OPT-P and OPT-K. The first year study indicated that NE recommendations can produce similar maize yields with much lower N rates, showing its promising future use in the region, especially in the low to medium fertility soils. The nutrient limiting factors in the region for maize production followed the order N > P > K.

Nutrient Management Research for Paddy Rice in Guizhou

Project Leader: Qing Zhu, Guizhou Academy of Agricultural Sciences, Soil and Fertilizer Institute, Guiyang, Guizhou. Email: zhuqing_gy@tom.com

Project Cooperator: Chen Zhenggang

Most of the nutrient management studies on paddy rice in Guizhou Province in the past were focused on medium to high fertility soils and largely ignoring the rice grown in the low to medium fertility soils. In order to improve paddy rice yield and nutrient management practices, three field experiments were carried out to test the effects of different N, P and K rates on rice yield and the soil nutrient status in the growing season. The objective was to determine the optimal fertilizer rates for paddy rice in three types of poor-fertility soils. The experiments consisted of 12 treatments including five rates of N (0, 90, 120, 150, and 180 kg N/ha), four rates of P (0, 45, 90, and 135 kg P2O5/ha) and four rates of K (0, 90, 135, and 180 kg K2O/ha). Nitrogen was used as urea (46% N), P as single superphosphate (SSP) and K as KCl. Phosphate was applied as basal application at seedling transplanting and at tillering stage with proportions of 40:60, while P fertilizer was applied only once at seedling transplanting.

The available N and P in the soil increased significantly with a rise in N and P application rates from tillering to jointing stages, but the treatment differences narrowed down gradually towards maturity. The available K in soil, however, was not remarkably affected by K fertilizer application rates. Rice yields increased significantly by 23.5% to 38% in the highly reduced paddy field, 16.7 to 36.9% in the paddy field with low soil temperatures, and 16.7% to 36.9% in the yellow earth paddy field under different treatment combinations. Preliminary results suggest that the optimal fertilizer recommendation for paddy rice is 90-45-135 kg of N-P2O5-K2O/ha in the highly reduced paddy field, 150-90-90 kg N-P2O5-K2O/ha for the paddy field with low soil temperatures, and 180-90-180 kg N-P2O5-K2O/ha for the yellow earth paddy field. These recommendations can be used in regions with similar soil types and other natural conditions and will be fine-tuned with future field validation experiments.
**Nutrient Management Research for Eggplant in Hainan**

Project Leader: Liangshang Xie, Hainan AAS, Soil and Fertilizer Institute, Haikou, Hainan. Email: lshxie@163.com
Project Cooperator: Zhang Wen

Due to high economic returns in vegetable production, over-application of fertilizers is a common practice in vegetable-growing regions of China. The objective of this study was to determine the optimal fertilizer rates for eggplant, one of the most widely grown winter vegetables in Hainan Province. The experiment consisted of treatments including six N application rates (0, 150, 225, 300, 375, and 450 kg N/ha) and six K rates (0, 75, 150, 225, 300, and 375 kg K₂O/ha) with a fixed P rate (150 kg P₂O₅/ha). Nitrogen was used as urea (46% N), P as SSP (12% P₂O₅) and K as KCl (60% K₂O). Nitrogen and K fertilizers were split-applied four times, viz., basal application (30%) at seedling, transplanting and topdressings (70%) at seedling stage and after every other fruit harvest of eggplant as drip fertigation. Phosphate was applied only once as a basal application.

Eggplant yields significantly increased with an increase in N and K application rates, but leveled off at 300 kg N/ha and 225 K₂O/ha. This N and K combined treatment produced 17,218 kg/ha (119%) more eggplant yield and US$11,067 more return than the N omission treatment. It also resulted in 6,725 kg/ha (26%) more eggplant yield and $4,201 more economic return than the K omission treatment. The agronomic efficiency was 57.4 kg fruit/kg N applied and 30 kg fruit/kg K applied. Nevertheless, fertilizer recovery rates were rather low for both N and K, measured at 19 and 31%, respectively. Preliminary results suggest that the optimal N and K rates for eggplant production in this region are around 300-150-225 kg N-P₂O₅-K₂O/ha. More studies will be conducted to validate this optimum fertilizer rate before it is extended to large areas. *IPNI-2013-CHN-HA12*

**Maize Yield and Nutrient Losses as Affected by Different Fertilizer Rates**

Project Leader: Chaowen Lin, Soil and Fertilizer Institute, Sichuan Academy of Agricultural Sciences. Shizishan Road 4, Jinjiang District, Chengdu, China. Email: lcw-11@163.com

This project continued to evaluate the effects of different application rates of N, P and K fertilizers on maize yield and nutrient losses from Sichuan’s sloping farmlands during the summer rainy season. The fertilizer application rates were the same as in 2012, i.e., five rates of N (0, 225, 300, 375, and 450 kg N/ha), three rates of P (0, 150 and 300 kg P₂O₅/ha) and three rates of K (0, 75 and 150 kg K₂O/ha). Nitrogen was applied as urea (N 46%), P as MAP (N 11% and P₂O₅ 44%), and K as KCl (K₂O 60%). Nitrogen was split applied four times (basal application at seeding, topdressing at seeding, elongation and tasseling stages in 10:20:20:50 ratio). The P and K fertilizers were applied once at seeding.

Results showed that the optimal fertilizer rates in 2013 were 225-150-75 kg N-P₂O₅-K₂O/ha, which produced maximum maize grain yields of 6.9 t/ha along with the highest N use efficiency (NUE) of 47%. The NUE decreased at N rates above 225 kg/ha. All the NPK treatments significantly reduced soil erosion and water losses compared to the treatments omitting either N, P or K. Nutrient losses from the soil were affected by N application rates, described as a quadratic relationship. Minimal nutrient losses from the soil due to N fertilization were observed when 225 kg N/ha, 300 kg P₂O₅/ha and 375 kg K₂O/ha were applied. The optimal K rate helped reduce losses of N by 55%, P by 23% and K by 24% compared to the K omission plot. Nutrient losses in runoff increased again as K rates surpassed the optimal level. Except for the P omission treatment that significantly increased N loss, different P application rates did not significantly affect losses of soil, water and P and K.

The results further confirmed that good nutrient management will not only increase maize yields, but can also decrease soil erosion and nutrient losses from the soil and protect the environment. *IPNI-2013-CHN-SC20*

**Nutrient Management for Cucumber**

Project Leader: Yusheng Qin, Sichuan Academy of Agricultural Sciences, Soil and Fertilizer Institute, Chengdu, China. Email: shengyuq@126.com
Project Cooperator: Hua Yu

A field experiment was carried out to test the response of cucumber to macro- and secondary-nutrients in well-managed vegetable fields in Penzhou City, Sichuan Province. The experiment consisted of seven treatments, including the optimal treatment (OPT, 270-120-360 kg N-P₂O₅-K₂O/ha), OPT-N, OPT-P, OPT-K, OPT+1/2K, OPT–1/2K, and OPT+CaMg (750 kg Ca(OH)₂/300 kg MgSO₄/ha). Nitrogen was used as urea (46% N), P as SSP (12% P₂O₅) and K as KCl (60% K₂O). All P, lime and MgSO₄, 50% of N and 50% of K were applied as basal fertilizers at seedling transplanting. The remaining N and K fertilizers were topdressed at flowering and fruit harvest stages.

The OPT treatment produced 1.58 (2%), 0.66 (1%) and 10.28 (14%) t/ha more cucumber yields than the treatments omitting N, P or K, respectively. Thus, even in this well-managed vegetable base, K is still the number one nutrient limiting factor. Compared to the OPT, the OPT-1/2K treatment reduced cucumber yield by 8.2% and OPT+1/2 K treatment increased cucumber yield by 2.1%. Since the yield increases due to addition of N and P were quite small, N and P rates should be readjusted to lower levels in future studies. The OPT+CaMg treatment significantly increased cucumber yield by an additional 6.4 t/ha (8.9%) and also improved cucumber quality (enhanced vitamin C, amino acids, and lower nitrate contents in the fruit) indicating the importance of these two secondary nutrients in cucumber production in this vegetable area. *IPNI-2013-CHN-SC21*
Site Specific Nutrient Management for a Rice-Wheat System in Haryana

Project Leader: B.R. Kamboj, Central Soil Salinity Research Institute, CSISA Hub, Karnal, Haryana.
Email: m.jat@cgiar.org
Project Cooperator: Anil Bana

On-farm trials were conducted in seven districts of Haryana, India, to evaluate three different approaches to site-specific nutrient management (SSNM)-based recommendations from the Nutrient Expert® (NE) decision support system in no-till (NT) and conventional tillage (CT) wheat production systems. The evaluation parameters focused on yield, nutrient use efficiency and global warming potential (GWP). Performance of NE-based recommendations was evaluated against current state recommendation (SR) and farmers’ fertilization practices (FFP) for nutrient management. Three treatments used were: (a) ‘NE 80:20’ with 80% N applied at planting and 20% applied at the time of the second irrigation, (b) ‘NE 33:33:33’ with N application split equally and applied as basal, at the crown root initiation (CRI) stage and with second irrigation; and (c) ‘NE 80:GS’ with N split as 80% basal and further application of N based on optical sensor (Green Seeker™)-guided recommendations. Grain yield, nutrient use efficiency and economic profitability were determined following standard agronomic and economic measurements and calculations. Cool Farm Tool (CFT), an empirical model to estimate greenhouse gases (GHGs) from agriculture production, was used to estimate GHG emissions under different treatments.

