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**IPNI Research Projects:**

**INTERPRETIVE SUMMARIES**

**2017 CROP YEAR**





## Interpretive Summaries

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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:

**>research.ipni.net<**

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# IPNI Interpretive Summaries 2018 (2017 Crop Year)

## Table of Contents

<b>4R Research Fund Projects.....</b>	<b>9</b>
CAN-4RC01 Improving Nitrogen Management Tools for Reduced Environmental Losses from Corn Production.....	9
CAN-4RC02 Improved Nitrogen Application Methods and Nitrogen Sources for Corn in Southwestern Ontario .....	9
CAN-4RC03 Optimization of 4R Nitrogen Fertilization Practices in Response to Production System Uncertainties.....	10
CAN-4RC04 Can Foliar Urea Reduce Nitrogen Losses from Potato Production in Atlantic Canada? .....	10
CAN-4RC05 Nitrogen Stabilizers to Enhance Nitrogen Use Efficiency and Reduce Greenhouse Gas Emissions.....	11
CAN-4RC06 Coordinated Nitrogen and Sulfur Management in Sulfur Deficient Soils.....	11
CAN-4RC07 Effect of Broadcast Versus Banded Phosphorus Application on Fate of Applied Phosphorus in Soil and in Snowmelt Water Flow .....	12
CAN-4RC08 Enhanced Efficiency Fertilizer Technologies to Reduce Nitrous Oxide Emissions from Cropped Soils in Prairie Canada .....	12
CAN-4RC11 Impact of Degree of Fertilizer and Manure Incorporation and Timing of First Runoff Event on Phosphorus Losses to Surface Runoff .....	13
USA-4RN09 Evaluating the 4R Nutrient Stewardship Concept and Certification Program in the Western Lake Erie Basin .....	13
USA-4RN16 Impacts of 4R Nitrogen Management on Crop Production and Nitrate-Nitrogen Loss in Tile Drainage.....	14
USA-4RN26 Minimizing Phosphorus Loss with 4R Stewardship and Cover Crops.....	15
USA-4RN28 Relationships of Nitrous Oxide Emissions to Fertilizer Nitrogen Recovery Efficiencies in Rain-fed Corn Systems: Research Foundation Building.....	15
USA-4RN45 4R Fund Research Repository .....	16
USA-4RNF01 Nutri-Net: Coordinated Site Network for Studying the Impacts of 4R Nutrient Management on Crop Production and Nutrient Loss.....	16
USA-4RF02 Nutri-Net Iowa State University .....	17
USA-4RF03 Nutri-Net USDA-ARS Iowa .....	17
USA-4RF04 Nutri-Net University of Illinois - Pana (Dudley Smith Farm site) .....	17
USA-4RF05 Nutri-Net University of Illinois - Arcola.....	18
USA-4RF06 Nutri-Net Purdue University (site and repository).....	18
USA-4RF07 Nutri-Net University of Missouri.....	19
USA-4RF08 Nutri-Net University of Minnesota.....	19
USA-4RF09 Nutri-Net AAFC Ontario Canada site.....	19
USA-4RF10 Nutri-Net EDF - Synthesis .....	20
<b>Global Maize Projects.....</b>	<b>21</b>
BRA-GM18 Global Maize Project in Brazil: Itiquira, Mato Grosso .....	21
BRA-GM19 Global Maize Project in Brazil: Ponta Grossa, Paraná.....	21
CHN-GM20 Global Maize Project in China: Liufangzi, Gongzhuling, Jilin Province .....	22
CHN-GM21 Global Maize Project in China: Dahe, Shijiazhuang, Hebei Province.....	22
ARG-GM24 Global Maize Project in Argentina: Balcarce, Buenos Aires .....	23
ARG-GM25 Global Maize Project in Argentina: Oro Verde, Entre Ríos.....	23
ARG-GM27 Global Maize Project in the United States: West Lafayette, Indiana .....	23

RUS-GM41	Improvement of Maize and Soybean Mineral Nutrition on a Calcareous Common Chernozem, Russia.....	24
USA-GM45	Global Maize Project in the United States: Virginia.....	25
USA-GM51	Advancing Intensive Management of Corn Systems in Minnesota .....	25
USA-GM65	Advancing Intensive Management of Corn Systems in Minnesota (Irrigated) .....	25
<b>Special Projects.....</b>		<b>27</b>
GBL-10	HarvestZinc Fertilizer Project: Use of Zinc-Containing Fertilizers for Enriching Cereal Grains with Zinc and Improving Yield.....	27
GBL-64	4R Nitrogen Management Science Consensus to Modify Nitrous Oxide Estimation in the Field to Market Fieldprint Calculator.....	27
<b>Australia/New Zealand Program.....</b>		<b>29</b>
<b>Australia</b>		
AUS-16	Nutrient Balances for Australian Natural Resource Management Zones .....	29
AUS-020	Managing Micronutrient Deficiencies in Cropping Systems of Eastern Australia .....	29
AUS-022	Optimizing the Yield and Economic Potential of High Input Cropping Systems in the High Rainfall Zone....	29
AUS-023	Nutrient Performance Indicators for the Australian Grains Industry .....	30
AUS-024	Potassium Responses in Winter Crops and Pastures.....	30
<b>Brazil Program.....</b>		<b>33</b>
BRA-56	Rates and Residual Effect of Potassium Fertilization in a Brazilian Soil .....	33
BRA-61	Brazilian Soil Fertility Survey.....	33
BRA-63	Brazilian Nutrient Balance.....	34
BRA-70	Phosphorus Management in Farming Systems with Annual Crops .....	34
BRA-72	Nutrient Budget for Coffee Plantations in Brazil .....	35
BRA-73	Study of Doses of Potassium Fertilization in Soils in the State of Piauí.....	35
BRA-74	Biomass Production of Forage Grasses in Response to Nutrient Use in Brazil .....	35
<b>Latin America–Southern Cone Program.....</b>		<b>37</b>
<b>Argentina</b>		
ARG-12	Establishing a Plant Nutrition Network for the CREA Region in Southern Santa Fé .....	37
<b>Uruguay</b>		
URY-2	Exploration of Responses to Potassium in Western Uruguay.....	37
<b>Multi-Country</b>		
GBL-62	Breaking Soybean Yield Barriers: Integrating Crop Production Practices & Comprehensive Fertilization Strategies—A Cropping System Approach.....	38
<b>Mexico and Central America Program.....</b>		<b>41</b>
<b>Mexico</b>		
MEX-62	Maize Response to Potassium and Gypsum in Acid Soils of Chiapas, Mexico.....	41
<b>North America Program.....</b>		<b>43</b>
<b>Canada</b>		
CAN-AB35	Seed Row Tolerance of 16-20-0-13 and 12-40-0-6.5S-1Zn in Western Canada .....	43

CAN-AB37	Evaluation of Enhanced Nitrogen Use Efficiency Products .....	43
CAN-AB38	Update of Gray Wooded (Luvisolic) Soils Management Publication .....	44
CAN-AB39	Supplemental Magnesium on Soils that Grow Crops Low in Magnesium.....	44
CAN-ON13	Kenneth M Pretty Graduate Scholarship .....	44
CAN-ON29	Long-Term Optimum Nitrogen Rate for Corn Yield and Soil Organic Matter .....	45
CAN-SK43	Improving Phosphorus Efficiency in Crops Through the Management of Highly Effective Beneficial Soil Microorganisms .....	45
CAN-SK46	Seed Row Tolerance of 16-20-0-13 and 12-40-0-6.5S-1Zn in Western Canada .....	46
CAN-SK47	Developing Three Training Videos. Topic “Training Agriculture Retail Staff to Use 4R Nutrient Management with Farm Customers” .....	46

## United States

USA-IA9	Variability in Soil Test Potassium and Crop Yield .....	47
USA-GA26	Loblolly Pine Stand Fertilization at Mid-Rotation to Increase Small and Large Sawtimber Volume .....	47
USA-ID13	Measuring the Nutrient Accumulation Rates of High-Yielding Potatoes and Sugar Beets.....	48
USA-IA20	Improving the Reliability of Soil Potassium Testing and Recommendations .....	48
USA-KS23	Effect of Long-Term Nitrogen, Phosphorus and Potassium Fertilization of Irrigated Corn and Grain Sorghum .....	49
USA-KS43	Characterization of Nitrogen Fixation in US Soybean Systems.....	49
USA-MT19	Pushing the Limits of Fertilizer Nitrogen Recovery in a Semiarid Climate with Improved Nitrogen Management .....	50
USA-TN20	Documenting Nutrient Deficiency and Accumulation Rate in Vegetables.....	50
USA-MI14	Validating Weather and Sensor-based Nitrogen Prediction Models for Michigan Corn Production.....	51
USA-ID14	Documenting Nutrient Accumulation Rates in Four Barley Varieties .....	51
USA-101	Evaluation of Cotton Yield, Quality, and Plant Growth Response to Soil-Applied Potassium.....	52
USA-AZ10	Improving Nitrogen Fertilizer Management in Subsurface Drip-Irrigated Cotton.....	52
USA-KY13	Do Critical Soil Phosphorus Concentrations Vary in Space and If So, Why?.....	53
USA-OR17	Improving Nitrogen Fertilizer Management in Subsurface Drip-Irrigated Cotton.....	53

## China Program.....55

CHN-NESR	Field Validation of Nutrient Expert for Single Season Rice in China .....	55
CHN-NES	Field Validation of Nutrient Expert Soybean in China.....	55
CHN-NEER	Field Validation of Nutrient Expert for Early and Late Rice in China.....	56
CHN-NEMR	Field Validation of Nutrient Expert for Middle Season Rice in China.....	56
CHN-C14	Best Management Practice of Potassium for Sunflower in Northwest China .....	57
CHN-NM01	Effect of Different N Rates on Yield and Benefit of Edible Sunflower in Inner Mongolia .....	57
CHN-HB45	Better Nutrient Management Strategy for Rice-Wheat, Rice-Rapeseed and Rice-Rice Cropping Systems.....	58
CHN-SN01	Combination of Right K and P Source on Apple Fruit Yield and Economic Income in Shaanxi .....	58

## South Asia Program .....61

### India

IND-525	Evaluating Principles of 4R Nutrient Stewardship in the Rice-Maize-Green Gram Cropping System for Improved Productivity and Profitability of Farmers in Odisha .....	61
IND-526	Indigenous Nutrient Supplying Capacity of Vertisols under Cotton and Soybean.....	61
IND-528	On-Farm Precision Nutrient Prescription Under Predominant Cereal-Cereal Systems Using Nutrient Expert®.....	62
IND-531	Assessing the Indigenous Nutrient Supplying Capacity of Soils to Soybean in Vertisols of Northern Karnataka.....	62

IND-532	Agronomic, Economic, Social and Environmental Benefits of Improved Nutrient Management Practices in Maize Production Systems Under Variable Farm Size, Climate, Soil Fertility Conditions and Farmer Resource Endowment in Telangana, India .....	63
IND-533	Yield Maximization in Cotton through Targeted Yield Approach and Omission Plot Techniques in Vertisols of Karnataka .....	64
IND-536	Optimizing Nutrient use Efficiency under Zero Tillage Operations in Rice - Maize Cropping System in Coochbehar and Malda District of West Bengal .....	64
IND-538	Study of Variable Nutrient Responses in Soybean Grown at New Alluvial Soils of Bihar .....	64
IND-539	Nutrient Expert® Soybean Validation Trial at Red and Lateritic Soil of Jharkhand .....	65
IND-540	Ecological Intensification for Climate Resilient Maize Based Cropping Systems .....	65
IND-541	Bridging Yield Gap of Soybean through Site-Specific Nutrient Management .....	66
IND-542	Efficiency of Nitrogen Carriers in Calcareous Soil under Hybrid Rice-Wheat-Green gram Cropping System: a step towards Nutrient Expert® based 4R Stewardship plant nutrition approach .....	66
<b>Nepal</b>		
NPL-1	Transfer, Evaluation and Dissemination of an Innovative Fertilizer Management Tool (Nutrient Expert®) for Increasing Crop Yields and Farmers' Income in Eastern Nepal .....	67
<b>Southeast Asia Program .....</b>		<b>69</b>
<b>Indonesia</b>		
IDN-27	Cocoa Intensification in Indonesia - IPNI Cocoa Care Program .....	69
IDN-28	Estate-Scale Experiments (ESE) in Oil Palm: Supporting the Oil Palm and the Fertilizer Industry to Meet the Demands of Sustainable Intensification .....	69
IDN-29	The Role of Boron in Sustainable Intensification of Smallholder Cacao Systems in Sulawesi, Indonesia .....	70
SEAP-7	IPNI Southeast Asia's International Publication Partnership on Oil Palm Nutrition .....	70
SEAP-09	Publication Development and Knowledge Sharing .....	71
SEAP-00	Seed Project and Incubator Program .....	72
<b>Philippines</b>		
PHL-5	Sustainable Yield Intensification in Philippine Cassava Systems .....	72
PHL-6	Scaling of Maize Fertilizer Recommendations Philippines .....	73
<b>Myanmar</b>		
MMR-4	Myanmar 4R Nutrient Stewardship Program .....	74
<b>Vietnam</b>		
VNM-01	Improving Coffee Crop Nutrition in Vietnam .....	74
<b>Multi-Country</b>		
SEAP-4	Best Management Practice for Maximum Economic Yield in All Growth Stages of Oil Palm .....	74
SEAP-03	Oil Palm Training Program .....	75
GBL-52	Nutrient Expert Development and Assessment .....	75
GBL-53	Transferring Oil Palm Plantation Best Management Practices (BMP) from Southeast Asia to West Africa .....	76
<b>Sub-Saharan Africa Program .....</b>		<b>77</b>
<b>Ethiopia</b>		
ETH-1	Out-scaling 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification in Ethiopia .....	77
<b>Kenya</b>		
SSAP-2	Development and Dissemination of 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification in Western Kenya .....	77
<b>Multi-Country</b>		
SSAP-1	Strengthening the Capacity for Dissemination of Integrated Soil Fertility Management Technologies in East and Southern Africa .....	78

SSAP-03	Enhancing the Capacity for Dissemination of Site-Specific Maize Production Intensification Technologies under Variable Farm, Climatic and Soil Fertility Conditions in Kenya and Zimbabwe.....	79
SSAP-04	Taking Maize Agronomy to Scale in Africa (TAMASA).....	79
ZWE-1	Evaluating the Impact of Soil Fertility Heterogeneity on Maize Nutrient Requirement and Productivity in Smallholder Farming Systems .....	80

## **North Africa Program .....81**

### **Algeria**

DZA-1	Improving Nutrient Management Knowledge in Rain-fed Wheat Cropping Systems of Algeria .....	81
-------	---	----

### **Morocco**

MAR-1	Best Management Practice of Nutrient of Olive Orchards in Rainfed and Irrigated Areas of Morocco .....	81
MAR-2	Development and Dissemination of 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification .....	82
MAR-3	Towards Management of Fertilization to Control Wheat Crown Rot Caused by Fusarium culmorum .....	82

### **Senegal**

SEN-01	Assessment and Validation of Nutrient Expert® for Fertilization Recommendations of Maize in Senegal..	83
--------	---	----