The three NE-based nutrient management strategies increased yield, nutrient use efficiency, and the net economic return compared to the SR and FFP treatments. On average, NE-based nutrient management strategies increased grain yield and biomass yield by 5 and 3%, respectively, over SR and by 14 and 9 %, respectively over FFP. Greater efficiency of applied nutrients was obtained using NE than using FFP. This indicated that location-specific nutrient application rate and better timing of nutrient application (i.e., greater number of splits and matching application of nutrients with their physiological demand by a crop) reduced N losses and enhanced the efficiency of nutrient utilization. Global warming potential of wheat production was found to be lower with the NT system as compared to the CT system and lower with NE-based nutrient management as compared to FFP. State recommended nutrient management had similar GWP as NE-based nutrient management except in the NE80:GS treatment, where GWP was the lowest. Estimated N₂O emission per ton of wheat production was 620 g under CT, which was significantly higher than that under NT (595 g N₂O/t). In the case of nutrient management strategies (averaged over tillage methods), estimated N₂O emission was the highest (3.3 kg/ha) under FFP and lowest under NE:GS system (2.8 kg/ha). Results suggested that using no-tillage production systems along with site-specific approaches for nutrient management can increase yield, nutrient use efficiency and profitability while decreasing GHG emissions from wheat production in Northwest India. IPNI-2009-IND-508

GIS-based Spatial Variability Mapping of Agricultural Holdings for Precision Nutrient Management in the Red and Lateritic Soil Zone

Project Leader: G.N. Chattopadhyay, Visva Bharati University, Soil Testing Laboratory, Sriniketan, West Bengal.
Email: gunin_c@yahoo.com
Project Cooperator: T. Ravishankar

This project studied the correlations between soil parameters, yield, and actual crop response to applied nutrients in the red and lateritic soil zone of West Bengal. Due to the large spatial variability among farmlands, plot-to-plot fertility assessment constitutes the basic requisite for precision nutrient management. However, large-scale adoption of this practice is a challenge in smallholder systems in India due to inadequate
soil testing facilities. GIS-based soil fertility mapping provides an opportunity to estimate the spatial variations in fertility status between farmlands, thus aiding in precision nutrient management. This study assessed the efficiency of using GIS-based spatial variability maps as a fertilizer decision support tool in the red and lateritic soil zone of West Bengal, India. Forty-five soil samples were collected from about 76 ha area of Meherpur village in Birbhum district, West Bengal and were analyzed for relevant soil properties. Yield data of monsoon rice from these plots were also collected. These data were used for developing GIS maps for the study area that indicated the presence of eight management zones. On-farm trials, covering all these management zones, were carried out using following treatments: T1: Farmers’ practice, T2: Fertilizer management based on a targeted yield approach, T3: Fertilizer management based on GIS management zones, T4: Soil test-based NPK, T5: T4 without K, T6: T4 without P, and T7: T4 without N.

Rice grain yield was highest (4.2 t/ha) under targeted yield approach-based treatment, which was on a par with the management zone-based approach and soil test-based NPK fertilization. Grain yield was most affected by the omission of N followed by P and K in omission plot trials. A similar study with wheat as a test crop was carried out with the inclusion of an additional treatment where the fertilizer rate was derived from Nutrient Expert® (NE). The targeted yield approach and the recommendations of NE resulted in similar grain yields of wheat. These were closely followed by soil test-based NPK treatment and management zone-based approach. Similar to rice, omission of N from the fertilization schedule resulted in maximum decline in wheat crop yield. However, the wheat yield response to added nutrients was higher for K than P. The results from this study have shown that the management zone-based approach, developed from GIS mapping, performed equally well as the actual soil test-based fertilizer application. This suggests that the GIS-based fertility maps could effectively be utilized as fertilizer decision support tools in smallholder systems and provide an opportunity to evaluate the soil fertility status of an area with limited soil sampling and analysis. IPNI-2010-IND-501

Fertility Mapping and Balanced Fertilization for Sustaining Higher Productivity of the Pearl Millet-Wheat Cropping System in Agra District

Project Leader: Vinay Singh, Raja Balwant Singh College, Agra University, Department of Agricultural Chemistry & Soil Science, Agra, Uttar Pradesh. Email: apsr_1999@yahoo.co.in

This project was initiated to assess the spatial variability in soil fertility in an intensively cultivated village of Uttar Pradesh. More than 100 soil samples were collected from Panwari village of Agra district to assess the spatial distribution of N, P, K, S, and Zn. Soil analysis revealed that available N content of the study area varied from 100 to 308 kg/ha, available P from 8 to 62 kg/ha, available K from 70 to 235 kg/ha, available S from 10 to 45 kg/ha and available Zn from 0.4 to 1 mg/kg. Most of the soil samples (97%) from Panwari village were low in available N status. About 48 to 51 % samples were categorized as medium and high, respectively, in available P. Available K status was low and medium in 35 and 65% samples, respectively. Available S status was low to medium in all the samples. About 36% samples were deficient in available Zn.

In the second phase of the study, omission plots with four treatments, viz., ample NPKS, -N, -P, and -S were set up in Panwari, Garhi Bhuria, Gamri, Nagar, and Atoos villages of Agra district to assess the impact of nutrient omission on wheat yields. The fertilizer rates used in the ample NPKS were 180 kg N, 90 kg P₂O₅, 100 kg K₂O, and 40 kg S/ha. Two other treatments were also included in the study to compare the yields between the state recommended (SR) fertilizer rates (120 kg N, 60 kg P₂O₅, 40 kg K₂O/ha) and Nutrient Expert® (NE)-based fertilizer recommendation rates. Nitrogen, P, K, and S omissions reduced average wheat yields by 42, 10, 25, and 8%, respectively, as compared to the ample NPKS treatment across all sites. The corresponding reduction in yield of pearl millet due to omissions of N, P, K, and S were 31, 18, 6, and 3%, respectively. Field experiments also compared the ample NPKS treatment with the NE-based fertilizer recommendation and the ad-hoc recommendation for wheat. Results revealed that ample NPKS produced the highest average grain yield (7.04 t/ha), followed closely by the NE-based fertilizer recommendation (6.98 t/ha). Net returns from the ample NPKS treatment (INR 75,850/ha) were statistically similar to the net returns from NE-based recommendation (INR 74,776/ha). Ad-hoc fertilizer recommendation for wheat in the region produced lower average yield (5.98 t/ha) and average net return (INR 63,172/ha) as compared to ample NPKS and NE treatments. IPNI-2010-IND-506

Development and Validation of Nutrient Expert for Maize in Bangladesh

Project Leader: Mahesh Gathala, International Maize and Wheat Improvement Center (CIMMYT), Bangladesh House 10/B, Road 53, Gulshan-2, Dhaka, 1213, Bangladesh. Email: M.Gathala@cimmyt.org

Nutrient Expert® (NE), a fertilizer decision support tool for hybrid maize in Bangladesh, was developed for easy implementation of site-specific nutrient management (SSNM) strategies in farmer fields. The tool was evaluated in Rabi (winter) season in various districts of Bangladesh against existing farmer nutrient management practices to assess the robustness of the tool in different maize growing regions. On-farm NE validation trials in maize were conducted at 181 locations across Bhola, Barisal, Patuakhali, Satkhira, Khulna,
Site Specific Nutrient Management for a Rice-Wheat System in Punjab

Chuadanga, Rajbari, Rangpur, Dinajpur, Nilphamari, Kurigram, Mymensingh, Comilla, and Rajshahi districts of Bangladesh. Data across the fourteen districts showed that farmers on an average applied 161:66:68 kg/ha of N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O, respectively in maize (ranging between 53 to 360, 0 to 258 and 0 to 149 kg/ha of N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O, respectively). On the other hand, the average recommended rate from Nutrient Expert® was 168 kg N, 40 kg P<sub>2</sub>O<sub>5</sub>, and 120 kg K<sub>2</sub>O (ranging between 82 to 322 kg N, 0 to 127 kg P<sub>2</sub>O<sub>5</sub>, and 0 to 210 kg K<sub>2</sub>O/ha at different locations).

Average yield achieved by farmers was 7.9 t/ha (range 3.3 to 12.5 t/ha), while the NE treatment yielded 4.2 to 14.2 t/ha, with an average yield of 8.6 t/ha. This work clearly shows that the NE tool was able to capture the difference in growing environments across sites and increased the average yield by 0.7 t/ha, compared to the farmers’ current practice. The average N application rates by farmers did not differ significantly from the NE recommended rate. However, the P fertilizer application rate was significantly higher in farmers’ practice, while the K rates recommended by the NE tool were significantly higher than farmers’ current practice. The NE validation trials also included four treatments to assess the effect of nutrient omissions across sites. The treatments comprised of an ample NPK treatment and three treatments where each of the three nutrients were subsequently omitted. Ample application of NPK produced an average yield of 9 t/ha across 181 locations. Omissions of N, P and K from the ample NPK treatment reduced grain yields by 45, 12 and 13%, respectively (ranging between 2.4 to 11.4, 3.4 to 13.2, and 1.6 to 13 t/ha, respectively). Certain locations showed more pronounced K response than N response and highlighted the necessity of adequate and balanced K application to improve yields in such locations. *IPNI-2013-BGD-7*

Indigenous Nutrient Supplying Capacity of Vertisols under Cotton and Soybean

Project Leader: V. K. Kharche, Panjabrao Deshmukh Krishi Vidyapeeth, Department of Soil Science and Agricultural Chemistry, Maharashtra, India. Email: vilaskharche@rediffmail.com


Cotton and soybean are major crops in the region of Maharasthra with vertisol soils. The current project was initiated to characterize and assess the fertility status of soils in intensive cotton and soybean growing areas of Maharasthra, to study the yield response of cotton and soybean to the addition of nutrients, and to assess the spatial and temporal variability of these nutrient responses. Fifteen on-farm trials were initiated with cotton and soybean during 2013 and 2014. The initial soil analysis of the 15 soybean sites showed that the pH varied from 7.1 to 8.1. The EC was low (0.15 to 0.33 dS/m), organic carbon (OC) was low to moderate (0.56 to 0.72%) and the CaCO<sub>3</sub> content ranged from 5.3 to 15.2%. The NPK fertilizer application rates applied at the soybean sites ranged from 125 to 224, 16 to 21, and 324 to 392 kg/ha, respectively. In cotton, the soil pH varied from 8.0 to 8.6 across different sites. The EC was low (0.11 to 0.43 dS/m), OC was low to moderate (0.32 to 0.79%), and the CaCO<sub>3</sub> content ranged from 6.7 to 16.2%.

The average grain yield of soybean recorded at 15 sites was 1.8 t/ha in the -P treatment, 2.1 t/ha in the -N treatment, 2.2 t/ha in the -K treatment, and 2.4 t/ha in adequate NPK treatments. Yield parameters were recorded at each site and plant samples were collected for nutrient uptake analysis. Post harvest soil samples have been collected at all the 15 sites for soybean. Cotton yield is assessment is in progress. The data will be used to develop a site-specific nutrient recommendation tool for cotton and soybean similar to Nutrient Expert® developed for major cereals. *IPNI-2013-IND-526*

Site Specific Nutrient Management for a Rice-Wheat System in Punjab

Project Leader: H.S. Sidhu, Punjab Agricultural University, CSISA Hub, Ludhiana, Punjab. Email: h.sidhu@cgiar.org

Project Cooperator: Naveen Gupta

This study was initiated to validate Nutrient Expert® (NE) for wheat, a decision support tool for field-specific nutrient recommendation for wheat, in Punjab State. On-farm experiments in wheat were established at 23 farmer fields in five different southern districts (Barnala, Mansa, Bathinda, Fazilka, and Muktsar) of Punjab, where the cotton-wheat rotation is the predominant cropping system. Four treatments included: (a) NE recommendation with N applied in three splits (33:33:34%), (b) NE recommendation with N applied in two splits (50:50%), (c) the current state recommendation (SR), and (d) the typical farmer fertilization practice (FFP).