### **Tunisia**

TUN-01	Optimizing the Fertilization of Olive Orchards in Tunisia.....	83
TUN-02	Optimizing Nutrient Management of Wheat in Tunisia.....	84

## **Middle East Program .....85**

### **Egypt**

EGY-1	Balanced Fertilization of Major Crops in Egypt .....	85
EGY-2	Balanced Fertilization of Egypt's Major Crops through Fertigation .....	85

### **Jordan**

JOR-1	Balanced Fertilization of Major Crops of Rain-fed Areas in Jordan .....	85
JOR-2	Fertigation of Major Crops of Irrigated Areas in Jordan.....	86

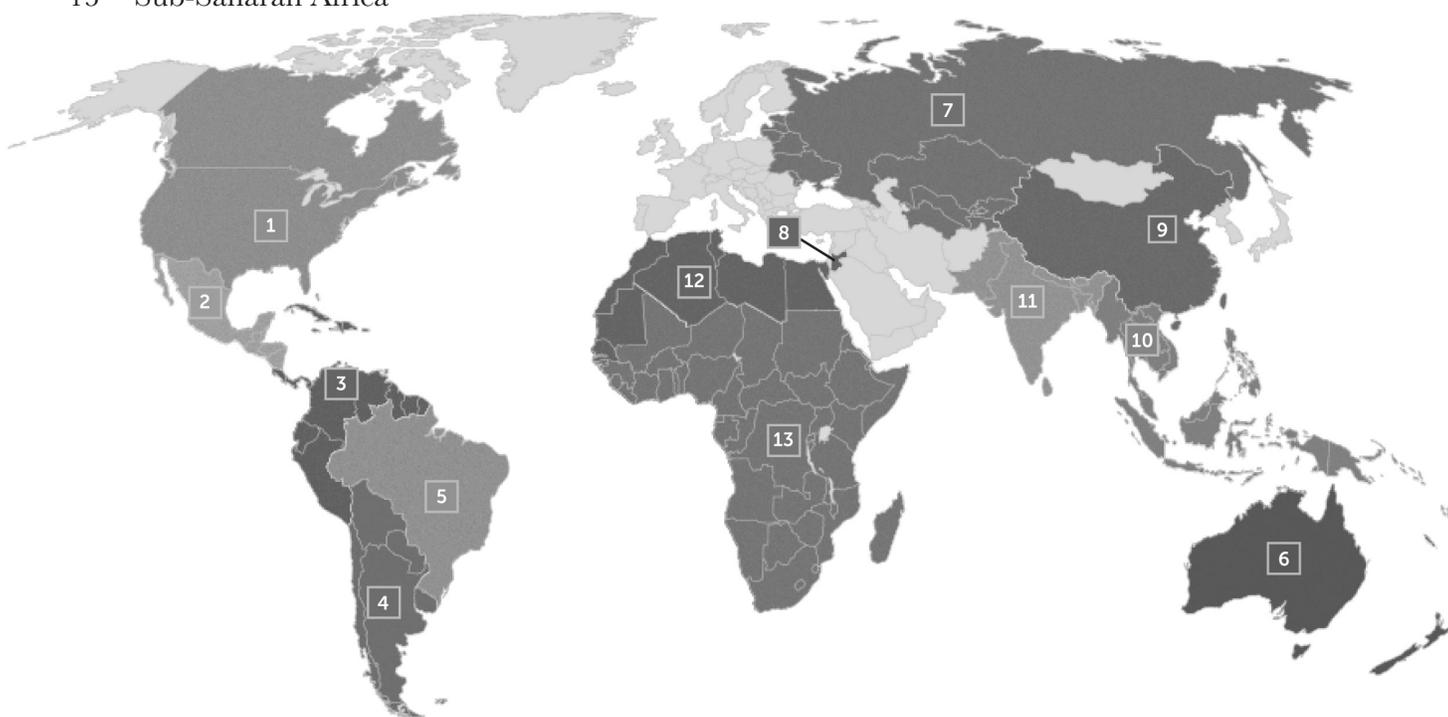
## **Russia Program .....87**

RUS-1	Improvement of Recommendations for Potash Fertilizer Use and Adjustment of Currently Used Soil Potassium Test Interpretation Classes in Intensive Cropping Systems .....	87
RUS-4	Fertigation of Field Vegetable Crops .....	87
RUS-5	Optimization of Spring Rapeseed Nutrition .....	88
RUS-6	Optimization of Winter Wheat Nutrition.....	88
RUS-8	Intensification of Forage Production in the Vologda Region.....	89
RUS-9	Improving N and S Fertilizer Management System under Crop Rotation.....	89



# IPNI Map Legend

- 1 North America
- 2 Mexico & Central America
- 3 Northern Latin America
- 4 Latin America-Southern Cone
- 5 Brazil
- 6 Australia & New Zealand
- 7 Eastern Europe & Central Asia
- 8 Middle East
- 9 China
- 10 Southeast Asia
- 11 South Asia
- 12 North Africa
- 13 Sub-Saharan Africa



## 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<sup>-</sup> = chloride; Cu = copper; Fe = iron; Mn = manganese; Mo = molybdenum; 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 (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.



# 4R Research Fund Projects

The 4R Research Fund was established by the fertilizer industry to help determine sustainability indicators and environmental impact data for implementation of 4R Nutrient Stewardship across North America. The fund provides needed resource support with a focus on measuring and documenting the economic, social, and environmental impacts of 4R Nutrient Stewardship.

## ***Improving Nitrogen Management Tools for Reduced Environmental Losses from Corn Production***

Project Leader: Claudia Wagner-Riddle, University of Guelph, School of Environmental Sciences, Guelph, ON, Canada. Email: cwagnerr@uoguelph.ca

Nitrogen (N) is a key input for sustaining high crop yields, but fertilizer N uptake efficiency in crops is relatively low. Part of the applied N that is not taken up by crops, is vulnerable to losses such as nitrate leaching and nitrous oxide emissions. The overall goal of this project is to determine how Right Time and Right Source practices for N fertilizer management affect N losses.

Nitrous oxide emissions were monitored continuously using micro meteorological towers, with 12 observations per day. Nitrate losses were assessed using soil solution samplers installed at a depth of 30 inches. Four plots, each ten acres in size, received four different N fertilizer treatments: two with urea applied pre-planting and two with urea-ammonium nitrate (UAN) applied as sidedress at the 6<sup>th</sup> leaf stage. At each timing, the fertilizer is applied with and without inhibitors of urease and nitrification.

Monitored over the 80 days following N fertilizer application, nitrous oxide emissions were reduced by about 40% in two out of three years in response to inhibitors applied with urea, and by about 50 to 60% in response to inhibitors applied with UAN. In one year of three, nitrous oxide emissions were reduced by 75% when UAN was applied with inhibitors in comparison to urea without. Nitrate leaching and corn yield differed little among treatments.

This experiment has shown a substantial and robust reduction in nitrous oxide emission in response to the use of urease and nitrification inhibitors. These results come at an opportune time to inform concurrent development of a certification program for 4R Nutrient Stewardship, supporting quantification of benefit to the environment. *IPNI-2014-CAN-4RC01*

## ***Improved Nitrogen Application Methods and Nitrogen Sources for Corn in Southwestern Ontario***

Project Leader: Craig Drury, Agriculture & Agri-Food Canada, Greenhouse & Proc. Crops Res. Centre, Harrow, ON, Canada. Email: druryc@agr.gc.ca

Corn producers often apply nitrogen (N) fertilizer by either streaming urea-ammonium nitrate (UAN) or broadcasting urea onto the soil. Producers are considering adding inhibitors to reduce losses of applied N. Compared to other N sources, urea and UAN fertilizers have higher risks of ammonia loss. As with other N sources, denitrification and nitrous oxide (N<sub>2</sub>O) losses can also be substantial. The objectives of this project are to measure the impact of these N sources, and their timing and placement, on corn yield, ammonia loss, and nitrous oxide emissions.

Phase 1 of this study compared N fertilizer treatments applied at sidedress in 2013 and 2014. The inhibitors and the band-injection treatments had large beneficial effects on reducing losses. Compared to broadcast urea, on average over the two years, injection of UAN with urease and nitrification inhibitors increased yields by 19% to 174 bu/A, while reducing loss of ammonia-N by 98% to less than 1 lb/A, and reducing N<sub>2</sub>O-N emission during the growing season by 30% to 1.5 lb/A.

Phase 2 of this study expanded the treatments to include the timing of N fertilizer application, during the period of 2015 to 2017. Averaged over the three years, injecting UAN at sidedress, in comparison to broadcast urea at planting, increased yield by 17% to 198 bu/A, reduced N<sub>2</sub>O-N emissions during the growing season by 36% to 1.2 lb/A, and reduced ammonia-N emissions by 80% to 4 lb/A. Additionally, the combined urease and nitrification inhibitors increased yields by 4%, reduced ammonia emissions by 49%, and reduced nitrous oxide emissions by 8%.

Crop N uptake data remain to be analyzed. The results from this project demonstrate that implementing the 4Rs (right source, rate, time, and place) for N management can dramatically improve sustainability of corn production in terms of productivity, profitability and environmental impact. *IPNI-2014-CAN-4RC02*

## **Optimization of 4R Nitrogen Fertilization Practices in Response to Production System Uncertainties**

Project Leader: Nicolas Tremblay, Agriculture and Agri-Food Canada, St-Jean, QC, Canada.

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Nitrogen (N) fertilization provides essential benefits for food production, but its optimal management is subject to a high level of complexity. The fertilizer industry, agronomists, consultants, and farmers recognize the 4Rs as the basis for optimum fertilization, but their implementation is knowledge-intensive and site-specific. For a full implementation of the 4R strategy for N, it is necessary to address the risks and opportunities at the field scale, with respect to weather and its interactions with soils and other management factors.

The goal of this project is to quantify the influence of soil and weather conditions (i.e., temperature, precipitation): 1) experienced prior to the growing season; 2) from sowing to topdressing application (if applicable); and 3) after the last N application on the potential for crop yield response and N losses. For this matter, it will be necessary to study the accuracy of site-specific weather forecasts and the opportunity for their inclusion in a probabilistic strategy to optimize N use efficiency, while safeguarding crop yield potential, and to explore system sensitivity to possible interactions with other soil amendments, cultivar specification, tillage systems, and different influential management-induced factors.

In 2015, a decision-support tool called webSCAN was developed based on a dataset of 322 site-years of corn N response data from Ontario and Quebec. The webSCAN tool adjusts N rates for rainfall prior to and around sidedress application time. This tool, combining the “right time” and “right rate” approaches was found to enhance profitability of N use on corn. Work in 2016 expanded the crop response database to include 302 site-years for potatoes.

In 2017, the decision-support tool was implemented online at [www.numericag.com](http://www.numericag.com). As detailed in a paper submitted for the 14<sup>th</sup> International Conference on Precision Agriculture to be held June 24-26, 2018 in Montreal, Canada, NumericAg enables the determination of the optimum average application rate that maximizes expected profits for farm specific conditions including soil texture, weather, and price variability. The current version is illustrated using nutrient application with only one crop and only one fertilizer. The tool is evolving with ongoing advancements and will help farmers and crop advisers not only to select the most profitable application rate, but also to manage risks associated with over and under application.

*IPNI-2014-CAN-4RC03*

## **Can Foliar Urea Reduce Nitrogen Losses from Potato Production in Atlantic Canada?**

Project Leader: David Burton, Dalhousie University, Dept. of Environmental Sciences, Truro, NS, Canada.

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In recent years it has become increasingly popular for potato producers in Atlantic Canada to include urea in the foliar applications of fungicides. This project examined the potential to reduce the amount of nitrogen (N) fertilizer added at planting in situations where foliar urea will be applied to the crop. The project evaluated whether using in-season foliar urea in combination with reduced N fertilizer rates at planting is an effective practice for sustaining potato yields, improving N use efficiency, and reducing nitrous oxide emissions and nitrate leaching.

An experiment at the research station in Harrington, Prince Edward Island, was conducted from 2013 through 2016. The treatments included five rates of N fertilizer application at planting (0, 120, 150, 180, 240 kg N/ha), as well as two treatments with 30 kg N/ha of foliar-applied urea with potatoes fertilized at planting with 120 and 150 kg N/ha. In 2015 and 2016, an additional fertilizer treatment was added with foliar urea to potatoes at planting with 60 kg N/ha. Marketable yield, growing season nitrous oxide emissions, soil nitrate concentration, and nitrate flux (ion exchange membranes) were measured during the growing season. Monitoring of nitrous oxide emissions, from field-scale side-by-side demonstration plots comparing 4R and grower practices in 2015 and 2016, revealed high variability with an inconsistent impact of 4R practices.

Over the four years of the research station study, there was no yield benefit to N application rates higher than 120 kg/ha and application of foliar urea did not further increase yields. Nitrous oxide emissions were much higher in 2014 than in the other three years. In 2014, fertilizer-induced emissions of nitrous oxide averaged 1.7% of the N applied. The N fertilizer treatments (other than the check) did not differ in nitrous oxide emissions. Use of ion exchange membranes (IEMS), as soil test probes for nitrate, explained about 60% of the variation in nitrous oxide emissions. Therefore, the use of IEMs might serve as a useful proxy metric for nitrous oxide emission, in addition to a management guide of N application.

This study has now completed. The finding regarding ion exchange membranes contributed toward development of a potential metric for nitrous oxide emissions to be used within a 4R Nutrient Stewardship system. *IPNI-2014-CAN-4RC04*

### ***Nitrogen Stabilizers to Enhance Nitrogen Use Efficiency and Reduce Greenhouse Gas Emissions***

Project Leader: Miles Dyck, University of Alberta, Dept. of Renewable Resources, Edmonton, AB, Canada.  
Email: milesdyck@ualberta.ca

The main objective of this project is to assess the effect of various commercially available forms of stabilized nitrogen (N) on nitrous oxide ( $N_2O$ ) emissions, nitrate leaching, nutrient use efficiency (NUE), and crop yield response in cereal and oilseed crops. The experiment used a factorial set of 4R-based treatments involving the form, rate, timing, and placement of N fertilizers. Nitrogen forms included untreated urea, urea treated with both a nitrification and urease inhibitor (Super U<sup>®</sup>), urea treated with a nitrification inhibitor only (eNtrench<sup>®</sup>), and a polymer-coated controlled-release urea (ESN<sup>®</sup>). Nitrogen application rates included 0, 50, 100, and 150% of the local recommended fertilization rates for wheat, specifically 0, 40, 80, and 120 kg N/ha. Timing of N application included fall banded, and pre-plant spring banded. Identical experiments were conducted at two sites, differing in geography and climate (Elderslie research farm near Edmonton, Alberta on a Black soil; and the Lethbridge Research Station, near Lethbridge, Alberta, on a Dark Brown soil).

There was a significant effect of year and crop on  $N_2O$  emissions, and spring fluxes dominated total growing season  $N_2O$  emissions. The Lethbridge site also included split application treatments of N fertilizer for both canola and wheat. The rates of total N applied were 0, 30, 60, 90, and 120 kg N/ha. The in-season fertigation applied 30 kg N/ha using urea ammonium nitrate (UAN), and this was part of the total N applied. For example, the 60 kg N/ha rate had 30 kg N/ha applied as urea in a pre-plant operation, and the remaining 30 kg N/ha applied using fertigation-applied UAN. The results analyzed from the 2015 and 2016 years indicate that the split fertigation treatments have lower cumulative  $N_2O$  emissions compared to all N fertilizer being applied before planting. The 2017 samples taken for  $N_2O$  emissions have all been measured and the data is being analyzed to compare the various experimental treatments. A final report will be completed in 2018. *IPNI-2014-CAN-4RC05*

### ***Coordinated Nitrogen and Sulfur Management in Sulfur-Deficient Soils***

Project Leader: Miles Dyck, University of Alberta, Dept. of Renewable Resources, Edmonton, AB, Canada.  
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Approximately, 60% of the current increase in atmospheric nitrous oxide ( $N_2O$ ) emanates from agricultural soils. There is evidence that  $N_2O$  emissions increase in direct proportion to the sum of fertilizer and non-fertilizer nitrogen (N) inputs in agricultural and non-agricultural ecosystems, but other factors such as soil moisture and temperature, fertilizer N type/placement, accompanying phosphorus (P), potassium (K), and sulfur (S) fertilizer applications, crop type/rotation, inclusion of legumes, lime applications, microbial community diversity, and tillage all contribute to the variability of  $N_2O$  emissions. It has been shown that long-term N plus S fertilization increased soil organic matter content, compared to N fertilization without additional S fertilization in the S-deficient soils at the Breton Plots in west-central Alberta. There are few examples of long-term management effects or management legacy effect on current annual or growing season  $N_2O$  emissions.

A field study has been conducted over five growing seasons (2013 to 2017) in order to evaluate the effect of long-term fertilization history and crop rotation on cumulative growing season  $N_2O$  and carbon dioxide ( $CO_2$ ) emissions (measured semi-weekly), wheat yield, wheat N uptake, soil properties, and  $N_2O$  emission intensity (kg  $N_2O$ /kg wheat N uptake or kg  $N_2O$ /kg wheat grain) in Gray Luvisolic soils at the Breton Classical Plots, Breton, Alberta, Canada. Fertility treatments included a check (no fertilizer) and manure amendments compared to inorganic fertilizer applications of NPKS, NPK, PKS in two contrasting crop rotations: 2-years of wheat-fallow (WF) and 5 years of wheat-oat-barley-alfalfa/brome hay (WOBHH). The greater long-term N inputs in the fertility treatments of the WOBHH rotation since the plots were established, was reflected in significantly greater total soil N in the top 15 cm compared to the WF rotation. Rotation was a significant factor affecting cumulative growing season  $N_2O$  emissions and, within each rotation, long-term additions of fertilizer or manure N increased  $N_2O$  emissions compared to the check treatment. When averaged across fertility treatments, cumulative growing season  $N_2O$  emissions from the 5-year rotation were 1.29 kg  $N_2O$ -N/ha, significantly higher than the 0.58 kg  $N_2O$ -N/ha in the WF rotation, but  $N_2O$  emission intensities were

comparable between the two rotations. Cumulative  $N_2O$  emissions were positively correlated to the total soil N (0 to 15 cm) and wheat N uptake, but  $N_2O$  emission intensities were negatively correlated to total soil N.

The results suggest that long-term crop rotation and balanced soil fertility treatments including N, P, K, and S increase yield and crop N uptake, and reduce the growing season  $N_2O$  emission intensity, or the volume of  $N_2O$  produced per unit of crop yield. The main conclusions are that long-term N balance drives productivity and  $N_2O$  emissions, with variability affected by different growing season weather conditions. Also, N balances are driven by rotation and fertilization, and all forms of soil N contribute to  $N_2O$  emissions. *IPNI-2014-CAN-4RC06*

### ***Effect of Broadcast Versus Banded Phosphorus Application on Fate of Applied Phosphorus in Soil and in Snowmelt Water Flow***

Project Leader: Jeff Schoenau, University of Saskatchewan, Dept. of Soil Science, Saskatoon, SK, Canada.  
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Phosphorus (P) moves very slowly in the soil and is often called immobile. In soils that are deficient in P, it is important to place the P so that the roots of the crops grow into the area where the P fertilizer is placed. The objective of this study is to compare various P fertilizer placement methods in relation to the seed row. These treatments included pre-plant banding below the seed row, seed row placement during the planting operation, pre-plant broadcast and incorporation, and pre-plant broadcast without incorporation. The study was conducted in the field for three years, specifically soybean in 2014, wheat in 2015, and canola in 2016. In 2017 further laboratory analyses have been conducted to improve the understanding of the fate of applied P in the fertilizer treatments. There were seven P treatments including a zero-P control, with the four placement methods described above, all at 20 kg  $P_2O_5$ /ha, and then two more broadcast-without-incorporation treatments at rates of 40 and 80 kg/ha. All treatments were replicated four times for a total of 28 plots, using a randomized complete block design.

Measurements have been completed on plant and soil samples taken during the three years of field research. These measurements included: grain and straw yield, P uptake and removal, post-harvest soil and residue P amounts, forms, and distribution [extraction, PRS, sequential, x-ray absorption near edge structure (XANES), P-31 nuclear magnetic resonance (NMR) spectroscopy identification of soil P forms, and run-off water P forms and amounts - chemical speciation and P-31 NMR]. The work conducted to date in this project supports the implementation of several agricultural methods that fit within the 4R Nutrient Stewardship framework, specifically regarding the right place and the right rate of fertilizer application. The findings so far suggest that in-soil placement of fertilizer P, especially in a band, may be considered as an effective method to achieve the greatest yield response, as well as limit the potential off-site transport of applied P. In general, placement of fertilizer P in a band below the seed row caused a greater proportion of applied P to be absorbed into the plant as available inorganic orthophosphate. These findings are in line with our previous results that band placement resulted in greater uptake and recovery of applied fertilizer P. Ongoing work will further evaluate the effectiveness of the P speciation techniques to reveal the nature of P residual in the soils and in the runoff water. A final report from this project will be added to the IPNI Research Database when completed.  
*IPNI-2014-CAN-4RC07*

### ***Enhanced Efficiency Fertilizer Technologies to Reduce Nitrous Oxide Emissions from Cropped Soils in Prairie Canada***

Project Leader: Mario Tenuta, University of Manitoba, Dept. of Soil Sciences, Winnipeg, MB, Canada.  
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This Prairie Province-wide project seeks to assess the environmental and agronomic benefits achieved through grower adoption of enhanced efficiency nitrogen (N) fertilizer technologies, applied in the fall or spring. The application of N fertilizers to agricultural land, and resulting emissions of nitrous oxide ( $N_2O$ ), have been identified as a major driver impeding greenhouse gas reductions for the agriculture sector. It is important to develop methods to reduce  $N_2O$  emissions from cropped land after N fertilizer applications. This project is evaluating the benefit of timing N fertilizer application (fall vs. spring), and the use of enhanced-efficiency products (EEF) for urea and anhydrous ammonia N fertilizers for reduced  $N_2O$  emissions. In 2015, two sites were successfully conducted comparing fall and spring N treatments for spring wheat. Nitrous oxide emissions were monitored through the growing season and into fall. Soil sampling, as well as moisture and temperature monitoring were also completed regularly and grain yield was determined.

Grain yields were greater with spring compared to fall applications using urea and anhydrous ammonia fertilizers. However, some EEF treatments did result in yields from fall applications being equal to that of spring applications. This research was expanded for the 2016 and 2017 crop years after receiving funding from

the Climate Change and Emissions Management Corporation (CCEMC), and the Western Grains Research Foundation (WGRF). This includes one site in Alberta and two sites in Saskatchewan, as well as the two original sites in Manitoba. The research sites have been used each year for outreach (tours) to growers, consultants, ag-retailers, funders and stakeholder events. Several presentations have occurred at multiple conferences and grower meetings. Analyses of N<sub>2</sub>O emissions have been completed for the first two crop years of the study in Manitoba, Saskatchewan and Alberta. Statistical analyses for crop yields and N<sub>2</sub>O emissions are on-going for the 2017 crop year. The amount and timing of precipitation events greatly interacted with the N fertilizer forms, rates, timing, and placement. The crop years of 2015 and 2016 had similar patterns where two EEF products containing nitrification inhibitors (eNtrench<sup>®</sup>-treated urea and Super U) had lower cumulative N<sub>2</sub>O emissions compared to regular urea, anhydrous ammonia, urea treated with urease inhibitor (Limus<sup>®</sup>), and nitrapyrin-treated anhydrous ammonia. At the Manitoba sites, the 2017 crop year experienced a wet fall followed by a dry spring. There were much greater cumulative N<sub>2</sub>O emissions from the fall applications compared to spring applications. Research samples from all the sites in 2017 are still being analyzed and will be included in a final report later in 2018. *IPNI-2014-CAN-4RC08*

### ***Impact of Degree of Fertilizer and Manure Incorporation and Timing of First Runoff Event on Phosphorus Losses to Surface Runoff***

Project Leader: Ivan O'Halloran, University of Guelph, Ridgetown, ON, Canada. Email: [iohallor@uoguelph.ca](mailto:iohallor@uoguelph.ca)

Recent observations in the Great Lakes watershed suggest that losses of dissolved forms of phosphorus (P) from agricultural land are increasing. Combined trends in tillage practices, along with timing and placement of fertilizer and manure, may drive this increase in loss of soluble P. This project aims to assess the effect of timing and placement on losses of dissolved and particulate forms of P. The project has three major objectives: 1) controlled runoff studies assessing fertilizer and manure P placement/incorporation; 2) controlled runoff studies assessing commercial fertilizer placement and timing to first runoff event; and 3) a field study relating runoff and incorporation methods on P losses from fertilizer and manure.

For the first objective, three soils (of clay, silt loam, and sandy loam texture class) were placed in controlled environment runoff boxes (40-inches long, 8-inches wide and 4-inches deep). Treatments compared surface broadcast, incorporation, surface band, and subsurface band application methods. The three P sources were monoammonium phosphate fertilizer, solid cattle manure, and liquid dairy manure, each applied at a rate to match two years of crop removal from a typical corn-soybean rotation. Artificial rainfall, representing a storm of 1 in 10 years frequency, was applied 7 days after P application, and again 7 days after the first runoff event.

Losses of dissolved P were dramatically reduced in all three soils when fertilizer or manure was either subsurface banded or incorporated, as compared to being left on the soil surface. The results confirm that subsurface placement can reduce concentrations of dissolved P in runoff water several folds to levels that are close to targets set for the mitigation of harmful algal blooms in Lake Erie. Further analysis is continuing on a study assessing timing of application of monoammonium phosphate or ammonium polyphosphate in relation to wetting and drying events. In addition, a field study assessing the impact of fertilizer placement on runoff losses from fall to spring is still underway. Results are expected to inform the development of a risk assessment tool for P loss that is needed for implementation of 4R Nutrient Stewardship, one of the key strategies listed in the February 2018 Canada-Ontario Lake Erie Action Plan. *IPNI-2015-CAN-4RC11*

### ***Evaluating the 4R Nutrient Stewardship Concept and Certification Program in the Western Lake Erie Basin***

Project Leader: Kevin King, USDA-ARS, Soil Drainage Research Unit, Columbus, OH, USA.  
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The increase in harmful algal blooms in Lake Erie since the mid-1990s is correlated with an increasing trend in dissolved phosphate loading. This multi-disciplinary research project, initiated in July 2014 with an end date of June 2019, aims to quantify the water quality benefits of 4R initiatives in the Western Lake Erie Basin (WLEB). As of January 2018, 37 retail locations reaching almost two million acres, had achieved certification in 4R Nutrient Stewardship. There remains a need to better understand and quantify the water quality benefits of the 4R program.

The 2017 efforts of this project included five objectives:

(1) Edge-of-field (EOF) monitoring: Water quality data was collected from 20 paired sites comparing 4R and other crop and soil management practices. Collaborators prepared over 40 presentations summarizing

EOF data. Several peer-reviewed articles indicated that shifting from broadcast to subsurface placement of phosphorus (P) fertilizer (“right place”) will limit stratification and has potential to limit dissolved P leaching in tile-drained landscapes.

(2) Watershed monitoring: Preliminary analysis comparing 4R certification to corresponding watershed nutrient export data was initiated. Monitoring data was summarized in over 25 presentations.

(3) Watershed modeling: The SWAT model was expanded to include nine paired sites (18 fields). An additional suite of BMP scenarios with a 4R focus (specifically placement and timing) were integrated into the model.

(4) Lake ecosystem modeling: A sensitivity analysis was conducted using the Western Lake Erie Ecosystem Model to explore the impact of algal growth and sediment-related parameters on predicted cyanobacteria biomass.

(5) Socio-economic surveys: Survey results were published in a technical report titled “*4R Nutrient Stewardship in the Western Lake Erie Basin*.” A producer survey was sent out to assess knowledge and adoption of 4R practices. A video was produced highlighting the 4R initiative and promoting the benefits of subsurface placement. *IPNI-2014-USA-4RN09*

### **Impacts of 4R Nitrogen Management on Crop Production and Nitrate-Nitrogen Loss in Tile Drainage**

Project Leader: Matthew Helmers, Iowa State University, Ames, IA, USA. Email: mhelmers@iastate.edu

Project Cooperator: John Sawyer

This three-year study near Sutherland, Iowa, began in January 2015 to evaluate three nitrogen (N) management practices on corn applied at 135 lb N/A (150 kg N/ha), and a no N control: 1) fall-applied anhydrous ammonia with nitrification inhibitor (Nitrapyrin); 2) spring-applied anhydrous ammonia (no inhibitor); and 3) split with 40 lb urea N/A (45 kg/ha) added at planting plus variable N at sidedress added as urease inhibitor-treated urea (Agrotain®). Each treatment is replicated four times within a corn-soybean rotation, with each phase of the rotation present each year. The objectives are to: 1) determine the effects of N fertilizer application timing on nitrate leaching losses through water flowing in tile drains; 2) determine the effects of N fertilizer application timing on crop yield; and 3) disseminate project findings to scientific and farmer groups.

In 2017, corn yield increased by more than 75 bu/A with treatments 1 and 2 compared to the unfertilized control. In 2017 there was a lower corn yield with the split N application compared to fall and spring ammonia timing; likely due to the limited precipitation after the sidedress N application and dry summer conditions which limited N movement into the corn root zone. Soybean yields in 2017 were greater than 60 bu/A. Soybean yield differences following the previous corn N treatments occurred in 2017, but were inconsistent and not explainable by corn N fertilizer treatment.

For the corn phase, there was no significant difference in the nitrate concentration of water draining from the N-fertilized or the non-fertilized plots.

For the soybean phase, the treatment where no N was applied to the previous 2016 corn crop had a statistically significant lower nitrate concentration than the treatment that received N fertilizer immediately prior to planting in 2016.

For both corn and soybean phases, the nitrate concentration was the same for the control and the split N application in 2017. Of note is that the quantity of drainage was much lower than in previous years, with average drainage of about 3.5 inches compared to 10 inches in 2015 and 17 inches in 2016.

Overall, the total phosphorus (TP) and total reactive phosphorus (TRP) concentrations in the tile flow are small, and there were no statistically significant differences in TP or TRP concentrations between treatments. Based on comparing concentrations of TP and TRP, it is evident most of the TP is in the TRP form.