The highest average wheat grain yield of 4.8 t/ha (range 3.5 to 7.5 t/ha) was observed with 33:33:34 treatment, which was not significantly different from 4.7 t/ha (range 3.2 to 7.5 t/ha) grain yield obtained with the 50:50 treatment. This suggests that N application in either two or three splits is beneficial for high wheat productivity in the study area. The average grain yields in FFP and SR were 4.3 t/ha (range 2.6 to 5.9) and 4.5 t/ha (range 2.6 to 7.0), respectively. Thus, the application of nutrients based on NE provided a yield advantage of 300 to 400 kg/ha over FFP and SR. The planting of wheat in a cotton-wheat rotation system is usually delayed by about a month due to the late harvest of cotton. Therefore the average grain yield of wheat in this region of Punjab could be lower by about 1 t/ha compared to the average wheat grain yield in the regions under rice-wheat system. Thus, the results...
Development of Soil Fertility Map as a Decision Support Tool for Fertilizer Recommendations in Citrus

Project Leader: A.K. Srivastava, National Research Center on Citrus, Soil Science, Nagpur, Maharashtra. Email: aksrivas_2007@yahoo.co.in

The development of a decision support tool to manage spatial and temporal variability in soil fertility is a viable option to address soil nutrient mining and fluctuating yield levels of citrus across India. Precision tools, like a Geographical Information System (GIS) for mapping the fertility status of soils, provide the desired accuracy and effectiveness in location-specific fertilizer recommendations. In this project, the changes in area of either fruit yield zones or nutrient availability zones in Khasi mandarin orchards of Umsaitning and Ribhoi district of Meghalaya were assessed using GIS variograms. The zones of variograms were based on indices earlier worked out for Khasi mandarin using the Diagnosis and Recommendation Integrated System (DRIS) interpretation tool.

Variable-rate fertilizer application was done after identifying fruit yield zones within orchards as very low, low, optimum, high, and very high using GIS variograms. The initial potassium permanganate-extractable N was optimum in 56% area of the orchard, which improved to 62% after variable-rate fertilization based on production zones. The initial field zones suggested that Olsen-P was low in 73% of the area, which reduced to 35% after variable rate fertilization as per production zones. Nearly 89% of total orchard area showed optimum soil ammonium acetate extractable K. Between 97 to 100% of the area was identified as optimum in DTPA-extractable Fe, irrespective of the grid size used for soil sampling. DTPA-extractable Cu was optimum in 55% of the orchard area, showing discernible changes with change in sampling grid sizes. High level of DTPA-extractable Cu was observed in 11 to 17% of orchard area using grid sizes up to 40 x 40 m. The deficient zone for DTPA-extractable Mn was observed to cover 38 to 41% of the orchard, which reduced to 29 to 32% after variable rate fertilizer application. Soil DTPA-extractable Zn was deficient in 88 to 91% of the total orchard area, which did not reduce significantly even after Zn application and may require more time to improve Zn fertility levels of the orchard soil. *IPNI-2010-IND-503*
Site Specific Nutrient Management for the Rice-Maize System in Bihar

Project Leader: M.L. Jat, CIMMYT, New Delhi, India. Email: m.jat@cgiar.org

Project Cooperator: Vishal Bahadur Shahi

This study was initiated to develop and disseminate site-specific nutrient management (SSNM) strategies in maize and wheat-growing areas of Bihar using the Nutrient Expert® (NE) nutrient decision support tool. Nutrient Expert® recommendations for maize and wheat were used to provide location-specific fertilizer recommendation to farmers in different districts of Bihar. On-farm trials in eight districts of Bihar were established during the winter wheat season of 2012-13 and for maize during the rainy season (kharif) of 2013. The trials, in collaboration with the Bihar State Department of Agriculture, compared two treatments, viz., NE-based fertilizer recommendation (NE) and Farmers' Fertilizer Practice (FFP).

Results from 81 evaluation trials showed that the average winter wheat yield in the NE treatment was 4.2 t/ha (range 2.5 to 5.7), while the average yield in FFP was only 3.4 t/ha (range 1.7 to 5.5). Average N+P+K used in NE and FFP were 264 and 216 kg/ha, respectively. The NE recommendation used similar N and P application rates as the FFP, but used 35 kg/ha of extra K₂O to achieve 790 kg/ha of additional wheat yield. Similar evaluation trials in kharif maize (n=134) showed that NE recommendations produced an average yield of 4.7 t/ha across eight districts of Bihar. The highest yield achieved in this treatment across all locations was 7.5 t/ha. Average yield in farmers' fields across all locations was 3.1 t/ha (range 1.6 to 6.5). The total N+P+K used in NE and FFP were 218 and 128 kg/ha, respectively. The average nutrient recommendation from NE was higher by 32 kg N, 10 kg P₂O₅, and 35 kg K₂O/ha over the FFP, but produced more than 1.5 t/ha of additional grain yield. The nutrients used in NE and FP for both the crops clearly brought out the fact that farmers either do not use K or underuse it in Bihar. The NE tool utilized the cropping system nutrient balance as one of the criteria for nutrient recommendation, assessed the deficit of K application by farmers and recommended much higher amounts of K than the farmers' rates. This led to significant improvement in crop yields, and underlines the necessity of adequate and balanced K application in maize and wheat in Bihar. The evaluation trials also showed that NE effectively captured the differences in wheat- and maize-growing environments across a large number of locations, and NE recommendations produced better yield for the two major staple food crops of Bihar. *IPNI-2010-IND-509*

Comparative Evaluation of Nutrient Dynamics under Conventional and No-till Systems of Crop Establishment in Rice-Wheat and Rice-Maize Cropping Systems

Project Leader: B.S. Dwivedi, Indian Agricultural Research Institute, Soil Science, New Delhi, India. Email: bsdwivedi@rediffmail.com

Project Cooperators: M.C. Meena, Anand Swarup, M.L. Jat, R.K. Gupta, and Animesh Singh

A nutrient omission study with four treatments (- N, - P, - K, and complete NPK) was initiated to assess the indigenous N, P and K supply in rice and maize growing soils of Odisha. The 25 rice trials and 15 maize trials were set up in multiple locations in Puri and Bhadrak districts of Odisha.

Among the 15 experiments in maize, the highest yield (8.2 t/ha) was recorded in Sunidha village of Puri district and lowest (6.8 t/ha) yield was recorded in Pagar village of Bhadrak district in the ample NPK treatment. Nitrogen response in each location varied from 4.2 to 5.3 t/ha, with an average N response of 4.7 t/ha. Nitrogen responses were higher in Puri as compare to in Bhadrak district. Efficiency of N (AEN) in these trials varied in different locations ranging from 23.5 to 29.6 kg grain/kg fertilizer N, with an average value of 25.9 kg/kg N. Phosphorus responses ranged from 2.2 to 3.6 t/ha, with an average value of 2.7 t/ha. The agronomic efficiency of phosphorus (AEP) averaged 23.2 kg/kg P (range 19.3 to 31.4 kg/kg P). Potassium responses varied from 1.1 to 2.1 t/ha, with an average response of 1.5 t/ha. Average agronomic efficiency of potassium (AEK) was 9.2 kg/kg K (range 6.7 to 12.8 kg/kg of K). The 25 on-farm rice omission plot trials in two districts of Odisha showed highest grain yield of 7.1 t/ha in the ample NPK plot at Patli village in Bhadrak district. Yield response to fertilizer N ranged from 4.3 to 4.8 t/ha, with an average value of 4.5 t/ha. AEN varied from 21.3 to 23.7 kg/kg N, with an average value of 22.7 kg/kg N. Yield response to applied P in the rice experiments ranged between 1.1 to 1.8 t/ha, with an average value of 1.6 t/ha. AEP varied from 15.8 to 22.6 kg/kg P, with an average value of 19.7 kg/kg P. Yield response to applied K fertilizer ranged between 0.66 and 1.6 t/ha, with an average value of 1.1 t/ha. The AEK in the current rice experiment varied between 8.8 and 17.4 kg/kg K, with an average value of 12.6 kg/kg K. *IPNI-2010-IND-517*

Balanced Fertilization for Enhancing the Productivity of the Pearl Millet-Wheat-Green Gram Crop Sequence in Agra, Uttar Pradesh

Project Leader: Vinay Singh, R.B.S. College Bichupuri, Agra, Department of Agricultural Chemistry and Soil Science, Agra, Uttar Pradesh. Email: apsr_1999@yahoo.co.in

On-farm trials were conducted in five villages of Agra district during kharif, rabi and summer seasons of 2012-13 to study the effect of balanced use of nutrients on pearl millet and wheat yield. The economics of
fertilization and the effects of residual soil fertility were also measured. Eight nutrient application treatments used were: T1, Farmers current practice; T2, fertilization to achieve target yields of 3.75 and 3 t/ha of pearl millet and wheat, respectively; T3, fertilization to achieve a 4 t/ha target yield of pearl millet and wheat; T4, fertilization to achieve a 4.5 and 5 t/ha target yield of pearl millet and wheat, respectively; T5, fertilization to achieve 5 and 6 t/ha target yield of pearl millet and wheat, respectively; T6, N fertilizer omitted from T5; T7, P fertilizer omitted from T5; and T8, K fertilizer omitted from T5).

The experimental results showed that treatment T5 (150 kg N + 98 kg P₂O₅ + 70 kg K₂O/ha) increased the pearl millet grain yield from 3.2 t/ha under farmer practice (T1) to 6 t/ha. The corresponding increase in net profit was from INR 26,176 (T1) to 48,912/ha (T5). Nitrogen (T6), P (T7) and K (T8) omissions reduced the pearl millet grain yield by 53, 42 and 18%, respectively, over T5. For wheat, T6 (Nutrient Expert® based recommendation for 6 t/ha targeted yield) produced the highest mean grain yield (6.1 t/ha), followed by T4 (5.7 t/ha) and least in the N omission (2.76 t/ha) treatment. Further, the farmer practice of fertilizer application proved suboptimal and produced only 4.9 t/ha of wheat grain. Omission of nutrients caused wheat grain yield reductions by 55% (-N), 29% (-P), and 10% (-K). The highest yielding treatment (140 kg N, 93 kg P₂O₅, 92 or 102 kg K₂O/ha) produced markedly higher net returns (INR 79,553/ha) and a Benefit: Cost ratio of 2.8 compared to the other treatments.