*IPNI-2014-USA-4RN16*

## **Minimizing Phosphorus Loss with 4R Stewardship and Cover Crops**

Project Leader: Nathan Nelson, Kansas State University, Manhattan, KS, USA. Email: nonelson@ksu.edu

Project Cooperator: Kraig Roozeboom

The objectives of this research are to determine how interactions between cover crops and phosphorus (P) fertilizer management impact P loss, P use efficiency, crop yield, and net return. A watershed study at the Kansas Agricultural Watershed Field Laboratory (near Manhattan) has been established to address these objectives. The study consists of 18 small (1.2 to 1.5 acre) watersheds equipped with automated runoff monitoring equipment. Treatments for the study (replicated 3 times) include: 1) no P fertilizer and no cover crop; 2) no P fertilizer, with cover crop; 3) fall-broadcast P and no cover crop; 4) fall broadcast P, with cover crop; 5) spring injected P and no cover crop; and 6) spring injected P, with cover crop. The site has a history of a conventionally tilled wheat-soybean rotation, but for this study a no-till corn-soybean rotation was adopted in 2015.

Results from the third year of the study, which was the second year of no-till, were consistent with results from the prior two (2015 and 2016) years. Cover crops decreased sediment loss by 70% and also decreased particulate P loss by 40%. Although cover crops were effective at reducing sediment and particulate P loss, dissolved P loss increased. Sub-surface application of P fertilizer decreased total P loss by about 30% and dissolved P loss by about 40%. Relative to a fall broadcast application, sub-surface P application tended to maintain lower total P and dissolved P losses during the March and April runoff events which were prior to corn planting. Averaged across all cover crop treatments, fall broadcast and spring injected P fertilizer increased corn yield by 18%, from 95 to 112 bu/A. The use of a cover crop decreased corn yield by 26%, from 122 bu/A without cover crop to 90 bu/A with cover crop.

Copies of presentations are available on the project web site at <http://www.ksu.edu/kaw>. This study will continue in 2018 with no-till soybean as the primary grain crop. The fifth and final year of the study will begin following soybean harvest when cover crops will be direct seeded into soybean residue. *IPNI-2014-USA-4RN26*

## **Relationships of Nitrous Oxide Emissions to Fertilizer Nitrogen Recovery Efficiencies in Rain-fed Corn Systems: Research Foundation Building**

Project Leader: Tony Vyn, Purdue University, West Lafayette, IN, USA. Email: tvyn@purdue.edu

Little is known about relationships between nitrous oxide loss and crop nitrogen (N) use efficiency metrics despite years of past research. It is commonly assumed that higher fertilizer N recovery will lead to lower nitrous oxide emissions. However, few studies have assessed the hypothesis that greater plant uptake of N or higher recovery efficiency will actually reduce nitrous oxide emissions during crop production.

A two-year study suggested that a functional, negative linear relationship existed between nitrous oxide emission and recovery efficiency for Indiana high-yielding corn production under a wide range of N management and tillage systems. Nitrogen fertilizer management contrasts involved altering rates, timing, and presence of nitrification inhibitors, while corn management contrasts involved multiple tillage systems and two plant densities. The majority of the data supported the hypothesis that nitrous oxide emissions decrease with increased N recovery efficiency following optimized N fertilizer applications to corn. Models showed that cumulative nitrous oxide losses during the growing season were reduced by up to 35 g N/ha for every one percent increase of recovery efficiency by corn in that season. However, both the slope and strength of the relationships varied significantly due to: 1) year-to-year variability of nitrous oxide emission and N recovery efficiency; 2) insufficient data points employed in the models; and 3) perhaps because the relative timings of peak emissions and peak corn plant N uptake did not coincide sufficiently (even with sidedress N timing). This research has made a strong contribution to the understanding of nitrous oxide relationships with N fertilizer efficiencies in a rain-fed production environment.

A companion study was published in 2017, which synthesized these relationships across North America's maize production systems. This synthesis indicated that the appropriate N rate applied at the right time can increase recovery efficiency and reduce nitrous oxide losses, particularly in management systems that increased grain N or plant N uptake relative to the amount of total fertilizer applied to maize.

*IPNI-2015-USA-4RN28*

## **4R Fund Research Repository**

Project Leader: Sylvie Brouder, Purdue University, West Lafayette, IN, USA. Email: sbrouder@purdue.edu

Project Cooperator: Jeff Volenec

The objectives of this project are to develop: 1) a data repository for projects funded under the 4R Fund; 2) data preprocessing protocols for repository ingestion; 3) best practices toolkits; and 4) data/metadata standards for agronomic researchers.

The 4R Research Repository team at Purdue University has accomplished the following to date:

- Objective 1 was accomplished by opening up the use of the Purdue University Research Repository (<https://purr.purdue.edu>) to research projects outside of those conducted by Purdue University.
- Objective 2 is being accomplished through an iterative process of examining a submitted data set, using expert knowledge to develop a data quality checklist for that data set, testing the completeness of that checklist with a new data set, making needed revisions, and so on. Currently, data sets from eight projects are in review.
- Objective 3 has been accomplished in part with the development of a data template that researchers can use at their discretion.
- Objective 4 has been started with the on-going development of a data dictionary. Definitions of various terms are first sought from the Library of Congress and, when none exist, other definitions are incorporated from authoritative sources.

Work for this project is ongoing and will be extended into 2018. *IPNI-2015-USA-4RN45*

## **Nutri-Net: Coordinated Site Network for Studying the Impacts of 4R Nutrient Management on Crop Production and Nutrient Loss**

Project Leader: Matt Helmers, Iowa State University, Agricultural and Biosystems Engineering Ames, IA, USA.  
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Project Cooperators: Sylvie Brouder, Laura Christianson, Cameron Pittelkow, Kelly Nelson, Dan Jaynes, John Kovar, Lowell Gentry, Craig Drury, Fabian Fernandez, Alison Eagle, and Jeffrey Volenec

Currently, there is a lack of research data linking agronomic and environmental performance across a wide variety of management conditions, leading to uncertainty regarding the full efficacy of 4R practices. Although there has been a concerted effort to promote 4R nutrient management strategies for using commercial fertilizer and organic materials, our ability to quantify and track the impacts of 4R management on crop yield, phosphorus (P) and nitrate loss to water, nitrogen (N) loss to the atmosphere, and changes in soil health under a range of practices needs further improvement.

The objective of this research is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous N loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario. Although sites will focus on N management, the consistent comparison across all sites will include partial nutrient balances for N, P, and K. All field sites are capable of capturing nutrient leaching losses in subsurface tile drains. Locally relevant and current nutrient management practices will be compared to the more advanced 4R management systems. In addition, several sites will investigate specific 4R variations including timing of N application and N placement by side-dress application.

The novelty of this network approach is that existing investment in agronomic/drainage research sites across the corn-belt can be leveraged to answer additional questions about the effectiveness of 4R practices. Data generated in this three-year project will be combined into a centralized database. Future studies on N management will allow for continued improvement of knowledge that supports management and policy recommendations. This effort will extend to help answer key questions about the impacts of nutrient management in corn-based cropping systems on water quality in the Mississippi River basin and eutrophication in the Gulf of Mexico. *IPNI-2017-USA-4RF01*

### **Nutri-Net Iowa State University**

Project Leader: Matt Helmers, Iowa State University, Agricultural and Biological Engineering, Ames, IA, USA. Email: mhelmeh@iastate.edu

This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

Research at the Sutherland, Iowa site began in January 2015 as part of a five-year study. The project is evaluating three N management practices in corn at 135 lbs of N/A, and a no N control: 1) fall anhydrous ammonia with nitrification inhibitor (nitrapyrin); 2) spring anhydrous ammonia (no inhibitor); and 3) split with starter and variable N at sidedress (40 lb of N/A of urea starter at planting plus in-season urease-inhibitor-treated urea). Each treatment is replicated four times within a corn-soybean rotation, with each phase of the rotation present each year. The objectives are to determine the effects of N fertilizer application timing on: 1) nitrate-N leaching losses through tile flow in each crop phase; 2) determine the effects of N fertilizer application timing on crop yields; and 3) disseminate project findings. Crop sensing, stalk nitrate, grain N, and soil nitrate-N data has also been collected and will continue to be throughout the project.

*IPNI-2017-USA-4RF02*

### **Nutri-Net USDA-ARS Iowa**

Project Leaders: Dan Jaynes, National Laboratory for Agriculture and the Environment, USDA-ARS, Ames, IA, USA. John Kovar, USDA-ARS, Ames, IA, USA. Email: john.kovar@ars.usda.gov

This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

This Iowa site study compares soil and crop nutrient cycling and losses in alternative production systems to a conventional corn-soybean rotation. The alternate systems include cover crops and relay cropping within a corn-soybean system. The study objectives are to quantify: 1) the impacts of 4R nutrient management on crop yield; 2) availability and cycling in the soil of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S); 3) losses via drainage water of ammonium, nitrate, P, K, and S; 4) N losses to the atmosphere; and 5) changes in soil health. These variables will be measured at the same site location under a range of crop management practices.

All treatments are for a two-year rotation of corn and soybean except where noted. The practices include a zero-N check treatment, a *4R Basic* treatment that is currently being used by many Iowa farmers (fall tillage after corn, spring tillage and pre-plant N application), a *4R Advanced* practice that includes no-till and side dressing N as informed by soil sampling, a *4R Aspirational* treatment that includes no-till, side-dressing N, and fall cover crops, and a *Long term Agroecosystems Research Aspirational* treatment that will include the relay crop Camelina planted in the fall after corn and followed by soybean after harvest (two-year rotation).

*IPNI-2017-USA-4RF03*

### **Nutri-Net University of Illinois - Pana (Dudley Smith Farm site)**

Project Leaders: Laura Christianson, University of Illinois, Crop Sciences, Urbana, IL, USA. Email: lechris@illinois.edu; Cameron Pittelkow, University of Illinois, Crop Sciences, Urbana, IL, USA. Email: cmpitt@illinois.edu

This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

The overall goal for the University of Illinois Dudley Smith Research Farm is to develop balanced strategies for achieving water quality, N management, and corn productivity goals in Illinois. The objectives are to evaluate the effects of recommended water quality practices (e.g., the 4R approach to nutrient management, winter cover crops, and woodchip bioreactors) on tile drainage nutrient losses, nutrient use efficiency, and crop yields. Monitoring will assess if synergies are occurring among in-field and edge-of-field practices, while also accounting for potential tradeoffs which may include increased soil nitrous oxide emissions or losses of dissolved phosphorus in tile drainage water. To test these objectives, sixteen individually drained

(hydrologically isolated) two-acre plots have been divided into four blocks with the following treatments (4 replications per treatment):

1. Control: 0 lb N/A application rate
2. Conventional: 120 lb N/A applied in the fall using anhydrous ammonia, plus 80 lb N/A applied in the spring as pre-plant using urea ammonium nitrate (200 lb N/A total application rate)
3. 4R Management: 80 lb N/A applied in the spring as pre-plant using urea ammonium nitrate, plus 120 lb N/A applied as side-dress using urea ammonium nitrate (200 lb N/A total application rate)
4. 4R Management + Winter Cover Crop: Same N management as the “4R” treatment above, plus a cereal rye cover crop planted after corn harvest and terminated around two weeks before corn planting.

*IPNI-2017-USA-4RF04*

### **Nutri-Net University of Illinois - Arcola**

Project Leader: Lowell Gentry, University of Illinois, Natural Resources and Environmental Sciences, Urbana, IL, USA.  
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This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

This site in Arcola, Illinois is evaluating the 4Rs of nutrient stewardship and includes a cover crop treatment. The site already contains three years of crop and tile drain water quality monitoring. The overall goal is to identify N fertilizer management systems that limit nitrate loss to tile drains, but promote increased crop yields in a corn and soybean rotation. The research aims to determine when and why tile nitrate losses occur in these systems, during both corn and soybean phases of the two-year crop rotation. The site was established in 2015 with six treatments, each with three replicates in a randomized complete block design. Each year simultaneous monitoring of 36 parallel tile lines occurs during both phases of the rotation. Tiles are 100-feet apart and the average tile length is approximately 1,800 feet for an average plot size of 4.2 acres.

Treatments include:

1. Full rate of anhydrous ammonia (NH<sub>3</sub>) (160 lb N/A) applied in the fall after November 1 with nitrapyrin 80 lb N applied as NH<sub>3</sub> in the fall with nitrapyrin, followed by 40 lb N/A as urea ammonia nitrate (UAN) at planting, followed by 40 lb N/A side-dressed as UAN
2. Full rate of N applied as NH<sub>3</sub> (no nitrapyrin) in early spring (to before planting), with placement between rows by real-time kinematic (RTK) GPS if possible
3. Reduced N rate (120 lb N/A) applied as NH<sub>3</sub> (no nitrapyrin) in early spring (before planting), with placement between rows by RTK GPS if possible
4. 80 lb N applied as NH<sub>3</sub> early spring (before planting), followed by 80 lb N as UAN side-dressed
5. Same as Treatment 5, but with cover crops (oats-radish mixture seeded into standing soybean crop the previous early fall; cereal rye after corn)

Preliminary results suggest that split applications of N fertilizer can reduce tile nitrate losses without sacrificing corn yields. Cereal rye after corn reduced tile nitrate loss by 40%, but decreased soybean yield by 5% under poor growing conditions. There was no negative effect on soybean yield under excellent growing conditions that were experienced. *IPNI-2017-USA-4RF05*

### **Nutri-Net Purdue University (site and repository)**

Project Leaders: Sylvie Brouder, Purdue University, Agronomy West Lafayette, IN, USA. Email: sbrouder@purdue.edu;  
Jeffrey Volenec, Purdue University, Agronomy West Lafayette, IN, USA. Email: jvolenec@purdue.edu

This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

The objective at the Purdue University, West Lafayette, Indiana site is to characterize the agronomic and environmental performance of current farmer practice (FP) and sustainably intensified (SI) cropping systems,

including system impacts on radiation capture, nutrient use, greenhouse gas emissions, water use efficiency and water quality, and soil health.

Many of the treatments have been in place since 1992. These systems provide a near-continuous data record on productivity and environmental impacts from conventional corn belt cropping systems (maize-soybean rotation; continuous maize) or from native vegetation (prairie). Treatments 6 and 7 (linked as a maize-soybean rotation) and Treatment 12 (continuous maize) represent grain production controls using current FP, with extensive periods of bare soil. The SI treatments include a cover crop (Treatments 3, 8, and 9 linked in rotation) or a mulch cropping system with kura clover-maize intercropping (Treatment 5). An unfertilized native perennial prairie (Treatment 1) represents a pre-agriculture control. Biomass treatments (Treatments 2 and 4) were established in 2007 and represent bioenergy production systems currently receiving serious consideration by the Department of Energy and United States Department of Agriculture for Generation 2 cellulosic biofuels production. An unfertilized maize-soybean rotation (Treatments 10 and 11) will be used to quantify the environmental impacts of this two-year production system without N and inform the N credit from soybean to the subsequent maize crop. Each treatment is replicated four times. *IPNI-2017-USA-4RF06*

### **Nutri-Net University of Missouri**

Project Leader: Kelly Nelson, University of Missouri, Plant Sciences, Novelty, MO, USA. Email: nelsonke@missouri.edu

This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

The objectives for the Missouri site are to: 1) determine the effect of enhanced nutrient management systems on nutrient fate in a poorly drained clay-pan soil with shallow subsurface drain tile spacing and depths; and 2) evaluate nutrient use efficiency and fate in the presence and absence of subsurface drainage. The Missouri site is a corn-soybean rotation with treatments including a fall application of anhydrous ammonia at 170 lbs N/A with a nitrification inhibitor, pre-plant anhydrous ammonia at 170 lbs N/A, top-dress application of 25% urea blended with 75% polymer-coated urea at 150 lbs N/A as an enhanced 4R management program, and a non-treated control. The fall and spring treatments will be applied to subsurface drained and non-drained treatments. *IPNI-2017-USA-4RF07*

### **Nutri-Net University of Minnesota**

Project Leader: Fabián Fernández, University of Minnesota, Soil, Water, and Climate, St. Paul, MN, USA.  
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This is one of the eight study sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

The objectives of this Minnesota site are to: 1) quantify the effect of N application timing and N sources on nitrate concentration and load in tile-drain water and nitrous oxide emissions to the atmosphere; 2) quantify N use efficiency in terms of corn N uptake and yield based on fertilization management; and 3) utilize research findings to help farmers and crop consultants make informed decisions regarding N management to meet productivity and environmental quality goals. Starting in 2014, a continuous corn cropping system with conventional tillage was established with yearly applications of the maximum return to N (MRTN) rate. Four treatments were arranged in a randomized complete block design with four replications: pre-plant urea, pre-plant polymer-coated urea, and split-applied N fertilizer, with N application rate at one-third pre-plant and two-third side-dress at V4 of urea/urea + urease inhibitor and polymer-coated urea. The pre-plant N fertilizer is broadcast and incorporated into the soil, while the split-application is broadcast and left on the soil surface. *IPNI-2017-USA-4RF08*

### **Nutri-Net AAFC Ontario Canada site**

Project Leader: Craig Drury, Agriculture & Agri-Food Canada, Harrow, ON, Canada. Email: craig.drury@agr.gc.ca

The Ontario study site is one of the eight sites within the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop

yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario. There are two field sites within the Ontario study.

The first site will be established in April 2018 on a Brookston clay loam soil in southwestern Ontario. The objective of this study is to examine different N placement methods and use of enhanced-efficiency fertilizers to decrease N losses through ammonia volatilization, nitrous oxide emissions, and nitrate leaching, thereby increasing corn grain yields. A single slot versus double slot injection fertilizer applicator, and the impact of closing wheels will be evaluated and compared to broadcast urea with and without enhanced-efficiency fertilizers. The overall goal is to provide farmers with tools to improve the management of N in their soils, which should increase profitability while minimizing environmental impacts to the air and water.

The second site will examine the impact of fertilization and crop rotation on surface nitrate leaching through tile drainage. This is a long-term site established in 1959 on a clay loam soil in southwestern Ontario. A recent study found that water partitioning was dramatically affected by both fertilization and crop rotation and the impacts of these treatments on nitrate leaching will be compared to estimates obtained from the new study. *IPNI-2017-CAN-4RF09*

### **Nutri-Net EDF - Synthesis**

Project Leader: Alison Eagle, Environmental Defense Fund, Raleigh, NC, USA. Email: [aeagle@edf.org](mailto:aeagle@edf.org)

This is the synthesis portion of the Nutri-Net project. The objective of the overarching Nutri-Net research project is to quantify the impact of 4R Nutrient Stewardship practices on crop yield, soil health, nutrient use efficiency, nutrient loss via leaching, and gaseous nitrogen (N) loss across eight coordinated field sites in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ontario.

There are two main tasks within the synthesis: 1) ensure standardization of all data collected for the project, and 2) analyze the results across sites to look for trends. Since the beginning of the project, focus has been on ensuring that data was collected in a consistent manner, reported with the same units (or can be converted easily), and using the same terminology. With all researchers committed to making their data open-access, the up-front focus on data will allow this multi-location project to provide a large dataset with consistent and clearly defined variables, ability to document the relationships between field management, productivity, and environmental outcomes.

Held in October 2017, a project kick-off meeting brought together all field researchers to discuss ways to make the data from each individual project site fit better together, including how to collect soil samples (e.g., standardizing the depth of samples and when they would be collected), what crop response data to measure, and what units to use when reporting.

To facilitate consistent terminology, the team drafted a Data Dictionary as a guiding reference for the researchers, including a template for data entry and reporting. *IPNI-2017-USA-4RF10* ❖

# Global Maize Projects

The Global Maize Project was implemented in 2008 to challenge scientists around the world to use the principles of ecological intensification to create new management systems that could outperform current farmer practices. Improved crop nutrition is the primary focus of the project, but other practices are also being examined to develop a complete set of recommendations to boost yields. The research is conducted within a network of 20 cooperating research centers in nine countries.

## **Global Maize Project in Brazil: Itiquira, Mato Grosso**

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Project Cooperators: Scott Murrell, Aildson P. Duarte, and Adriel F. Fonseca

Cropping system intensification will be necessary to meet the future demand for corn (maize). Ecological Intensification (EI) seeks cereal production systems that satisfy future demands, while developing cultivation practices with minimum interference to the surrounding environment. A Global Maize Project (GMP) site was established to identify gaps in yield between the current technology and improved technology aimed at achieving EI. This experiment was initiated in November 2009 at Itiquira, Mato Grosso on an Oxisol that has been under cultivation for 20 years. The experiment has a split-plot design with the main plots involving three types of cultivation systems and the sub plots having three levels of nitrogen (N) input plus a control. The types of cultivation systems being evaluated are: farmer practice (FP) of soybean followed by corn; FP + a forage crop (*Brachiaria decumbens*) in the winter; and EI involving a 3-year complete crop rotation cycle of soybean, corn (second crop), forage, soybean, crotalaria, regular corn, and forage. The EI treatment occurs three times, alternating the initiation point of the crop rotation to permit the production of corn every summer. The application rates of N fertilizer were 210 kg N/ha for the first corn crop (summer crop) or 40, 80, and 120 kg N/ha for the second corn crop, plus a control with no N added in both cases.

The results from last season indicated a diminishing returns response to N, which positively influenced maize yields. Maize yield with EI treatment averaged 9.6 t/ha, while FP yield was 8.3 t/ha. One explanation for this difference is the fact that no starter N (30 kg/ha) was applied to FP and FP+CC treatments, but only to EI treatment. Other than that case, all treatments received equal broadcast N rates. *Brachiaria* grass is no longer being intercropped with maize and the winter legume is now pigeonpea, which is in substitution for crotalaria. Soybean also seemed to benefit from the EI treatment yielding 5.2 t/ha, while in FP yielded 4.9 t/ha.

Changes made in the project did promote a better development of crops under EI. This is a long-term project intended to influence current opinions on how to best manage cereal production in the region.  
*IPNI-2009-BRA-GM18*

## **Global Maize Project in Brazil: Ponta Grossa, Paraná**

Project Leader: Luís Prochnow, International Plant Nutrition Institute, Piracicaba, SP, Brazil. Email: [lprochnow@ipni.net](mailto: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 demands for corn production. The proposed approach of 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 site was established to identify gaps in yield between current technology and improved technology aimed at achieving the goals of EI. The trial was first established at Ponta Grossa, Paraná, in May 2011, by seeding winter crops to respective treatment plots. The soil in the region is an Oxisol that had been under no-till cultivation for six years.

The experiment had a split-plot design with the main plots including three types of management systems and the sub plots having three nitrogen (N) application rates plus an unfertilized control. The different management systems were: 1) farmer practice (FP) involving a 2-year complete crop rotation cycle of black oats, corn, wheat, and soybean; 2) FP + silage production; and 3) EI of forage peas, corn, wheat (changed in 2014), 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 rates of topdressed N application for maize were 70, 140, and 210 kg

N/ha, plus a control with no N added. A 30 kg N/ha in furrow rate was applied to every maize plot.

The results from last season indicated different responses to N, which positively influenced maize yields. Dependent of the crop rotation system a weak response to N was found when forage peas or white oats were part of the rotation, versus a strong response to N when black oat was the winter crop. Maize yield with EI treatment averaged 12.8 t/ha, while FP average yield was 10.4 t/ha. Control (no N) treatment at EI yielded 12.4 t/ha versus 7.9 t/ha for the control at FP. Soybean yield was not affected by the differences in crop rotation and averaged 5.0 t/ha in both systems (EI and FP). This is a long-term project intended to influence current opinions on how to best manage cereal production in the region. *IPNI-2009-BRA-GM19*

### **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, China. Email: xiejiagui@163.com

Project Cooperators: Jiagui Xie and Xiufang Wang

A long-term field experiment was established in 2009 in Liufangzi, Gongzhuling City, Jilin Province, where mono-cropping of spring maize is common. The experiment was conducted to compare the performance of ecological intensification (EI) practices with farmers' practices (FP) for maize yield and nitrogen (N) use efficiency. The EI and FP practices differed in fertilizer rates, time, cultivars, and planting density. The applied fertilizer rates for EI and FP were 200-75-90 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha and 251-145-100 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha, respectively. 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 (N all yr) treatment produced 13 t/ha of grain yield, which was higher than the grain yield (11.4 t/ha) in the FP treatment that received higher N input. The agronomic efficiency (AE), partial factor productivity (PFP), and recovery efficiency (RE) of N were calculated for the treatments to assess the agronomic effectiveness of the EI treatment. The AE, PFP, and RE of N were 58.6 kg/kg, 68.0 kg/kg, and 102% in the EI treatment; while the corresponding values in the FP treatment were 40.2 kg/kg, 45.6 kg/kg, and 70%, respectively. The EI treatment with N application in two out of three years (N 2/3 yr) produced similar grain yield (13 t/ha) as the EI (N all yr) treatment. *IPNI-2009-CHN-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, China. Email: lmchao1758@126.com

Project Cooperator: Liangliang Jia

This long-term experiment was initiated in 2009 at the Dahe Experimental Station, Shijiazhuang, Hebei Province, where summer maize followed by winter wheat is the main cropping system. The experiment had two main plots of ecological intensification (EI) and farmers' practices (FP), and three subplots of nitrogen (N) application: 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 years (N 0 yr).

The fertilizer applications for maize in the EI and FP treatments were 182-73-70 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha and 225-120-50 kg/ha, respectively. The grain yield of maize in the EI treatment (8.5 t/ha) was not significantly different from FP treatment (8.8 t/ha). The agronomic efficiency (AE), partial factor of productivity (PFP), and recovery efficiency (RE) of N was 3.9 kg/kg, 46.0 kg/kg, and 41% in the EI treatment, respectively. The corresponding values for the FP treatment were 4.1 kg/kg, 39.2 kg/kg, and 27%.

The fertilizer rates applied to the following winter wheat were 182-107-86 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha and 225-120-50 kg/ha, for EI and FP, respectively. Similar to summer maize, no significant difference in grain yield was observed between EI and FP. However, higher AE, PFP, and RE were also observed in the EI treatment (17.8 kg/kg, 46.5 kg/kg, and 82%, respectively) as compared to the FP treatment (14.8 kg/kg, 39.9 kg/kg, 67%, respectively). The results also showed that the EI treatment, with N applied in two out of three years, produced 8 t/ha and 8.3 t/ha of summer maize and winter wheat in 2017, respectively.

Results showed that N use efficiency was improved with optimized nutrient management in the EI treatment, without any obvious advantage in grain yield over the FP treatment. *IPNI-2009-CHN-GM21*

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

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

A long-term field experiment was first established at Balcarce, Buenos Aires, Argentina in the 2009/10 growing season under a maize-wheat/double cropped-soybean rotation, with both crop phases occurring each year. The treatments included current Farmer Practice (FP) and Ecological Intensification (EI) practice. Treatments differed by cultivar, planting date, pest and weed control, and nutrient management practice. In the 2014/15 season, the crop rotation was modified to a maize full-season soybean-wheat (or barley)/double cropped soybean rotation, adding a third phase to the experiment.

Climatic conditions were normal during the 2016/17 season. Maize yields were significantly higher (+18%) under EI (9.2 t/ha) than under FP (7.8 t/ha). Barley was the winter crop this season, and grain yields were 5.1 t/ha in FP and 6.3 t/ha in EI treatments with a significant difference of +23%. Double-cropped soybeans were not planted due to severe drought in January 2017.

Summarizing the first eight years of this field experiment, grain yields were 17% and 42% higher in EI than FP for maize and wheat (or barley), respectively. Results from the first six years have shown that EI resulted in more efficient water use (kg grain/ha/mm) and productivity (kg grain/total annual precipitation) than FP. Nitrogen (N) physiological use efficiency (kg grain/kg N uptake) in maize was not reduced with EI, despite the increase in N uptake. Partial factor productivity of N fertilizer (PFP-N) was high, averaging 185 and 159 kg maize/kg N for FP and EI, respectively. Partial N budgets (PNB) have been negative, averaging -49 and -26 kg N/ha for FP and EI, respectively. These values of PFP-N and PNB would indicate that soil N is being depleted and that N fertilizer rates would need to be increased for sustainable production. *IPNI-2010-ARG-GM24*

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

Project Leaders: Octavio Caviglia, Instituto Nacional de Tecnología Agropecuaria, Estación Experimental Agropecuaria Paraná, Verde, Entre Ríos, Argentina. Email: ocaviglia@parana.inta.gov.ar

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

This long-term maize-wheat/double cropped-soybean field experiment was established in 2009 at Oro Verde, Entre Ríos, Argentina. Soil samples were collected during site establishment to characterize initial conditions, especially the soil carbon content throughout the soil profile. Treatments included current farmer practice (FP) and ecological intensification (EI) practices. The treatments were created through the use of different cultivars, planting dates, pest and weed control, and nutrient management practices.

Grain yields in the 2016-2017 season showed significant yield differences between FP and EI treatments for maize and wheat, but not for double-cropped soybean. Maize yields were 6.8 t/ha and 8.4 t/ha for FP and EI treatments, respectively, with a significant difference of +23%. Wheat yields were 3.1 and 4.6 t/ha (+46%); and double-cropped soybean yields were 3 and 3.4 t/ha for FP and EI treatments, respectively. Cropping intensification (i.e., inclusion of a cover crop before maize) did not affect grain yields.