Greengram (mung bean) was grown in sequence following wheat harvest during the summer season on residual fertility. The effect of yield target-based fertilizer application in pearl millet and wheat was clearly evident in greengram yields. Highest yield of greengram (1.5 t/ha) was obtained in the T5 treatment, where fertilization was done targeting highest yields of pearl millet and greengram. The P omission plot (T7), with no P application in previous crops, produced the lowest yield (1 t/ha). The average net income from greengram in the T5 treatment was INR 58,900/ha. Agricultural fields are typically kept vacant for nearly 3 months after the harvest of winter wheat and before planting of pearl millet. The inclusion of greengram in the cropping system improved the system productivity of the conventional pearl millet-wheat cropping system and provided further income opportunities to smallholder farmers and employment to landless laborers in the “lean” season of the region. **IPNI-2012-IND-519**

**Climate Change Mitigation and Adaptation through Conservation Agriculture and Precise Nutrient Management in Current and Future Cereal-based Cropping Systems of the Indo Gangetic Plains**

Project Leader: Yashpal Singh Saharawat, Indian Agricultural Research Institute, Soil Science Indian Agricultural Research Institute, New Delhi, India

Project Cooperators: B.S. Dwivedi and Kaushik Majumdar

Participatory trials in eight farmer fields in Haryana were conducted to assess the effect of nutrient and residue management on wheat yield, nutrient uptake and carbon sustainability index. Three residue management levels, viz., T1- full residue retention from the previous rice crop (FR), T2- partial residue (30 to 50%) retention from the previous rice crop (PR), and T3- complete residual removal (RR) were tested at all farmer’s fields. Under each residue management scenario, four nutrient management treatments were superimposed, S1: No N application (- N plot), S2: No P application (- P plot), S3: No K application (- K plot), and S4: ample NPK application (+NPK plot). The nutrients applied in the ample NPK treatment were 180 kg N, 80 kg P₂O₅, and 100 kg K₂O/ha. The C sustainability index was calculated based upon the total inputs and outputs under different scenarios at each farmer’s field. The inputs included tillage operations and implements, seed and seed rate, nutrient application both basal and splits, irrigation number and volume, biocide application and their residual effect, crop residue retained/removed and fuel consumed. The outputs included grain, straw and root biomass.

Wheat grain yield varied among different villages/sites due to variation in growing conditions. Highest wheat yields in the ample NPK treatment were recorded at Nakatpur, both under full residue retained (5.6 t/ha) and residue removed (5.4 t/ha). Average wheat yields improved by 2% under residue retention over residue removal. Averaged among the residue management practices, ample NPK application enhanced wheat yield by 224, 17 and 14% over –N, -P and –K treatments, respectively. Yield enhancement in the ample N PK treatment vis-a-vis the –N treatment was highest (600%) in Nakatpur and least in Taraori (79%). Nitrogen, P and K uptake changed significantly under different residue management as well as nutrient omission scenarios. The maximum nutrient uptake was recorded under no residue retained treatment, followed by full residue and least in partial residue. The study also showed that with ample NPK application, residue retention doubled the C sustainability index over residue removal, indicating lesser global warming potential and higher adaptation to climate change. Omission of nutrients reduced the C sustainability index under both residue management scenarios. **IPNI-2013-IND-520**
Assessment of Agronomic and Economic Benefits of Fertilizer Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Eastern India

Project Leader: Kaushik Majumdar, International Plant Nutrition Institute (IPNI), Gurgaon, Haryana.
Email: kmajumdar@ipni.net


This project was started with the aim of understanding current fertilization practices of maize-growing farmers in eastern India and provide better recommendations to improve return on investment for farmers in Eastern India. A survey with a thoroughly pre-tested structured interview schedule was conducted in the four eastern Indian states of Bihar, Jharkhand, Odisha, and West Bengal. In each state, two districts with distinct agro-ecological systems were considered for the survey work. Fifteen farmers from each of the three villages under each of the two selected blocks of a district were selected (through sequential multistage sampling for selection of blocks and districts, and systematic/interval sampling for selection of farmers) amassing a sample size of 180 for the state. Collected data was analyzed for examining variables that individually influenced maize yield. Nutrient Expert® (NE) was used for predicting crop growth over a range of target yields. The target yield for the farmers can be increased progressively in short increments over the actual farmers’ achieved yields to estimate the benefit and the benefit:cost ratio of fertilizer use.

The analysis suggests that the NE recommendation based on farmer resources can potentially improve economic returns for the smallholding maize farmers in eastern India. This is achieved through better assessment of growing conditions as well as critical estimation of indigenous nutrient supply (such as crop residues, irrigation water, organic matter, and nutrient carryover from the previous crops) that subsequently helps in deciding the right rate of fertilizer application. Better efficiency of applied nutrients was ensured through the guidance for right source of fertilizer application at the right time of physiological nutrient demand, leading to better production economics. IPNI-2012-IND-321

Nutrient Optimization and Yield Intensification of Major Cereal Systems of Eastern India

Project Leader: Mahua Banerjee, Visva Bharati University, Department of Agronomy, Soil Science, Agril. Engineering, Plant Physiology, Animal Sciences (ASEPAN), Birbhum, West Bengal. Email: mbanerjee16@rediffmail.com

Project Cooperators: Ganesh Malik and Debanu Maiti

India is the second largest producer of rice in the world with a production of 100 million t in 2010-11. However, its current productivity is far below it’s attainable yield level. Introducing hybrid rice into the predominant cropping system of eastern India and changing the blanket fertilizer recommendations for high yielding varieties (HYV) for rice to site-specific fertilizer recommendations can help boost rice productivity. Therefore, we started this project to optimize fertilizer recommendations in a HYV rice–hybrid rice–pulse cropping system by using the omission plot technique to assess rice responses to NPK application. The trials are being conducted in five farmer fields each in Burdwan and Birbhum districts as well as one experiment at the research farm of Visva Bharati University, West Bengal. The treatments being used include: T1) Ample dose of N+P+K+S+Zn; T2) P+K+S+Zn (-N); T3) N+K+S+Zn (-P); T4) N+P+S+Zn (-K); T5) N+P+K+Zn (-S); T6) N+P+K+S (-Zn); T7) Local variety under the unfertilized check; T8) Local variety under ample fertilizer treatment; and T9) Control (without any fertilizer, but plant protection measures will be taken). The ample N, P, K, S, and Zn rates were determined based on nutrient requirements for a predetermined yield target of each crop. Other deficient nutrients were applied as needed.
After the first season of the experiment, the maximum yield of HYV rice (> 5.5 t/ha) was achieved with T1 at all locations. Omission of individual nutrients reduced crop yields. Interestingly, the yield of HYV under control or no fertilizer application was reduced by almost 3 t/ha, compared with the fully fertilized treatment. This reinforces the observation that high yielding varieties cannot reach their potential without proper fertilizer application. *IPNI-2013-IND-522*

**Assessing the Contribution of Nutrients to Yield of Hybrid Rice and Maize through Omission Plot Techniques in Bihar**

Project Leaders: Shiveshwar Singh, Rajendra Agricultural University, Pusa, Bihar, Department of Soil Science. Email: sp26814@gmail.com; S.P. Singh, Department of Soil Science, Rajendra Agricultural University, Pusa, Samastipur, Bihar. Email: sp26814@gmail.com

Project Cooperator: M.P. Singh

This study was designed to evaluate yield response to nutrient additions in a hybrid rice-maize cropping system. Specific objectives of this study were to evaluate the soil supplying capacity of different nutrients (N, P, K, and Zn) under hybrid rice-maize cropping system and to determine the nutrient requirement of high yielding hybrid rice–hybrid maize cropping system. The experiment was started in the summer of 2013 in farmer fields as well as at the research farm of Rajendra Agricultural University, Pusa, Bihar. The following treatments were included in the experimental design: T1, an ample dose of N+P+K+S+Zn; T2, ample but without N; T3, ample but without P; T4, ample but without K; T5, ample but without S; T6, ample but without Zn; T7, local crop variety with no added nutrients; T8, local crop variety with ample fertilizer; and T9, no fertilizer, but with plant protection measures. The ample N, P, K, S and Zn rates were determined based on crop’s nutrient requirement for a predetermined yield target. Other deficient nutrients were considered for application as per site-specific requirements.

Initial observation shows that the grain yield of hybrid rice (cv. Arize 6444) varied from 2.0 to 3.4 t/ha in unfertilized control plots and from 4.1 to 6.8 t/ha in the NPK plots across different locations. Omission of nutrients reduced the yield, with N being the single most limiting element. The reduction in grain yields due to N, P, K, S, and Zn omissions varied from 34 to 42, 9 to 15, 7 to 8, 4 to 6 and 3 to 5%, respectively, over the ample fertilizer treatment plot. The grain yields dropped by 49 to 54% in control plots over the ample fertilization treatment. The varietal impact was also observed in the yields of local rice (cv. Rajshree) where grain harvest ranged from 1.6 to 2.4 and 2.8 to 4.6 t/ha in control and ample fertilization treatment plots, respectively, at different locations. *IPNI-2013-IND-523*
Assessment of Nutrient Contribution towards Yield of Bt Cotton through Omission Plot Techniques in Karnataka

Project Leader: Y.R. Aladakatti, University of Agricultural Sciences, Department of Agronomy, Agricultural Research Station, Karnataka, India. Email: yraladakatti@rediffmail.com
Project Cooperators: D.P. Biradar, Yogesh Kumar Singh, and S.K. Pattanayak

On-farm studies were initiated in farmer fields of northern Karnataka where transgenic cotton is grown. The objectives of this study were to assess the yield responses to applied nutrients and understand the extent of indigenous nutrient supplying capacity of soils. Experiments were conducted at 30 farms in six different districts (Dharwad, Gadag, Haveri, Belgaum, Bijapur, and Bagalkot) of northern Karnataka, with soil types varying from medium black to deep black. All the selected locations had rainfed ecology, with supplemental irrigation occurring during critical stages of crop growth as needed. The local farmers differed in the hybrid of transgenic cotton being grown. The pH of the experimental soils was alkaline (ranging from pH 7.6 to 8.9), with low to medium amounts of available N (168 to 290 kg/ha) and high available P and K contents. The experiment consisted of four treatments, viz., ample NPK treatment consisting of 100 kg N, 70 kg P\textsubscript{2}O\textsubscript{5} and 80 kg K\textsubscript{2}O/ha, and omission treatments without N, P or K.

Yields of transgenic cotton across different locations with ample NPK varied from 3.2 to 4.0 t/ha, with an average of 3.6 t/ha, respectively. Omission of N, P and K resulted in average yields of 2.0, 3.2 and 3.0 t/ha, respectively. The highest yield response was observed with the application of N (1.6 t/ha) followed by K (0.6 t/ha) and then by P (0.4 t/ha). Higher net return of INR 74,036/ha and benefit-to-cost (B:C) ratio of 2.05 were realized with ample NPK treatment. The net returns were reduced by 71, 19 and 27% with the omissions of N, P and K, respectively, from the ample NPK treatment. Post-harvest analysis of the soil is currently underway and plant samples are being measured to determine nutrient uptake. The data generated from this study will be utilized for the development of a decision support tool known as Nutrient Expert\textsuperscript{®} for cotton. IPNI-2013-IND-524

Evaluating Principles of 4R Nutrient Stewardship in the Rice-Maize-Greengram Cropping System for Improved Productivity and Profitability of Farmers in Odisha

Project Leader: Sushanta Kumar Pattanayak, Orissa University of Agriculture and Technology, Soil Science and Agricultural Chemistry, Odisha, India. Email: sushanta_1959@yahoo.com
Project Cooperator: Ashok Kumar Mohapatra

Rice has been a traditional crop in the state of Odisha and is grown under rainfed lowland conditions, covering over 53% of the gross cropped area (8.4 million ha) in the state. The cropping intensity in Odisha is quite low in comparison to the other states of India and most parts of the state do not grow any second crop following rice harvest. Crop intensification has immense prospects to overcome uncertainties in single-crop rice areas of Odisha. Therefore, a study exploring the feasibility of accommodating succeeding crops like maize or green gram in sequence with rice was planned for ensuring sustainable crop productivity and soil fertility in the region. Also, developing principles of 4R Nutrient Stewardship in this newly proposed cropping system would provide nutrient management guidelines to farmers and help sustain the productivity and profitability of farmers practising this cropping system. Cuttack and Puri districts in the coastal agroecosystem and Dhenkanal district in the rainfed agroecosystem were chosen for this study. Four farmers from each district were selected and a high yielding rice variety was grown during the monsoon season of 2013 with a set of 10 treatments. The experimental treatments were formulated based on the results of the initial soil analysis. A total of 10 treatments were used at each location, viz., balanced fertilizer treatment (BFT) that included lime application, omissions of N, P, K, S, Zn, B, or lime from BFT, one absolute (unfertilized) control, and one farmers’ fertilizer practice (FFP).
In Cuttack, the grain yield of rice from the BFT was 3.5 t/ha, which was 27% higher than the yield in FFP and 165% higher than the control. Yield reduction due to omissions of N, P, K, S, B, Zn, and lime were 64, 19, 12, 35, 61, 46, and 32%, respectively. Similarly, in the Puri district, grain yield of rice due to BFT varied from 4.6 to 5.8 t/ha, with an average of 5.1 t/ha. This was 33 and 72% higher than the yields obtained in the FFP and control plots, respectively. At present, the post-harvest soil analysis and plant analysis for nutrient uptake are underway. Maize was sown as a succeeding crop to rice during the winter season at all the locations using the Nutrient Expert® program to estimate the attainable yield targets for each location and calculate the BFT. Green gram will be sown as a third crop in the system and will be grown completely on residual fertility.

Assessment of Agronomic and Economic Benefits of Fertilizer Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Odisha

Project Leader: Sushanta Kumar Pattanayak, Orissa University of Agriculture and Technology, Soil Science and Agricultural Chemistry, Odisha, India. Email: sushanta_1959@yahoo.com

Project Cooperator: Mitali Madal

Maize is gaining popularity among the farmers of Odisha, but productivity is very low in the state mainly due to improper input management, particularly nutrients. Small farm size, variable farmer management practices, lack of appropriate fertilizer recommendations tailored to farm size with consideration of small-farmer resources are some of the other constraints holding back the attainment of potential maize yields in the state. A study aimed at delineating current practices based on land holding, annual income, and crop yields was carried out to develop farmer resource-based fertilizer recommendations and ensure better adoption of improved nutrient management for higher crop yields and profit. Two districts (Navarangpur and Kalahandi) in Odisha were chosen with distinct maize growing environments and farmer resource availability. Two blocks in each district and three villages in each block were chosen for the survey considering variability criteria of yield gap, soil type, growing seasons, farmer holdings etc.

The survey revealed that >70% farmers in Odisha are literate, farm families are less dependent on off-farm income and involvement of labor from households is quite low. Categorization of farmers based on farm size and annual income to assess comparative differences in resource availability revealed that a majority of farmers with <1 ha holding fall in the lowest income group (< INR 50,000/yr). The assessment of the quantity of fertilizer used by farmers revealed that farmers’ risk perception plays an important role in nutrient management of maize. In Navarangpur district, higher quantities of fertilizer are used in winter maize, grown under irrigated conditions because it’s relatively risk free and farmers often harvest nearly 8 to 10 t/ha of maize grain. Besides market access, price of grain commodities also influenced farmers’ fertilizer use. Farmers growing irrigated winter maize in areas with good market access usually had better access to knowledge and inputs such as hybrid seeds, fertilizer, plant protection chemicals etc. through government and private industry extension services that allowed them to achieve relatively higher yields. This study also suggested that nutrient management interventions need to be directed towards (a) optimizing nutrient management for the lower income group of farmers and (b) providing guidance to improve maize yields of higher income group of farmers through appropriate use of nutrients. Currently, Nutrient Expert®, a decision support tool that provides site-specific fertilizer recommendations, is being used to provide appropriate resource-based farmer fertilizer recommendations. Additional field experiments are in progress to demonstrate the agronomic and economic benefits of appropriate fertilizer use. IPNI-2013-IND-527
Asia and Africa Group

Southeast Asia Program:
Dr. Thomas Oberthür, Director

Malaysia

Nutrient Expert® Development and Assessment

Project Leader: Thomas Oberthür, International Plant Nutrition Institute, Penang, Malaysia. Email: toberthur@ipni.net

The objectives of this project initiated in 2011 are to: 1) evaluate through local partners the Nutrient Expert® (NE) for Hybrid Maize (NEHM) in farmers' fields in Indonesia and the Philippines, 2) develop, test, and refine new versions of NE for maize in new geographies (China, South Asia and Africa) and NE for wheat in China and South Asia, and 3) develop NE for rice-based cropping systems in China and India. The NEHM has been adapted for maize growing conditions in South Asia, China and Africa, while NE for Wheat has been developed for South Asia and China and released after two years of field testing and evaluation by regional IPNI and local partners. Field validation of a beta version of NE maize for sub-Saharan Africa is ongoing, where NE recommendations are being tested against local recommendations and farmer’s fertilizer practices (FFP).

Field evaluations of NE maize in Indonesia and the Philippines since 2010 showed increased yield and economic benefits over current FFP. In the Philippines (n = 190), NE increased yield by 1.1 t/ha and gross profit by US$275/ha with increased application of P and K and comparable N rates. In Indonesia (n = 26), NE increased yield by 0.92 t/ha and gross profit by US$234/ha with N and P comparable to FFP rates but increased K. In India, field evaluation of NE for maize (n = 81) increased yield by 1.12 t/ha and gross profit by US$304/ha with substantial reduction in N, P and K rates. In India, NE for wheat was tested under conventional tillage (CT, n = 49) and zero tillage (ZT, n = 78) systems and showed increased yield by 0.75 and 0.71 t/ha and gross profits by US$166 and 151/ha with increased application of K and comparable N and P over FFP in CT and ZT, respectively. Both NE wheat and NE maize also performed better than local recommendations in India. In China, NE for maize and wheat crops slightly increased yields and economic benefits over FFP and showed comparable yield and economic benefits with local recommendations. Compared with FFP and local recommendations, NE reduced N application rates in both maize and wheat by 20 to 40%. NE increased K application rates over FFP by 25 to 60% in both maize and wheat. Field-validated versions (Version 1.0) of NE maize and NE wheat for China and for South Asia have been released for public use in 2013. On-farm validation trials of the beta version of NE maize for Africa started in 2012. In summary, the project has demonstrated that the use of NE can increase yield and farmer profits in India, Indonesia, and Philippines and increase fertilizer N use efficiency in China through tailored balanced nutrient management. IPNI-2010-GBL-52

Best Management Practice for Maximum Economic Yield in All Growth Stages of Oil Palm

Project Leader: Chris Donough, International Plant Nutrition Institute, Penang Malaysia. Email: crdonough@gmail.com

Project Cooperators: IJM Plantations, Wilmar International, and Canpotex International

This project was initiated in 2011 with the objectives to implement, test and refine the Best Management Practice (BMP) concept for yield intensification in order to increase productivity, profitability and sustainability of palm oil production in all growth stages including nursery, immature and mature development phases of the crop. The BMPs were implemented by IPNI and its plantation partners in five full-size management blocks in two collaborating plantations in Sumatra (Indonesia) and Sabah (Malaysia), which were re-plantings of existing plantations. Results from the BMP implementation were compared with those achieved under standard plantation
practices in the five reference blocks. At the outset of the research, reference and BMP blocks had similar conditions and performance.

In late 2013, due to the sequential planting, land preparation for BMP blocks and reference blocks that started in late 2011 is still ongoing. Transplanting of seedlings from the main nursery to field blocks that started in the second half of 2012 is also ongoing. Currently more than 200 ha have been planted and the remaining area will be planted in 2014. Data compiled from the monitoring of nursery phase is currently being analyzed, and monitoring in the immature palm blocks that were recently planted has started according to plan. Work on the second site in Sumatra started in 2012. Pre-nursery and main nursery for clones and DxP crosses have been set up. Nursery operations are running as planned. In parallel, field preparation has started in selected blocks. Through this process, estates are enabled to identify better ways to implement BMPs for yield intensification, and decisions on larger investments in BMPs are based on practical, commercial-scale evidence. This project is unique in its design as it includes all growth stages of oil palm and proposes monitoring over a period of 8 years. IPNI-2010-SEAP-4

**Best Management Practice for Crop Nutrition of Mature Oil Palm**

Project Leader: Chris Donough, International Plant Nutrition Institute, Penang Malaysia. Email: crdonough@gmail.com

Project Cooperator: Sungai Rangit Plantation, K + S GmbH

This project was initiated in 2011 in one plantation in Kalimantan, Indonesia, to implement, test and refine the Best Management Practice (BMP) concept specifically for fertilization and nutrition approaches for yield intensification in order to increase productivity, profitability, and sustainability of palm oil production in mature oil palm plantations. The ultimate goal will be to enable the use of BMPs for nutrient management to become standard within the industry. The project will deploy a two pronged approach including commercial block scale implementation of fertilizer management strategies, complemented by block embedded omission plots. Commercial block scale testing of application practices will contribute to more efficient fertilizer application management by the plantation and will contribute information for general fine-tuning of nutrient BMPs. Omission plots will generate site-specific information about fertilizer use efficiency for the plantation and will be developed into a general tool for plantation nutrient management. We are using 12 commercial blocks. Blocks are being distributed in sets of four within two estates of the plantation. Each set of four blocks contains two BMP blocks where fertilizers are applied in four splits—one with a high fertilizer rate (BMP 1), the other with a low fertilizer rate (BMP 2), and two reference blocks where all IPNI SEAP BMPs are deployed but fertilizer application follows current standard practice—one with high fertilizer rate (BMP 3), the other with low fertilizer rate (BMP 4). Fertilizers are applied as blended mixes including N-P-K-S-Mg-B. Omission plots are embedded in the 12 blocks. Each omission plot contains sub plots for zero and full application. The plot size is a 4m x 4m measurement plot, within a 6m x 6m plot, which is bounded by a trench.