Summarizing the eight years of field experiments, the EI treatment has significantly improved maize and wheat yields (+43% and +22%, respectively), but EI tended to increase double-cropped soybean yield by just 8%. Water use efficiency (determined as kg grain/ha/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 had higher physiological nitrogen (N) use efficiency. Partial factor productivity of N fertilizer (PFP-N) was high for both treatments, and partial N budgets (PNB) have been negative. These values of PFP-N and PNB would indicate that soil N is being depleted and that N fertilizer rates would need to be increased to maintain long-term sustainability. *IPNI-2010-ARG-GM25*

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

Project Leader: Jeffery Volenec, Purdue University, Dept. of Agronomy, West Lafayette, IN, USA.  
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We established our first field experiments in this international effort at Purdue's Agronomy Center for

Research and Education (West Lafayette, IN) in 2012. Like other ongoing studies, our research involved a comparison of traditional farmer practices (FP) versus ecological intensification (EI) practices for rain-fed maize in a conventional maize-soybean rotation. Unlike other studies, we employed a fall strip-till, three management levels, and six reps. The FP plots involve a normal plant density (approximately 31,000 plants/A), sidedress nitrogen (N) application with rates of 0, 100, and 160 lb of N/A following a starter application of 20 lb N/A at planting. The EI plots used the same hybrid (P1498 from 2012-2014, and P1417AMX from 2015-2017), but at a higher plant density (approximately 38,000 plants/A), with sidedress N rates of 0, 160, and 220 lb N/A plus an inhibitor (Instinct™) and ammonium sulfate (thiosulfate) in the coulter-banded UAN. The EI plots are now also receiving broadcast P<sub>2</sub>O<sub>5</sub> (MESZ starting 2017) and K<sub>2</sub>O (Aspire® starting 2015), despite soil-test phosphorus (P) and potassium (K) that are well above Tri-State critical levels in all treatments.

Maize yields were highly responsive to N rates in all six years, and were significantly higher with EI management compared to FP management in 2015 and 2017. Grain yields in 2017 with EI averaged 249 bu/A at 220 N, and 233 bu/A at 160 N, relative to just 202 bu/A at the comparable 160 lb N rate with FP. Zero N treatments averaged approximately 100 bu/A in 2012-2017. Fertilizer N recovery efficiency (NRE) by whole-plant biomass at maturity averaged 62% (maximum = 80%) from 2012-2017 with the 160 N in the EI treatment. Ear-leaf nutrient concentrations at flowering were highest with the 220 N EI treatment. Total plant nutrient uptakes by maturity (R6) for N, P, K, sulfur, zinc, copper, and boron were also significantly higher for the 220-N EI treatment.

With support from the 4R Research Fund, we added intensive greenhouse gas measurements during the 2015 and 2016 growing seasons. Cumulative N<sub>2</sub>O losses (per unit grain yield) were no higher in EI than in FP at comparable N rates. Another 2017 development was sampling conducted by Olmedo-Pico (Ph.D. student) for kernel weight and nutrient uptake progression at weekly intervals during grain fill. These samples confirmed the EI system provides benefits to achieve longer filling period durations and final kernel weights similar to those in the FP system (despite having more kernels/unit area via higher populations). We anticipate achieving further yield and nutrient efficiency gains in EI systems. *IPNI-2010-USA-GM27*

### ***Improvement of Maize and Soybean Mineral Nutrition on a Calcareous Common Chernozem, Russia***

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

Farmer fertilizer practice (FP) and the Ecological Intensification (EI) management system were studied at the A-site of the Global Maize project. Two different maize hybrids (Krasnodarskiy 291-FP and P9175-EI) were grown in 2017 under these crop management systems. The 2017 season had near normal weather conditions.

FP resulted in a maize yield of 6.3 t/ha (Moisture content = 15.5%) and the omission of nitrogen (N) (i.e., decreasing N rate from 30 to 9 kg/ha) caused a yield loss of only 2%. A maize yield of 7.1 t/ha was obtained in the EI treatment giving a considerable increase over FP (by 13%). The omission of N from the EI system (decreasing N from 85 to 17 kg/ha) caused a significant yield decline to 6.6 t/ha. For chickpea, FP had a yield of 2.6 t/ha (Moisture = 13%) and the addition of N (i.e., increasing N rate from 6 to 24 kg/ha), resulted in a non-significant yield increase by 1%. Seed yield of 3.0 t/ha was obtained with a moderate N fertilization rate of 24 kg/ha in the EI treatment, a considerable improvement over FP (by 16%). The omission of N in the EI system (i.e., decreasing N rate from 24 to 12 kg/ha) caused a statistically non-significant yield decline to 2.9 t/ha.

Prior to planting maize at the C-site, the soil had a low nitrate (NO<sub>3</sub>)-N concentration of 6 ppm, a NH<sub>4</sub>-N concentration of 6 ppm, high level of Olsen-extractable phosphorus (P) (15 ppm), very high level of exchangeable potassium (K) (353 ppm), low level of available sulfur (S) (4 ppm) routinely extracted with 1M potassium chloride (KCl) solution in the 0 to 20 cm layer. Fertilizer treatments (kg/ha) at the C-site in 2017 included: 1) 30N 40P (Grower Practice); 2) N40N 70P 60K; 3) 60N 70P 60K; 4) 80N 70P 60K; 5) 100N 70P 60K; 6) 80N 70P 60K 7S 0.5Zn; and 7) 80N 70P 60K 10S Zn1.

The N application rate of 80 kg/ha was found to be agronomically optimum during the second season, but the yield response to increasing N rates was low (by 6% compared to 40 kg N/ha). The highest grain yield of 6.25 t/ha was obtained in treatment seven, receiving 80 kg N, 70 kg P<sub>2</sub>O<sub>5</sub>, 60 kg K<sub>2</sub>O, 10 kg S, and 1 kg Zn/

ha. A yield increase over the Grower Practice reached 17%. Sulfur and Zn-containing fertilizers (NPSZn 16-34-6-0.4 and 12-40-10-1) applied at planting provided a yield improvement of 4%. *IPNI-2011-RUS-GM41*

### **Global Maize Project in the United States: Virginia**

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A total of nine individual studies were conducted at the Davis Farm near New Kent, Virginia in the summer of 2017. The four main A-site studies compared mid-Atlantic farmer standard practices for corn production to a suite of practices identified for inclusion in the “Ecological Intensification” (EI) treatment in irrigated and rain-fed fields. Corn was planted on April 20, 2017 into a recently killed wooly pod vetch + rye + turnip cover crop. The hybrid Pioneer 1197AM was planted in 30-inch rows for both treatments. The primary soil series for the site-A experiments (rain-fed and irrigated) was Pamunkey silt loam (fine-loamy, mixed, semi-active, thermic, ultic Hapludalfs).

The Virginia statewide average corn yield in 2017 was 154 bu/A, while the grain yields in these studies were 159 bu/A for both treatments in rain-fed and over 290 bu/A for the irrigated test. No statistical difference in grain yield was detected in the rain-fed study; but, in the irrigated study, grain yield for the EI treatment was found to be greater than the mid-Atlantic standard at the significance level of  $<0.05$  (306 vs. 293 bu/A). *IPNI-2012-USA-GM45*

### **Advancing Intensive Management of Corn Systems in Minnesota**

Project Leaders: Jeff Coulter, University of Minnesota, St. Paul, MN, USA. Email: coulter077@umn.edu; Jeff Vetsch, University of Minnesota, Southern Research and Outreach Center, St. Waseca, MN, USA. Email: jvetsch@umn.edu

Two Global Maize sites are located in Minnesota. The objective for both is to assess the potential of advanced fertilizer and crop management practices for increasing the yield and nitrogen (N) use efficiency of continuous corn. This site is a high-productivity, tile-drained, clay loam soil (Waseca, MN) with maximum corn yield in this study averaging 222 bu/A. High-yield management practices, including removing 40% of corn residue prior to tillage the previous fall, a longer-season hybrid (104 vs. 99 day), and a greater planting rate (41,000 vs. 36,000 seeds/A) increased corn yield by 13 to 34 bu/A depending on the year. Intensive practices also enhanced the agronomic efficiency of applied N fertilizer from 0.52 to 0.60 lb N/bu across the years.

Compared to standard practices, a fertilizer management program that included phosphorus and potassium applications based on grain nutrient removal, surface-banded N and sulfur applied near the row at planting, and an additional sidedressed 40 lb N/A increased corn yield by 7 to 26 bu/A, through the study. Yield increases with advanced fertilizer management were consistent with both standard and high-yield management. These results demonstrate the potential for growers to close yield gaps in continuous corn by pairing advanced fertilizer management with intensified cropping systems that include partial stover removal, longer-season hybrids, and higher seed planting rates. *IPNI-2013-USA-GM51*

### **Advancing Intensive Management of Corn Systems in Minnesota (Irrigated)**

Project Leader: Jeff Coulter, University of Minnesota, St. Paul, MN, USA. Email: coulter077@umn.edu

Project Cooperator: Jeffrey Vetsch

Two Global Maize sites are located in Minnesota. The objective for both is to assess the potential of advanced fertilizer and crop management practices for increasing the yield and nitrogen (N) use efficiency of continuous corn. This site is an irrigated sand (Becker, MN) and maximum corn yield in this study averaged 220 bu/A. Removing 40% of corn residue prior to tillage in the previous fall, coupled with a longer-season hybrid (103 vs. 97 day) and a greater planting rate (41,000 vs. 36,000 seeds/A) increased corn yield by 17 to 37 bu/A, depending on the year. It also enhanced the agronomic efficiency of applied N fertilizer from 0.75 to 0.79 lb N/bu.

Advanced fertilizer management, including surface-banded N and sulfur fertilizer applied near the row at planting and three in-season applications of N rather than two, increased corn yield by 13 to 31 bu/A among the years. Coupling advanced fertilizer management with advanced crop management enhanced the removal efficiency of applied N fertilizer to 0.87 lb N/bu across years. These results demonstrate that yield of irrigated

continuous corn can be increased with changes in residue management, hybrid selection, and planting rate. These results also show that advanced fertilizer management based on 4R principles can increase corn yield and N fertilizer efficiency on irrigated sands in both standard and high-yield systems. *IPNI-2013-USA-GM65* ❖

# Special Projects

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

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Phase 3 of the HarvestZinc project is now complete. Phase 3 studied four tasks: 1) Determine the response of newly developed high zinc (Zn) lines from HarvestPlus breeding programs to soil and foliar spray of Zn and other micronutrients; 2) Effect of next generation foliar micronutrient fertilizers and cocktail application of micronutrients (Zn, iodine, iron and selenium) on grain concentrations of micronutrients; 3) Understand the differential response of wheat and maize to foliar zinc fertilization; and 4) Promote and create awareness to facilitate the adoption of the Zn fertilizer strategy at the farmer and policy maker levels. Results from the project are summarized in the Executive Summary. Publications are being prepared for peer-reviewed journals and will be included as they become available.

Phase 4 of the project began in January 2018. New tasks in Phase 4 include: 1) Studying novel soil and fertilizer products; 2) Exploit the synergism between breeding and agronomy; 3) Farmer field trials and use of cocktail micronutrient fertilizers; 4) Compatibility of a cocktail of micronutrients with biocides; and 5) Consumer acceptance and test marketing study. *IPNI-2008-GBL-10*

## **4R Nitrogen Management Science Consensus to Modify Nitrous Oxide Estimation in the Field to Market Fieldprint Calculator**

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Many leaders of the global food supply chain are members of the large Field to Market Alliance for Sustainable Agriculture (>100 members). Several have committed to sizably reduce emissions of greenhouse gases (GHGs) (e.g., Pepsico - 25% by 2015; Walmart 20 MMT reduction by end of 2015; Unilever carbon positive by 2030; Monsanto - cumulative reduction of 45% from 2002; Kellogg's -65% by 2050), and recognize that nitrogen (N) inputs often account for the largest portion of cropping system GHG emissions. Several companies and environmental non-governmental organizations have incorrectly thought U.S. farmers (esp. corn farmers) universally apply 20 to 30% more N than needed for optimal yields; though in 2012, the USDA Economic Research Service and IPNI reported that corn farmers steadily improved their use since 2000. By 2010, 65 to 70% of U.S. corn farmers applied N at rates at or below university research-based N recommendations; and on average, those who rotated with soybeans used rates quite close to the university recommendations. Field to Market's Fieldprint Calculator uses a constant factor to estimate both direct and indirect emissions of nitrous oxide (N<sub>2</sub>O; potent GHG with ~300x warming effect compared to carbon dioxide) using a single coefficient from the Intergovernmental Panel on Climate Change (IPCC). These factors caused many food supply chain members to ask farmers to reduce fertilizer N use, for reduced N<sub>2</sub>O emissions.

Project leaders assembled scientists to develop suites of 4R N management practices that are critically important for GHG emission reduction; and assess how N<sub>2</sub>O emissions are sensitive to land resource regions in the U.S. (including cropping systems and soil texture). A new method of N<sub>2</sub>O emission estimation was proposed for U.S. corn, soybean, and wheat systems. The new estimation method, piloted by Field to Market in 2017, offers advantages because it:

- is consistent with current USDA GHG modeling that is sensitive to different land resource regions, surface soil texture, and crop;
- is sensitive to the actual applied N inputs by farmers (not just historic rates); and
- allows for downward adjustments of N<sub>2</sub>O emissions (7 to 14%) if farmers use N science-consensus-developed suites of N management practices that represent Intermediate or Advanced/Emerging 4R practice implementation.

IPNI is working to implement the nitrous oxide reduction metric based on suites of 4R N management practices published in 2016 (<http://www.ipni.net/issuereview>) in the Field to Market Fieldprint Calculator. *IPNI-2014-GBL-64* ❖



# Australia/New Zealand Program

Dr. Robert Norton, Director (Retired)

## Australia

### ***Nutrient Balances for Australian Natural Resource Management Zones***

Project Leader: Rob Norton, International Plant Nutrition Institute, Victoria, Australia. Email: rnorton@ipni.net

Using data published by the Australian Bureau of Statistics and the Australian Bureau of Agriculture and Resource Economics, a third set of data on nutrient use and agricultural productivity was collated to provide regional estimates of nutrient balance for nitrogen, phosphorus, potassium, and sulfur across Australia. The results add to earlier data sets giving three audit periods. In collaboration with the Centre for eResearch and Digital Innovation at Federation University, a revised website page was loaded and the data can be found at [http://www.ozdsm.com.au/ozdsm\\_map.php](http://www.ozdsm.com.au/ozdsm_map.php) *IPNI-2010-AUS-16*

### ***Managing Micronutrient Deficiencies in Cropping Systems of Eastern Australia***

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Project Cooperators: Ross Brennan, Mike Bell, Sergio Moroni, Mark Conyers, and Sjaan Davies

Between 2014 and 2017, a series of field experiments were undertaken to assess the effect on crop yield of multiple rates and application strategies of micronutrient fertilizers in soils deficient in the target micronutrients [copper (Cu), zinc (Zn), manganese, boron, and molybdenum]. A total of 22 experiments were conducted in South Australia, Victoria, southeastern Queensland, and southern New South Wales. The results have been reported on the IPNI ANZ research project website <http://research.ipni.net/project/IPNI-2014-AUS-020>, as well as on the On-Farm Trials database <https://www.farmtrials.com.au>. The latter is a searchable on-line database of trial results from field experiments, including nutrition trials.

The overall conclusion for this body of work is that the current guidelines for soil and tissue tests are still relevant and effective for micronutrient management. However, some current interpretations of soil tests are causing issues - the suggested levels to avoid deficiencies are much higher in some lab reports than what the project has experienced from its field trials. The project concluded that these interpretations are creating false impressions of the extent and severity of zinc and copper deficiencies.