Treatments BMP 1 and 2 are performing well after the reduction in residual effects from previous years’ management of commercial blocks. In the last 12 months of available data (until September 2013) BMP1 and BMP4 performed best in FFB production, followed by BMP2 and then by BMP3. In 2012, we started the bunch analyses process to determine the impact of management practices on oil extraction rates. Data analysis have been conducted in 2013 and will continue in 2014. Through this process, estates are enabled to identify better ways to implement BMPs for yield intensification, and decisions on larger investments in BMPs are based on practical, commercial-scale evidence. IPNI-2012-SEAP-5

**Plantation Intelligence to Upscale Best Management Practice in Oil Palm**

Project Leader: Julie Mae Pasuguin, International Plant Nutrition Institute (IPNI), Penang, Malaysia.
Email: jmpasuquin@ipni.net

The project was started in 2012 in several plantations in Indonesia and Malaysia to 1) develop an approach and performance indicators that facilitate up-scaling of the Best Management Practice (BMP) concept from commercial block scale to the whole plantation and to plantation groups and 2) develop a learning process based on commercial data analyses for improved management. Plantation data on management and specifically on fertilizer use and responses will be sought. Establishing an effective data management system is critical or the database soon becomes unmanageable. We will manage routinely collected plantation production and management information. All data can be stored in GIS. Careful protocols are needed to ensure data quality. Data analysis will include assessment of spatial variations in management practices, including fertilizer use, yield response to management and to N, P or K and return on investment for fertilizer. Block field data will be expanded with model data. A process will be developed that can be deployed by the plantations to derive performance indicators on regular bases. Data interpretation will start with a basic set of insights and expand to more specific detail and leading to site specific performance indicators. The general purpose of analysis and performance is to support
change towards a more profitable and intensive use of fertilizer in oil palm plantations. Key agents of change are plantation managers who use the developed process and performance indicators.

Operational setup, buy-in of industry, and generation of supporting information have all been completed. Eighty (80%) of the database for two plantations has been established, while 50% has been established for the remaining plantation. Partners have contributed large data sets, which are being analyzed simultaneously in a number of different ways. Task reports (35) have been drafted, describing a wide variety of observations about performance, much of it undocumented in the literature. About 100 data sets have been written, providing the basis for further progressive analysis. A dialogue at plantations with senior and middle managers has commenced in order to support industry decision-making. Furthermore, a publication was prepared for Better Crops and several monthly ‘Industry Snapshots’ were disseminated. Through this process, estates are enabled to identify better ways to implement BMPs for yield intensification, on full plantation scale, and across groups of plantations. IPNI-2012-SEAP-6

Cocoa Intensification in Indonesia - IPNI Cocoa Care Program

Project Leaders: Thomas Oberthur, International Plant Nutrition Institute, Penang, Malaysia. Email: toberthur@ipni.net; Noel Janetzki, PT Community Solutions International, Cocoa Care Program.

Since the early 2000’s there has been an ongoing decline in quality and productivity in cocoa in Indonesia, which has undermined cacao farm profitability and presents a substantial risk to the survival of the industry in Indonesia, while at the same time global markets are strong. This project that commenced in 2013 will identify cacao-farming families with the necessary land and family resources to become a sustainable cacao business family over the longer term. Project information can be used to estimate and project fertilizer market demand for Sulawesi, and thereby guide further market development programs. These cacao farmers will be trained both “in class” and “in field” on how to implement good agricultural practices on their farms for maximum productivity. Where necessary, dead or non-productive cacao trees will be rehabilitated or replaced with the best available planting materials. The project will be managed jointly by IPNI, Malaysia, and PT Community Solutions International, Cocoa Care program.

For this program, where we will focus on demonstrating the benefits of sustainable soil management and fertilizing practices, we will select farms which require the least amount of tree rehabilitation, but where evident we will support small scale remedial action outside the test plot areas to improve longer term farm productivity. Soil and leaf sampling will be undertaken within the farms to establish nutritional and other soil needs. This data will be analyzed and ideal soil management practices and fertilizer regimes developed (including potash fertilizers) to achieve the optimum, soil condition and nutritional levels for cacao farming. The program will explore and deploy the 4R Nutrient Stewardship Concept - right source, right rate, right time, and right place - to guide the fertilizer applications. Test plots will be established within each farm to monitor the impact of these interventions. The Cocoa Care team will conduct farmer identification, procurement, field trials implementation and monitoring, while IPNI will provide guidance on scientific methods, statistical analysis of results and managerial oversight. The project will enable a quantification of the contribution of fertilizers to yield gap reduction, cocoa quality improvement, and income generation for farmers, and soil quality improvement. More importantly, the project will demonstrate to farmers the benefits of good agricultural practices, including fertilization, and thereby provide motivation to growers for management change. IPNI-2013-SEAP-6
Transferring Oil Palm Plantation Best Management Practices (BMP) from Southeast Asia to West Africa

Email: szingore@ipni.net
Project Cooperator: Thomas Oberthur

The oil palm sector in West Africa is developing extensively, yet the plantations are under-performing with low yields (averaging about one-third of the optimum). In 2013, Best Management Practices (BMP) were implemented in three plantations in Ghana, West Africa, with the aim of identifying and implementing improved agronomic management practices that meet site-specific needs, and to provide opportunities for enhanced productivity, profitability and environmental sustainability. Parallel sets of comparable oil palm blocks representative of a plantation were selected at three plantations. Site-specific BMPs were introduced in one block, while the other block maintained standard estate practices (i.e., considered as a control or reference block; REF). The experimental setup is designed to provide an understanding of the maximum site yield potential and the magnitude of yield gaps due to poor harvesting and management, as well as plant nutrient constraints during the production phase.

Field audits were held every 2 to 3 months at each plantation in order to monitor the progress of BMP activities and to provide new action points in order to address these existing yield gaps. The overall magnitude of block performance was reflected in fresh fruit bunch (FFB) production. FFB was harvested at regular intervals from the BMP blocks (4 rounds/month), and irregular intervals for REF blocks (2 to 4 rounds/month). FFB production for 2013 was taken as the sum for all months, and yield gaps between treatments were taken as the difference of the total production. By the end of 2013, BMP blocks performed better than the REF blocks, with an average difference of 0.9 to 1.0 t/ha for all estates. The increase in productivity was mainly influenced by a shorter harvesting interval, which ensures that more crop is recovered from the field. Soil and leaf analysis were performed in mid-2013 which suggested the presence of nutrient deficiencies in all estates, particularly of P, K and B. Fertilizer recommendations for 2014 have been increased in order to rectify these prevailing deficiencies. It is expected that the combined effect of improved agronomic and nutrient management will result in even greater fertilizer responses by the end of 2014.

Evaluating the Impact of Soil Fertility Heterogeneity on Maize Nutrient Requirement and Productivity in Smallholder Farming Systems

Project Leader: Regis Chikowo, University of Zimbabwe, Department of Soil Science and Agricultural Engineering, Harare, Zimbabwe. Email: rchikowo@agric.uz.ac.zw

Strategic targeting of nutrient resources by smallholder farmers on different field types for optimized resource use efficiencies has remained poor, resulting in sub-economic returns to investments. This study investigated efficient strategies for use of nutrient resources to narrow the exploitable yield gap in maize production on heterogeneous coarse-textured soils under rainfed conditions in eastern Zimbabwe. A nutrient omission study was implemented between 2011 and 2013 across six on-farm sites with soil organic carbon (SOC) ranging from 0.33 to 0.89% and clay content ranging between 4 to 19%. Treatments used were: i) unfertilized control, ii) NK, iii) NPS, iv) PKS and v) NPKS. The nutrients PKS were basally applied at 40, 60 and 40 kg/ha, respectively, during Year 1 and repeated at a half rate (50% of year one) during Year 2. The rate of N application was adjusted as a function of seasonal rainfall, with a mandatory initial application of 20 kg/ha N at planting and two subsequent splits of 50 kg/ha N, if soil moisture permitted. Rainfall water productivity (kg grain/mm, RWP) was used as a proxy for water use efficiency for the different nutrient management strategies. During both seasons, only 70 kg/ha N could be applied across all sites as moisture limitations forced withholding of the second N topdressing targeted at maize anthesis.
Maize productivity was significantly influenced by nutrient management across sites for both seasons. During the first season, maize yields across sites ranged from 0.25 to 0.8 t/ha for the unfertilized control and 2.1 to 3.75 t/ha for the NPKS treatment. The corresponding RWP ranged from 0.38 to 1.13 kg grain/mm for the control and 3.15 to 7.66 kg grain/mm for the NPKS treatment. For the second season, maize yields for the control treatment ranged from 0.2 to 1.2 t/ha, while those for the NPKS treatments ranged from 2.4 to 3.6 t/ha. The N, P and K response factors were 0.56, 0.45 and 0.09, respectively, indicating poor response to K and highest response to N application. These results suggest that balanced nutrient management has an overriding effect on maize grain and water productivity, but only guaranteed when soil organic carbon content exceeded 0.4%. Nitrogen and P remain the most limiting nutrients for maize production. Complementary organic nutrient management approaches should be employed to increase SOC and sustain soil productivity. Variable N application strategies must be an integral component of farmer management if losses related to fertilizer investment are to be minimized under the risky rainfed production systems. *IPNI-2011-ZWE-1*

**Nutrient Management for Grain Legume Crop Production in Africa**

Project Leader: Shamie Zingore, International Plant Nutrition Institute (IPNI), Nairobi, Kenya. Email: szingore@ipni.net

There is growing interest to increase soybean yields in smallholder farming systems in western Kenya, but productivity has remained very poor due to poor soil fertility conditions and limited understanding of effective nutrient management strategies for soybean production intensification. On-farm experiments were established at three sites in western Kenya to assess the effect of fertilizer, manure and lime applications on yield and profitability of soybean under variable soil fertility conditions. Treatments included: a) control (without Rhizobia inoculant or fertilizer), b) inoculation alone, c) N+P+K, d) P+K, e) N+P, f) N+K, g) N+P+K+S+Ca+Mg+Zn+Mo, and h) N+P+K+S+Ca+Mg+Zn+Mo+Manure+Lime. Treatments b) to h) also had seed inoculation done with USDA-110. Fertilizers were applied at rates required to achieve the attainable yields in the study area as follows: 20 kg/ha N, 30 kg/ha P, 60 kg/ha K, 23 kg/ha S, 20 kg/ha Ca, 5 kg/ha Mg, 3 kg/ha Zn, 3 kg/ha Mo. Manure was applied at 10 t/ha and dolomitic lime at 5 t/ha. The experiment was conducted for two seasons in three fields with contrasting soil fertility conditions: Masaba (low fertility), Eshirali (medium fertility) and Nyabeda (high fertility).