We found no evidence of a major increase in the incidence or severity of micronutrient deficiencies in the cropping zones. Fluid delivery of micronutrients at seeding is a valid management strategy but rates of the target micronutrients need to be the same as those used when they are included with compounded fertilizers. Generally, all sources of foliar micronutrients were equally effective. *IPNI-2014-AUS-020*

### ***Optimising the Yield and Economic Potential of High Input Cropping Systems in the High Rainfall Zone***

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Cropping systems have been moving from the low and medium rainfall areas of Australia into the higher rainfall zones, typically those with average annual rainfall of more than 550 mm. The achievable yield potentials in these regions are high (around 8 t/ha for wheat and 5 t/ha for canola), but crop management and cultivar availability is limiting the achievement of those potentials. Since 2014, a collaborative project supported by the Grains Research and Development Corporation has investigated the role improved nutrient management can play in this region. A series of omission trials were conducted along with factorial nutrient interaction experiments to better understand how multiple nutrient limitations can be overcome.

These nutrient response experiments have established that by providing sufficient nutrients, the yield of wheat and canola crops can be equal to or exceed the water-limited potential, except in cases of severe waterlogging or drought. The greatest yield responses across all the sites were to phosphorus (P) followed

by nitrogen, sulfur, and potassium. The magnitude of these responses was generally consistent with the expectations based on current soil test critical values, although slightly higher critical values were required for soil test P, compared to research from other regions, to achieve 90% of maximal yield.

These research results were used in an economic analysis, which showed that the 90% critical value underestimated the economic optimum because of the higher yield potential in the HRZ. Since the economic optimum fertilizer application rate is also dependent on input prices, product price and seasonal outlook, three spreadsheets were developed to calculate the optimum rates under a wide range of conditions. The spreadsheets are populated with yield and nutrient response data from a biophysical model, but allow modification to suit individual circumstances.

Trial versions of these spreadsheets can be accessed at <http://extensionaus.com.au/crop-nutrition/try-new-decision-support-tools-better-hrz/> *IPNI-2014-AUS-022*

### **Nutrient Performance Indicators for the Australian Grains Industry**

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Project Cooperators: Shukee Lam and Elaina vanderMark

This project aimed to develop nutrient performance indicators for Australian grain farms. Data on nutrient removal, nutrient use, crop management and estimates of nitrogen (N) fixation from 500 paddocks was collected and collated. A series of articles on this work was developed in collaboration with the ExtensioAus network to share these results with growers and advisors across the nation.

The survey found that one third of the paddocks had 50% more N removed than supplied. This led to declining soil organic matter as the extra N to balance crop demand comes from mineralization of that important organic matter. In terms of N effectiveness, on average there were 77 kg of grain produced for every kilogram of N supplied - which came from fixed and fertilizer sources.

Unlike the deficit of N, about 80% of the paddocks surveyed had more phosphorus (P) applied than was removed. In terms of production efficiency, these paddocks produced 227 kg of grain per kilogram of P applied. Results for potassium and sulfur varied across the region.

The key messages to growers and advisers was to make long term (five year or greater) estimates of performance indicators, but take care not to focus on a single number for a paddock when looking at partial nutrient balance (PNB) or partial factor productivity (PFP), but consider a whole farm context. High or low values for PNB or PFP do not mean the systems being evaluated are inherently efficient or inefficient. A PNB greater than one may be a viable strategy to exploit excess soil nutrients, or if there is a need to build soil test levels, a PNB less than one may be appropriate. Similarly, the magnitude of the deficit or surplus of nutrient should be viewed in relation to the productivity of the system - for example, a 5 kg N/ha deficit in a low rainfall area with low soil organic matter may be more significant than the same deficit in a high rainfall area with higher soil organic matter. Alignment with changes in soil tests can provide growers with strategies for more effective nutrient use. *IPNI-2015-AUS-023*

### **Potassium Responses in Winter Crops and Pastures**

Project Leaders: Jonathan Holland, New South Wales Department of Primary Industries, Wagga Wagga.

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Project Cooperators: Chris Kilby, James Cheetham, Richard Hayes, Megan Beveridge, Andrew Speirs, and Claudia Gebert

A field site was selected at Glenthompson in the high rainfall zone of southwest Victoria, Australia to further evaluate the responses in that region to potassium (K). The site selected was of moderate soil K status (assessed by bicarbonate extraction at 50 mg/kg K), although the reported critical values for soil test K are uncertain for these soils and environments. Five rates of K (0, 25, 50, 100, 150) were applied at seeding to wheat, canola, and faba beans in a small plot experiment.

Growth and yield of these crops were assessed and there was a significant interaction between the crop and K application. Canola yields increased from 2.4 to 3.1 t/ha with 25 kg K/ha, and to 3.4 t/ha with 50 kg K/ha. There was limited increase beyond this rate. Over the 0 to 150 kg K/ha rates, wheat yields decreased by 8% (4.4 to 4.0 t/ha). There was no significant response to K on faba beans although there was highly

variability, probably due to poor nodulation in the pulse, a consequence of a relatively low soil pH and high exchangeable aluminium (Al) concentrations at the site (ex-Al 9% of CEC). There were also no differences in the found in the timing of the applications for the 50 kg K/ha treatments. The mid-season differences can be viewed on-line at <http://anz.ipni.net/article/ANZ-3302>. Soil test information, mid-flowering biomass results and yield graphs can also be found on that site.

The results from this project will be added to the Better Fertilizer Decisions for Crops database to help improve regional soil test guidelines. *IPNI-2015-AUS-24* ❖



# Brazil Program

**Dr. Luís Prochnow, Director**

**Dr. Eros Francisco, Deputy Director**

## ***Rates and Residual Effect of Potassium Fertilization in a Brazilian Soil***

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Project Cooperators: Eros Francisco and Toni Wiendl

Potassium (K) fertilizers are a common necessity in terms of plant nutrition in acid soils of the tropics, including Brazil. In many areas, farmers cut back on fertilizer use due to expenses, which could compromise good yields, profit, and food safety in the future. Studying the impacts of K fertilizer cut back on Brazilian soils is important to demonstrate the effects in the medium to long run and this was the main objective of this study. The field trial has been carried out for seven years in a clay Oxisol in Itiquira, MT, growing soybeans every summer and maize second crop or Brachiaria grass during the fall/winter. Treatments involved: 1) four rates of  $K_2O$  (22.5, 45, 90, and 135 kg  $K_2O$ /ha), plus a control with no  $K_2O$  added, in interaction with suppression or not of K after the third year; 2) three levels of base saturation (40%, 55%, and 70%); 3) three rates of phosphogypsum application (0, 2, and 4 t/ha); 4) two times of  $K_2O$  application; and 5) two localities of application. Responses to  $K_2O$  were frequent along the years, but relatively small up to the sixth year. The average negative effect on grain yield of both crops from the suppression of  $K_2O$  up to the sixth year was 385 kg/ha for soybeans and 617 kg/ha for maize second crop, yearly, comparing the K recommended rate of 90 kg/ha and the control. In the seventh year the same comparisons rendered the same negative effects of 951 kg/ha and 862 kg/ha for soybean and maize, respectively, showing a trend for higher response to K from now on. Cutting back the K rate after the third year still did not have much of an effect on soybean and maize second crop. In certain years, yields of both crops were positively affected by phosphogypsum application, while maize second crop yield was also positively affected by liming.

The experiment has shown the soil to have a high buffering capacity in K. It is very possible that recycling of K from deeper soil layers is still helping to maintain yields even when applying relatively low rates of  $K_2O$ . It is intended to continue with this experiments for several more years to find out about the residual K effect in the long run. *IPNI-2010-BRA-56*

## ***Brazilian Soil Fertility Survey***

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Project Cooperators: Soil test laboratories in Brazil

Brazil lacks data for soil fertility surveys which can help the government, industry and crop consultants in their efforts to improve soil chemical properties for adequate plant nutrition. Such surveys can be instrumental in guiding, among others, the government to establish proper actions to ameliorate soil fertility, the industry in planning strategies to better serve with products and alternatives those regions most in need of soil fertility improvement, and researchers to plan their experiments. IPNI Brazil has been involved in guiding the process for obtaining such surveys.

The survey was completed based on samples gathered from soil testing results obtained from twenty-six different laboratories (94,904 samples from 501 different cities) in the state, which were analyzed for phosphorus (P) and potassium (K) in 2015. Results showed a median of 12 mg P/dm<sup>3</sup> and 1.6 mmolc K/dm<sup>3</sup>, which are considered low and medium concentrations respectively. For P, 20%, 40%, 28%, 8%, and 4% of the samples were in the range of very low (< 6.0 mg/dm<sup>3</sup>), low (6.0 to 15 mg/dm<sup>3</sup>), medium (15 to 40 mg/dm<sup>3</sup>), high (40 to 80 mg/dm<sup>3</sup>) and very high (> 80 mg/dm<sup>3</sup>) ranges, respectively. For K, these numbers were 13%, 33%, 35%, 16%, and 3% for the very low (< 0.80 mmolc/dm<sup>3</sup>), low (0.8 to 1.50 mmolc/dm<sup>3</sup>), medium (1.51 to 3.0 mmolc/dm<sup>3</sup>), high (3.01 to 6.0 mmolc/dm<sup>3</sup>), and very high (> 6.01 mmolc/dm<sup>3</sup>) ranges.

An interesting outcome is that 88% and 81% of the soil samples from the survey have potential for plant response to P and K, respectively. In other words, based on this survey, for the state of São Paulo only 12% (for P) and 19% (for K) of the samples had concentrations sufficient to sustain maximum potential crop

yields. For soil pH, the survey showed that 30% of the soil samples were in the range of high response to the application of lime. An improvement from last year was the publication of maps of soil fertility for pH, P, K, and base saturation. These maps, showing the situation by municipality, add very useful information that can be used locally by those interested in better programs to manage the soil fertility. IPNI Brazil intends to repeat the survey every five years and also to extend the work to the whole country. *IPNI-2010-BRA-61*

### **Brazilian Nutrient Balance**

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A nutrient budget is an important tool used to evaluate the agronomic use of fertilizers through the balance between inputs and outputs in crop production. In Brazil, IPNI has prepared several nutrient budgets over the years, and most recently has extended a Brazilian nutrient balance analysis that includes many crops for the period between 2013 to 2016. Manufactured mineral fertilizer (inputs) data were obtained directly from annual statistics of ANDA (Associação Nacional para Difusão de Adubos). Crop nutrient removals (outputs) were calculated using statistic data (IBGE, 2013 to 2016) for 18 crops (i.e., banana, beans, cassava, castor bean, cocoa, coffee, cotton, maize, orange, peanut, potato, rice, sorghum, soybean, sugarcane, tobacco, tomato, and wheat) and their respective nutrient concentration in the harvested product (as described in Cunha et al., 2014). The 18 crops represent 93% of all nutrient input in this country.

The annual nutrient use in Brazil for the evaluated period, considering the 18 crops, was 3.60, 4.37 and 4.97 million t of nitrogen (N),  $P_2O_5$  and  $K_2O$ , respectively. The respective removal to use ratios were 60, 0.51, and 0.78. Six states presented ratio values higher than 1.0 due mostly to low technology adoption and low yields. The relatively low ratio for  $P_2O_5$  reflects its dynamics in tropical soils. These soils generally fix a large amount of phosphorus (P), and also, recent expansion of crop production into new areas with previously low P fertility demand suggest that initial P application rates be very high. For N, its 0.60 removal-to-use ratio is lower than the previous nutrient budget performed in 2013 (0.65) presented by Cunha et al. (2014). This may be partially explained by the drought that occurred in 2015 that affected several regions, causing a significant decrease in crop production and N removal, but also no increase in yields has been observed recently. Potassium, which is the most consumed nutrient in Brazil, presents the most balanced budget among the three nutrients, mainly in response to a comprehensive understanding of the importance of K for crop production by farmers.

The collection of data regarding the period of 2013 to 2016 is published in the March 2017 issue of *Informações Agronômicas*. *IPNI-2014-BRA-63*

### **Phosphorus Management in Farming Systems with Annual Crops**

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The question of how to apply phosphorus (P) in cereal crops (in furrow or broadcast) has recently gained great interest in Brazil. Farmers are tending to broadcast P fertilizer for operational advantage, while many researchers have conflicting opinions about the efficacy of this practice. Agronomic and environmental discussions are widespread throughout the country over this topic. With that in mind, two agronomic experiments were installed in Nazareno, Minas Gerais, with the objective to study methods of applying P in grain production systems under soils that have long been cultivated and contain adequate levels of plant nutrients.

The first experiment targets maize in the summer and beans as a second crop. The second focus is a rotating soybean/wheat rotation in one year and soybean/maize second crop rotation in the other. The treatments vary in the application method of P: 1) Control without P; 2) P applied in furrow; 3) P broadcast onto the soil surface 30 days before seeding the summer crop; 4) P applied broadcast during seeding the summer crop; and 5) P broadcast during seeding the winter crop. In general, there was a positive yield response to P for most crops. The conclusion was that methods of application did not affect crop yields for the summer crop, but P applied in the wheat furrow was more effective than P broadcast. It is hypothesized that less precipitation during the winter was responsible for the better yield response to P applied in the furrow, due to better root development and increased uptake of water from deeper layers of the soil. *IPNI-2016-BRA-70*

## **Nutrient Budget for Coffee Plantations in Brazil**

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

Coffee in Brazil occupies 2.2 million ha, with a total production of 2.7 million t and an average yield of 1.45 t/ha. In 2017, Brazil exported 1.85 million t of coffee and this crop ranks 4th in fertilizer consumption after soybeans, maize, and sugarcane. Despite its importance, coffee plantations generally show low nutrient use efficiencies, presenting removal-to-use ratios of 0.14, 0.10, and 0.20 for nitrogen (N), phosphorus (P), and potassium (K), respectively in a recent survey.

This project aims to evaluate long term nutrient budgets of coffee plantations, considering yields from both high and low years in response to the biennial nature of the crop. Brazilian coffee production has undergone major changes in recent years, with one of the main changes being the significant increase in crop yield. This increase was due, among other factors, to the improvement of coffee tree nutrition knowledge in Brazil. To calculate the nutrient budget, information is being collected from plantations in different regions in São Paulo and Minas Gerais regarding crop management, nutrient application, and yield. Previous results have showed an average of removal-to-use ratio of 0.26, 0.09, and 0.36 for N, P, and K, with great difference between high and low yield years: 0.36, 0.14, and 0.50 for NPK in high yield year versus 0.09, 0.01, and 0.10 for NPK in low yield years.

In 2017, 15 more sites were added to the project and are under evaluation, showing preliminary results of removal-to-use ratio on average of 0.14, 0.07, and 0.15 for N, P, and K. *IPNI-2016-BRA-72*

## **Study of Doses of Potassium Fertilization in Soils in the State of Piauí**

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Project Cooperator: Tamara Araújo Schenfert

Potassium (K) stands out as the second most absorbed nutrient by crops after nitrogen (N). It has high mobility in the plant and performs functions of enzymatic activation, translocation and storage of assimilates, acting on osmotic regulation, maintenance of water in the plant and resistance to biotic and abiotic stresses. Considering the trend to reduce K fertilization in order to reduce the cost of production, the present work aims to evaluate the factors that influence the dose of K fertilization in soils in the state of Piauí. The treatments will have the following rates: (K1) 22.5 kg K<sub>2</sub>O/ha as KCl, (K2) 45 kg K<sub>2</sub>O/ha, (K3) 90 kg K<sub>2</sub>O/ha, and (K4) 135 kg K<sub>2</sub>O/ha. The importance of timing the K fertilizer application in soybean will be considered in this work, as the total rate will either be applied in advance or in two applications (1/2 in planting and 1/2 in the V4-V5 growth stage).