Inoculation alone significantly increased grain yield compared to control in Nyabeda. The treatment NK had significantly lower grain yield compared to NPK, NP and PK at all sites, suggesting that P was the most limiting nutrient at the experimental sites. However, the highest yields were achieved with N+P+K+S+Ca+Mg+Zn+Mo+Manure+Lime treatment at all sites. Soybean productivity and profitability was low on the infertile sandy soils of Masaba. Higher revenue was generated in fertilized treatments at the more-fertile Eshirali and Nyabeda sites. The study also highlighted that while the highest gross margins were realized with N+P application, achieving maximum yields would require the combination of mineral fertilizers along with manure and lime, with greater yield potential existing in the fertile clay soils. Thus, although there is a good scope for smallholder farmers to profitably intensify soybean production, this will largely depend on nutrient management strategies that address multiple soil fertility constraints and tailoring fertilizer recommendations to different soil fertility conditions. *IPNI-2012-SSAP-3*

**Strengthening the Capacity for Dissemination of Integrated Soil Fertility Management Technologies in East and Southern Africa**

Project Leader: Shamie Zingore, International Plant Nutrition Institute (IPNI), Nairobi, Kenya. Email: szingore@ipni.net

Project Cooperator: Rebbie Hararwa

Yields of food crops in sub-Sahara Africa (SSA) have stagnated at approximately 1 t/ha over the last five decades, mainly as a result of infertile soils and low nutrient use. Efforts to solve this problem have focused on the development of various integrated soil fertility management (ISFM) technologies adapted to smallholder farming systems. Research trials have demonstrated opportunities for doubling or tripling yields of both cereals and legumes when appropriate ISFM technologies suited to site-specific conditions are used. Despite the potential of ISFM technologies to improve crop productivity, their adoption by farmers has been very limited. The underlying challenges include poor integration of existing knowledge and lack of effective knowledge products for farmers and extension agents.

A soil health consortia of eight countries in Eastern and Southern Africa (Kenya, Uganda, Tanzania, Rwanda, Malawi, Mozambique, Ethiopia and Zambia) has been recently established with a focus on (i) harmonization of ISFM information at the country and regional level, (ii) development of a regional database for consistent agronomic information, and (iii) communication products developed to support farmers and
policy makers to make informed decisions on investment in ISFM technologies. The consortia provides a platform for knowledge integration and exchange between institutions and individuals working on different agricultural program related to ISFM. Over 100 institutions and 1,000 individuals are members of the consortia. In the first year of the project, a series of ISFM communication materials have been developed covering the right use of fertilizer based on the 4R Nutrient Stewardship, improved seed varieties and organic resources. A comprehensive database for the collation and synthesis of ISFM data at the country and regional levels has also been developed. Collection of legacy experimental data in Kenya, Malawi, Tanzania, Uganda and Rwanda has been initiated using over 5,000 publications covering wide-ranging ISFM technologies. The data will be analyzed and summarized to gain insights into how ISFM technologies can be adapted to wide-ranging soil and climatic conditions in SSA. IPNI-2013-SSAP-1

Development and Dissemination of 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification in Western Kenya

Project Leader: Shamie Zingore, International Plant Nutrition Institute (IPNI), Nairobi, Kenya. Email: szingore@ipni.net
Project Cooperators: Nesbert Mangale, Julius Nyabiche, Joseph Chacha, George Odour

The lack of appropriate site-specific nutrient management recommendations is a key contributor for low crop productivity in sub-Saharan Africa (SSA). The 4R Nutrient Stewardship Framework developed by the fertilizer industry aims to provide the context for efficient nutrient management focusing on four central components: applying the right fertilizer source, at the right rate, at the right time in the growing season and in the right place. To assess the impact of 4R practices in smallholder cropping systems, on-farm nutrient omission trials were initiated in 2013 in Western Kenya. The region has a high potential for agriculture intensification with current farmer yields being lower than 2 t/ha compared to research stations yields of up to 8 t/ha. The trials, implemented for two seasons, were established in 26 fields of varying soil texture and fertility levels. In each season, maize was planted at a spacing of 75 cm x 25 cm. N, P and K fertilizers were applied as urea, triple superphosphate (TSP), and KCl. All P and K fertilizers were applied at planting. Nitrogen applications were done in three equal splits at planting, three weeks after emergence and six weeks after emergence.

In both seasons, the NPK treatment resulted in highest average yields of 5.5 t/ha and 5.3 t/ha for the long rains (LR) and short rains (SR) seasons, respectively. This illustrated the importance of balanced nutrition in achieving and maintaining high yields. Current recommendations only cover N and P. Yield responses for N, P and K in the LR and SR seasons were 2.6 and 0.25, 0.4 and 2.5 and 1.3 and 0.7 t/ha, respectively. However, analysis of the agronomic efficiency (AE) of all the macronutrients for both seasons showed that long term omission of P and K from the system could adversely affect yields as the AE for N, P and K changed from 15, 13 and 11, respectively in the LR season to 17, 40 and 18 in the SR season. In both seasons, the unfertilized control yields were higher than the current farmer practice average yields, indicating that farmers are currently not applying the right agronomic practices such as the use of improved seeds, timely planting, weeding and plant spacing. The field sites were used to train farmer groups and extension agents about the 4R Nutrient Stewardship. IPNI-2013-SSAP-2
Asia and Africa Group
North Africa Program
Dr. Mohammed El Gharous, Consulting Director
Dr. Hakim Boulal, Deputy Director

Best Management Practice of Nutrient of Olive Orchards in Rainfed and Irrigated Areas of Morocco
Project Leader: Lhassane Sikaoui, INRA Marrakech. Email: sikaoulhassane@yahoo.fr
Project Cooperator: Bouizgaren, El Antari

This study was conducted under rainfed and irrigated farming conditions in the Tensift-Al Haouz region in collaboration with INRA Marrakech. Two on-farm experimental sites were selected with olive orchards in irrigated and rainfed areas of Marrakech and Essaouira provinces, respectively. At each site, four treatments were used, viz., plot without additional fertilization, farmer practice (FP), fertilization based on nutrient removal, and fertilization based on foliar analysis. To determine the initial status of soil fertility, soil samples were taken from the experimental plots and analyzed for pH, CEC, N, P, K, and soil organic matter. Tree leaves were sampled between the end of June and mid-July from olive groves of the on-farm experiments and also from 19 and 15 olive groves sites in Marrakech and Essaouira region, respectively. Foliar analysis showed a high spatial variability of nutritional status of macro- and micro-nutrients of olive groves in both regions. On average, 67% of the sampled sites were deficient in N, while all sites were deficient in P. Potassium was deficient at all sites in the rainfed area and in 90% of the sampled sites in irrigated area. Magnesium was more available (in the range of the optimum level) in 58% of sampled sites in the rainfed area compared to 15% in the irrigated area. Among the foliar micronutrients, Cu was not deficient in any of the sites and in both areas. Iron was at optimum level in 95% of the sites, while Mn was deficient in 40% of the sites. Deficiency of Zn was more prominent (52% of sites) in the rainfed area than in the irrigated area (31% of sites). According to the results of the foliar composition, additional fertilizers will be applied in the two on-farm experimental plots in February and March 2014 at rainfed and irrigated sites, respectively. Fertilizer recommendations will also be provided to the local farmers where olive orchards leaves were sampled and analyzed. IPNI-2013-MAR-1

Development and Dissemination of 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification
Project Leader: Hakim Boulal, IPNI North Africa Program. Email: h.boulal@ipni.net

The objective of the project is to develop a Nutrient Expert® (NE) tool for Moroccan farmers and extension specialists to implement appropriate nutrient management practices for wheat production. On-farm experiments were established in 2013 under semi-arid rainfed wheat production systems in the Chaouia region. Six experimental treatments were established at five locations - three sites in Settat province and two sites in Berrechid province. Each on-farm experimental plot was planted with bread wheat and with durum wheat under five nutrient treatments, viz., optimum treatment (OPT) (150 kg N + 75 kg P₂O₅ + 100 kg K₂O kg/ha), omitting N from OPT, omitting P from OPT, omitting K from OPT, control (without fertilizers) and farmer fertilizer practice (FFP). Among the six experimental plots, two were established under no tillage system. Grain yields will be measured and the response to added nutrients will be determined in the coming year. IPNI-2014-MAR-2
Evaluation of the Potassium Status of Arable Soils in Ukraine on the Basis of Modern Soil Diagnostic Techniques and Development of Recommendations for the Rational and Efficient Application of Potassium Fertilizers

Project Leader: Miroshnichenko Nikolai, National Scientific Center “Institute for Soil Science and Agrochemistry Research, Kharkov, Ukraine. Email: ecosoil@meta.ua

Project Cooperators: Khristenko Anatoly, Nosko Boris, Gladkih Ulia, and Istomina Evgenia

The project was initiated with the objectives to provide an accurate assessment of K status of arable soils, determine the response to K fertilizers, estimate the efficiency of K fertilizers in the soils of the main climatic zones, and work out fertilizer recommendations for K application in maize, wheat and sugar beet grown in rotation on leached chernozems. The project summarized the database containing information on crop response to K fertilizer applications in field trials conducted in Ukraine during the last 40 years. Some of the major factors that determine the efficiency of K fertilizers in different climatic zones of Ukraine were the amount of precipitation and temperature during the growing season, and adequate plant-available K in the soil. The mathematical relationships between soil K concentrations and agronomic efficiency of K fertilizer, as well as between hydrothermal coefficient and agronomic efficiency of K fertilizer for winter wheat, grain maize and sugar beet were determined. Efficiency of K fertilizer use tends to decline from West to East and in Southeast provinces, mainly due to decrease in precipitation.

Assessment of K status of arable soils by a new diagnostic approach (new soil test methods and soil K interpretation classes) showed that the majority of arable soils in Ukraine have medium content of extractable K. The comparison of plant-available K contents obtained by different extraction methods showed that the Chirikov method (0.5 M CH₃COOH) overestimated the K supply of chernozems. The minimum requirement for K fertilizers in Ukraine, as calculated from the average data for K removal by main agricultural crops during harvest, has been estimated to be 1.8 million t K₂O/year.

A 3-year field experiment on the efficiency of four different K fertilizer rates with two combinations of NP in crop rotation typical for the steep-forest zone of Ukraine (forage maize-wheat-sugar beet) was conducted. High efficiency and economic benefit resulted from applying K fertilizers to all three crops. Optimization of the N and P supply contributed to the increase on the economic return from K fertilizer. The highest economic benefit for the maize crop was obtained at the 90-90-40 kg N-P-K/ha application rate. Banded application of K fertilizer (before preplant cultivation) significantly increased the yield of maize green mass (14 to 18%) compared with broadcast application. Due to adverse weather conditions during the growing season, the yields of wheat (1.7 to 2.4 t/ha) and sugar beet (24 to 35 t/ha) were lower than expected. In the situation of summer drought, K fertilizers contributed up to 10% of the yield increase in plots with optimized NP fertilization. IPNI-2011-UKR-1
Improvement of Recommendations for Potash Fertilizer Use and Adjustment of Currently Used Soil Potassium Test Interpretation Classes in Intensive Cropping Systems

Project Leader: Romanenkov Vladimir, Pryanishnikov Research Institute for Agricultural Chemistry of the Russian Academy of Agricultural Sciences, Laboratory of Geographical Network of Fertilizer Experiments, Moscow, Moscow. Email: vriuageoset@gmail.com

Project Cooperators: Siskevich Yuriy, Korchagin Victor, Nazarenko Olga, and Lukin Sergey

This 3-year project has a special focus on optimization of fertilizer K rates for crops with high response to K, such as sugar beet, grain maize, rape, and soybean. The objectives of this project are to determine optimal potash fertilizer rates for major crops in crop rotation that have a high K demand, evaluate the validity of currently used soil test K interpretation classes for proper assessment of plant K requirements, and develop proposals for the Russian Ministry of Agriculture on possible fine-tuning of the current practice of fertilizer K recommendations. The project includes short-term field experiments executed on large industrial farms located in Central Russia (Lipetskaya, Voronezhskaya, Belgorodskaya oblast) and South of Russia (Rostovskaya oblast) and established on Chernozem soils with medium and “increased” (higher than medium) content of routinely extracted K. Total number of field trials is 48, including 24 studying the residual effect of K application.

Potassium fertilization increased the yield of sugar beet roots and grain maize substantially, regardless of the initial content of plant-available K in the Chernozem soil. In Voronezhskaya oblast, the maximum yield of sugar beet roots was 80 t/ha with a fertilizer K rate of 140 kg/ha. This demonstrated a 21% increase in yield due to K fertilization. In Lipetskaya oblast, the maximum yield of sugar beet roots was 70 t/ha with a fertilizer K rate of 280 kg/ha, demonstrating a 22% increase in yield due to K fertilization. The maximum yield of sugar beet roots achieved in the trials in Central Russia was almost 2 to 3 times higher than the average regional yield (32 t/ha) in Central Russia (between 2006 to 2010). In Rostovskaya oblast, the maximum yield of sugar beet roots was 59 t/ha with an application rate of 70 kg K/ha, a 4% increase in yield over NP treatment. In all trials with sugar beet, the sugar content in roots was also increased due to potash fertilization, which resulted in substantial increases in sugar yield (25, 28 and 3% in Voronezhskaya, Lipetskaya and Rostovskaya oblast, respectively) compared with the NP treatment). For maize, the maximum grain yield was 11.2 t/ha, achieved with a fertilizer K rate of 140 kg/ha in Voronezhskaya oblast and 9.4 t/ha with a fertilizer K rate of 280 kg/ha in Belgorodskaya oblast. This represented respective yield increases of 15 and 24% due to potash application as compared with the NP treatments. The high grain yield achieved for maize in this experiment was substantially higher than the average regional yields (4.2 and 6.1 t/ha in Voronezhskaya and Belgorodskaya oblast, respectively (between 2006 and 2010). Similarly, K application increased rapeseed yield up to 2.6 t/ha, which was 14% more than the yield obtained with NP treatment. Thus, for all crops from Central Russia, adequate K fertilization resulted in greater profitability from crop production. IPNI-2012-RUS-1
**Eastern Europe/Central Asia and Middle East Group**

**Russia Program**

**South & Eastern Region:**

**Dr. Vladimir Nosov, Director**

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**Improvement of Winter Wheat Mineral Nutrition on Calcareous Common Chernozems**

Project Leader: O.A. Biryukova, Southern Federal University, Department of Soil Science and Land Resources Evaluation, Rostov-on-Don, Rostov Oblast. Email: olga_alexan@mail.ru

Project Cooperators: I.M. Tyurin, D.V. Bozhkov, and A. Koretskiy

This project assessed the spatial variability in soil fertility parameters using 27 soil samples (0 to 20 cm soil depth) collected from the experimental area of 39 ha prior to starting the field experiment. The experiment comprised of two demonstration plots of 19.5 ha each. Soil test results showed that the nitrate-N concentration varied from very low to low (average 4.8 ppm), ammonium-N averaged 22.3 ppm, available P extracted with 1% ammonium carbonate at soil to solution ratio of 1:20 (AC-P) was low to medium (average 7.2 ppm), and available K extracted with ammonium carbonate solution (AC-K) was medium to 'increased' class (average 241 ppm). AC extraction is a routine method in Russia to assess available P and K in calcareous soils, including chernozems and chestnut soils. Olsen-P and exchangeable K extracted with ammonium acetate solution were also measured and averaged 15.7 and 277 ppm, respectively. Soil pH averaged 7.7.

Soil ammonium and nitrate concentrations were found to be the most variable parameters with coefficients of variation (CV) of 25 and 46%, respectively. Both Olsen-P and AC-P had moderate variability (CVs of 11% and 19%, respectively), while exchangeable K and AC-K were less variable parameters (CVs of 8 and 9%, respectively). Soil pH was quite consistent in the experimental area (CV of 1%). A noteworthy fact is that variable rate fertilizer application may be a profitable placement method when spatial variability exceeds 20%. A very strong correlation was found between exchangeable K and AC-K (R = 0.99), because cation exchange reactions between K and ammonium occur during both extraction procedures. Similarly, Olsen-P was strongly correlated with AC-P (R = 0.88). Thus, routine soil testing methods may provide adequate assessment on the availability of soil P and K to plants in calcareous chernozems.

Dry conditions prevailed during winter wheat planting and then during spring-summer season too. The farmer used reduced tillage and applied fertilizers (monoammonium phosphate, potassium chloride) before planting to the surface soil layer. Ammonium nitrate was topdressed at early spring. The farmer harvested 2.75 t/ha yield in K-omission or farmer’s fertilizer practice (54-52 kg N-P/ha) plot. Application of 40 kg K₂O/ha had practically no effect on grain yield as only a nonsignificant yield increase of 0.04 t/ha (or 1.5%) was observed in the field. *IPNI-2012-RUS-3*
**Balanced Fertilization of Major Crops in Egypt**

**Project Leader:** Mohamed M. El-Fouly, National Research Center, Fertilization Technology Department, Cairo-Egypt.  
Email: mohelfouly@link.net

**Project Cooperators:** El-Zanty Abu El Nour, Adel Andel Chalet, and Fuad Al-Said Abdullah

The objectives of this project are to determine the effect of balanced fertilization on the yield of major crops in the common cropping systems of Egypt and extend to farmers the most efficient fertilization and irrigation techniques. For this, field experiments were conducted at two locations with seven treatments, viz., no fertilizer, NPK according to the farmer’s practice, NP at the recommended rate, NK as recommended by the Egyptian Ministry of Agriculture (MOA), NPK as recommended by MOA, NPK based on soil testing, and NPK based on soil testing + micronutrients (balanced fertilization treatment).

For all crops and locations, balanced fertilization helped maximize yield and yield components. At the El-Behira site, wheat grain yield was highest (6.6 t/ha) in the NPK+micronutrients treatment plot, whereas control and the farmers’ practice treatments resulted in lowest yields (2.3 and 4.2 t/ha, respectively). A similar trend was observed with the maize crop, where the highest grain yield (8 t/ha) was obtained in the NPK+micronutrients treatment plot, while control and farmers’ practice treatments yielded the lowest (2.6 and 3.2 t/ha, respectively). Similarly, at the El-Monofia site, wheat grain yield was highest (6.5 t/ha) for the NPK+micronutrients treatment, while control and farmers’ practice treatments resulted in lowest yields (5.1 and 5.3 t/ha, respectively). Consistently, the maize crop recorded highest yield (13.2 ton/ha) with NPK+micronutrients treatment, while control and farmers’ practice treatments had grain yields of 8.5 and 9.7 t/ha, respectively.  

**IPNI-2012-EGY-1**

**Balanced Fertilization of Egypt’s Major Crops through Fertigation**

**Project Leader:** Maybelle Gaballah, National Research Center (NCR), Head of Water Relations & Field Irrigation Dept., Cairo-EGYPT. Email: msgaballa54@yahoo.com

**Project Cooperator:** Osama Nofal, National Research Center (NCR), Head of Plant Nutrition Dept., Cairo-EGYPT  
Email: nofalosama@hotmail.com

The main objectives of this study are to (a) enhance maize productivity with innovative techniques like fertigation, (b) maximize water and fertilizer use efficiencies, and (c) increase awareness and transfer the technology of fertigation management. The field experiment was conducted at the experimental station of the National Research Center in Nubaria District of El-Behrea Governorate in Egypt. The treatments investigated for maize production included: T1, unfertilized control; T2, the recommended N application rate; T3, the recommended P rate; T4, the recommended K rate; T5, the recommended NP rate; T6, the recommended NK rate; T7, the recommended NPK rate; and T8, the recommended rate of NPK+micronutrients.

The results of this study showed that the highest maize grain yield was obtained using balanced fertilization of NPK and NPK plus micronutrients, both of which produced 4.4 t/ha of maize. As expected, the lowest yield (1.6 t/ha) was obtained in the unfertilized control treatment.  

**IPNI-2013-EGY-2**
Effect of Potash Fertilization on Yield and Quality of Cotton, Maize, Watermelon and Hazelnuts in Turkey

Project Leaders: Ibrahim Ortas, Cukurova University, Department of Soil Science and Plant Nutrition. Email: iortas@cu.edu.tr; Mehmet Niyazi, Cotton Research Institute; Omur Duyar, Hazelnut Research Institute

The objectives of this project are to a) evaluate the effect of K fertilizer application on the yield of different crops under different soil and climatic conditions in Turkey and b) transfer the knowledge and technology of fertilizer application to farmers, fertilizer company dealers, and decision makers in Turkey using social media and publishing extension materials. Field experiments were conducted at three locations to investigate the effect of different application rates of K from two fertilizer sources (KCl and K2SO4) on maize and cotton yields.

The results from the maize experiment in Adana indicated that the highest maize grain yield (14.5 t/ha) was obtained with the application of 60 kg K2O/ha as KCl followed by the application of 120 kg K/ha as K2SO4 (13.8 t/ha). The lowest yield was obtained when no K was applied (8.3 t/ha). The results from the cotton experiment conducted at the Cotton Research Station in Nazilli Kivilicim, Aydin showed that the highest cotton fiber yield (2.0 t/ha) was obtained with application of 60 kg K2O/ha irrespective of the source of K used and the lowest yield was obtained when no K was applied (1.6 t/ha). Using similar K rates (60 kg K2O/ha applied either as KCl or K2SO4) gave the highest, but significantly similar cotton seed yields of 4.62 and 4.59 t/ha, respectively, and the lowest cotton seed yield (3.65 t/ha) was obtained when no K was applied.

IPNI-2012-TUR-1