The proposed design will allow for several studies: 1) yield response to K fertilization, with a single or split applications; and 2) effect of application rate and the placement of K fertilizer. The parameters to evaluate these studies will be obtained by the following evaluations: 1) soil chemical analysis; 2) analysis of plant tissue; 3) weight of 100 seeds; and 4) grain yield. This project has been terminated. *IPNI-2016-BRA-73*

## **Biomass Production of Forage Grasses in Response to Nutrient Use in Brazil**

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Brazil is an important beef producer and exporter, with a herd size over 210 million head that occupies 170 million ha of pasture. The national cattle stocking rate is about only 1 head/ha in response to low grazing efficiency, poor soil nutrient management, and lack of technology adoption. Half of Brazil's pastures are considered to be degraded to some degree. The main causes of pasture degradation are related to adverse soil conditions (low fertility, acidity, and compaction), selecting the wrong plant species (variety adaptation or low tolerance to soil/climate conditions), and inadequate pasture management (weed competition, low seed germination, wrong seeding rate, etc.) This project aimed to study the effect of nutrient application on biomass production of forage grasses in different locations. Also, a case study evaluating the benefit of regular nutrient use in a cattle farm was performed.

Two demonstration plots were carried out in Dracena-SP and Itiquira-MT with eight basic treatments as: 1) control (no applied nutrients); 2) lime application alone (L); 3) phosphogypsum application alone (PG); 4) L plus N application (100 kg N/ha); 5) L plus phosphorus (P) application (45 kg P/ha); 6) L plus potassium (K) application (85 kg K/ha); 7) L plus nitrogen (N), P, and K application (same previous rates); and 8) L+PG plus NPK application (same previous rates). Treatments were set up on a representative local field with the most common type of forage in the region. Nitrogen application alone increased DM yield by 158% and 77% in Dracena-SP and Itiquira-MT, respectively, while NPK application plus liming further increased DM yield in 246% and 92% in the respective locations.

The biomass production of *Brachiaria* grass in fields with regular nutrient application at a farm located in Jaciara-MT was 77% higher, compared to a field with no nutrient application, allowing a stocking rate to be increased to 6 animal units (450 kg) per hectare.

Two field days were organized in Dracena-SP and Jaciara-MT to present and discuss the results to local farmers, who were impressed with the possibility of achieving higher stocking rates with fertilizer application.  
*IPNI-2016-BRA-74* ❖

# Latin America–Southern Cone Program

**Dr. Fernando García, Director**

## Argentina

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

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The Regional Consortium of Agricultural Experimentation (CREA), a farmers' organization based in Southern Santa Fe, has established a network of field experiments with the objectives of: 1) determining direct and residual responses to nitrogen (N), phosphorus (P), sulfur (S), and where indicated, to potassium (K), magnesium (Mg), boron (B), copper (Cu), and zinc (Zn); 2) evaluating recommendation methods for N, P, and S fertilization; 3) identifying the degree 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 2016-17, the two sites under corn-wheat/soybean (C-W/S) rotation were planted to corn, and the three sites under corn-soybean-wheat/soybean (C-S-W/S) rotation were planted to full season soybean.

Adequate precipitation in the 2016/17 season supported high yields in all crops and sites. Corn grain yield responses to N, P, and S were significant at Balducchi and San Alfredo. Responses to NPS averaged 5.9 t/ha (+102%) for both sites. Average response to PS in full season soybean was 386 kg/ha (+9%), but the response was only significant at the Lambare site. There were no significant responses to the other nutrients (K, Mg, B, Cu, and Zn) at any of the sites and crops evaluated this 2016/17 season.

Responses to N were related to available N at planting (soil + fertilizer N) for corn. Pooling data from this season and the previous ones, a critical availability of 166 to 231 kg N/ha to reach corn yields of 10 to 12 t/ha has been estimated. Significant relationships were observed between Bray P-1 soil P concentrations and P responses, with critical P concentrations ranging between 11 and 16 ppm Bray P-1 for the two crops. Below these critical levels, P responses are highly probable. Responses to S were related to pre-plant soil sulfate-S concentrations (0 to 20 cm), with a critical level of 8 to 10 ppm for corn and full season soybean.

There was a special study carried out by the College of Agronomy at the University of Rosario that was featured in Better Crops 2018, #1. It showed that balanced NPS fertilization during 12 consecutive years improved soil organic matter, soil microbial population and enzyme activity, and soil aggregate stability in fields with long annual cropping history and coarse soil texture. However, there were no effects in fields with short annual cropping history and fine soil texture.

For the 2017/18 season, all sites, either under C-W/S or C-S-W/S rotation, will be cropped to wheat/double-cropped soybean. *IPNI-2000-ARG-12*

## Uruguay

### ***Exploration of Responses to Potassium in Western Uruguay***

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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 potassium (K) deficiency and responses to K fertilization in field crops grown within the northwestern Uruguay region. Data from the initial field work, including 50 experiments under wheat, barley, maize, soybean, sunflower, and sorghum, indicated a critical soil K concentration of 0.30 to 0.40 cmol/kg [i.e., soil test K (STK) of 117 to 156 ppm]. Below this K concentration, there is a high probability of a positive yield 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 2016-17 growing season included field experiments evaluating K response in soybean (two) and pastures (two). Soybean grain yield responses were verified at the low soil test K location (0.26 cmol/kg), although without differences between rates of 60 and 120 kg K<sub>2</sub>O/ha. In the two pasture experiments, under low to medium soil test K conditions, responses in dry matter production were 9 to 19%, with larger impacts on grass production than on legumes.

A compilation of 110 studies, 50 experiments conducted through 2007 and another 60 field trials from 2007 through 2015, was carried out to correlate relative grain yields to STK. The STK ranged from 0.12 to 1.22 cmol K/kg and relative yields (yield without K application/yield with K application) from 54% to 105%. Crops responded positively to K application in 58% of the cases in soils testing <0.20 cmol K/kg, 43% of the cases when testing from 0.21 to 0.30 cmol/kg, 34% at soils from 0.30 to 0.40 cmol/kg, and 29% in soils from 0.40 to 0.50 cmol/kg. Only at three of 35 sites with soil testing above 0.51 cmol K/kg, was response to KCl application observed. Potassium increased crop yield more frequently for corn than for soybean. Critical levels were closer to the 0.3 to 0.4 cmol/kg range that was previously established.

Laboratory studies have shown that the Mehlich extractant acquires 11% less exchangeable K than the conventional ammonium acetate extractant used at Uruguay (Exch K-Mehlich 3 = 0.89 exch K-Ammon acetate +14.4). Similar studies with several soils in Uruguay, showed that the sodium tetraphenylboron extraction receives 50 to 100% more K than conventional ammonium acetate extractions. The non-exchangeable K reserve is larger in soils with illite as the dominant clay.

Several B.Sc. thesis and graduate students are involved in this research project. Results of the project and K management strategies have been presented at several meetings organized by companies and farmer associations, as well as at international meetings. *IPNI-2007-URY-2*

## Multi-Country

### ***Breaking Soybean Yield Barriers: Integrating Crop Production Practices and Comprehensive Fertilization Strategies – A Cropping System Approach***

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Project Cooperators: Juan Enrico, Guillermo Balboa, Gabriel Barth, and Claudinei Kappes

This project is studying the effects of different farming systems on soybean yield in the major production regions of the Americas. The objectives are to: 1) quantify soybean yields across various production and fertilization practices; 2) quantify the yield gap between common farmer practice and more intensive management systems; 3) measure nutrient uptake and removal; and 4) examine nutrient partitioning between soybean plant organs. Field experiments were conducted in the 2016/17 season at Ponta Grossa (Parana) and Itiquira (Mato Grosso) in Brazil and Oliveros (Santa Fe) in Argentina, and in 2017 near Scandia (Kansas, USA).

The experiments at Ponta Grossa and Itiquira evaluated different combinations of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), micronutrient fertilization, and liming. Average yields were lower at Ponta Grossa than Itiquira where soybean averaged 4,794 kg/ha and 5,423 kg/ha, respectively. While in the maize phase, yields averaged 15,588 and 7,926 kg/ha for Ponta Grossa and Itiquira, respectively. There was no significant response to treatments observed. A study on nutrient accumulation and partitioning on a modern variety has also been carried out at Ponta Grossa.

The experiment at Oliveros evaluated four treatments: common practice (CP); comprehensive fertilization (CF), or CP plus fertilizer input (N, P, K, S, and micronutrients); production intensity (PI), which included narrower rows and higher population, but no fertilizer; and ecological intensification (EI), or PI plus fertilizer input. Soybean yield was in the range of 4,000 to 4,500 kg/ha. Production intensity significantly improved grain yields by 6%, but fertilizer management just tended to increase yields by 4%. In maize, grain yields were between 7.3 and 11.3 t/ha. Grain yield increased by 44% under PI or EI. Fertilization management did not affect yield in late-planted maize (CF and FP treatments), and increased yield by only 4% in the production intensity treatment (comparison PI vs. EI).

The Scandia site included both dryland and irrigated experiments. Treatments included the same four as

Oliveros, plus an advanced (AD) treatment, which was EI plus micronutrients and fungicides. Under dryland, average yield was 4,200 kg/ha (range 2,880 to 5,690 kg/ha). Overall irrigated soybean yield was 4,350 kg/ha (range 2,950 to 5,490 kg/ha). Under both water conditions, the treatments of EI and AD showed the highest yields with differences with PI under irrigated conditions. There were no differences between EI and AD at both water environments. CF and PI yielded more than CP under irrigation (750 and 1,200 kg/ha). Production intensification with balanced nutrition (EI, AD) produced 55% and 58% more yield than CP for dryland and irrigated conditions. After four years of rotation in high yielding environments (irrigated), CP yields differed statistically from all other treatments showing the negative impact of the lack of a balanced nutrition program in the production system. The study is planned to continue in 2018. *IPNI-2014-GBL-62* ❖



# Mexico and Central America Program

Dr. Armando Tasistro, Director (Retired)

## Mexico

### ***Maize Response to Potassium and Gypsum in Acid Soils of Chiapas, Mexico***

Project Leader: Robertony Camas, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP)  
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This Canpotex-supported project, was carried out in cooperation with Mexico's National Agricultural Research Institute (INIFAP) and the International Maize and Wheat Improvement Center (CIMMYT). The project began in 2016 to fine-tune potassium (K) and gypsum rates for maize production in the acid soils of La Frailesca (Chiapas). Four K application rates (0, 60, 120, and 180 kg K<sub>2</sub>O/ha) and four gypsum application rates (0, 1.25, 2.5, and 5 t/ha) were factorially applied at two farms on soils with 0.2 cmol/kg of exchangeable K. Based on previous experience that showed the efficacy of correcting soil acidity first, both experimental sites received a blanket dolomitic limestone application calculated to decrease exchangeable aluminum (Al) below 20% of the effective cation exchange capacity, which is the critical threshold for maize in the area.

Maize yield increased linearly from 6.5 to 8.2 t/ha, when 120 kg K<sub>2</sub>O/ha was added and stabilized afterwards. Likewise, the response to gypsum peaked at 8.3 t/ha, when 1.25 t gypsum/ha was applied, with no further yield increase at higher rates. These results are consistent with those obtained earlier under comparable soil, environmental, and management conditions, and have allowed local advisers to start planning the transfer of these technological options to farmers. *IPNI-2016-MEX-62* ❖



# North America Program

**Dr. Tom Bruulsema, Vice President Americas & Research**

**Dr. Rob Mikkelsen, Vice President Communications**

**Dr. Tom Jensen, North America Program Director**

**Dr. Steve Phillis, North America Program Director**

**Dr. Tai McClellan Maaz, Nitrogen Program Director**

**Dr. Heidi Peterson, Phosphorus Program Director**

**Dr. Scott Murrell, Potassium Program Director**

## Canada

### ***Seed Row Tolerance of 16-20-0-13 and 12-40-0-6.5S-1Zn in Western Canada***

Project Leader: Bill Hamman, Hamman AG Research, Lethbridge, AB, Canada. Email: [whamman@shaw.ca](mailto:whamman@shaw.ca)

The majority of phosphorus (P)-based fertilizers are either applied directly in the seed furrow (seed row) or side banded close to the seed row, for the growing of small grain cereals, canola, and lentils in the western Prairie Provinces of Canada. Improved crop genetics have resulted in increased crop yield potentials, and accompanying increased removals of P in harvested grain. Farmers want to increase seed row P applications but information is lacking as to whether crop stands and yields may decrease at the higher seed row P application rates. A research study assessing the effect of low and elevated application rates of 16-20-0-13 sulfur (S) and 12-40-0-6.5S-1 zinc (Zn) compared to monoammonium phosphate (MAP) placed in the seed rows of spring wheat, canola, and lentils was continued with a regional research association (Farming Smarter) near Lethbridge, Alberta. During the crop seasons of 2015 and 2016, the research was conducted by a different private third-party research group, assessing seed row fertilizer effects on both canola and spring wheat.

This research was continued in 2017 to again assess the seed row fertilizer effects on canola, and this year spring wheat was replaced with lentils. The change to lentils instead of spring wheat was due to there being little to no adverse effect on the stands and yields of spring wheat observed in 2015 and 2016. Due to the increasing lentil acres grown, information on seed row effects is needed. The additional year of research was conducted on a medium-testing P soil a few km east of Lethbridge, AB. For canola, there was a minor observable decrease (9%) in stand establishment at all rates of P (20 through to 40 lb P<sub>2</sub>O<sub>5</sub>/A). However, even though the canola crop stand was somewhat decreased, it was compensated through growth by increasing stem branching to produce similar canola yields. There was a similar trend for lentils, with an 8 % reduction in crop stand on average for all of the P fertilizers applied in the seed row, but the yields were not adversely affected. This research shows that greater rates of seed row P can be tolerated, up to at least 30 lb P<sub>2</sub>O<sub>5</sub>/A, without significant adverse effects on yields. *IPNI-2015-CAN-AB35*

### ***Evaluation of Enhanced Nitrogen Use Efficiency Products***

Project Leader: Dani Degenhardt, Alberta Innovates Technology Futures, Edmonton, AB, Canada.

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This project first consisted of conducting a comprehensive literature review on enhanced efficiency nitrogen (N) fertilizer products from research conducted in western Canada. An impressive data set has been gathered from cooperating researchers and is being analyzed for an economic cost-benefit analysis. Work on the literature review progressed well in 2017. There are a few researchers that have recently submitted their results for peer-reviewed scientific publication, and this further information will be added to the study database of results. The majority of the research data was collected by May 2017. Agronomic yield data from field research trials, along with prices of the various enhanced-efficiency and regular N fertilizers, as well as equipment and labor costs, are being used to develop overall cropping system budgets and compare the various N fertilization products in the final report.

The final report of this project is planned to be completed in 2018. *IPNI-2016-CAN-AB37*

### **Update of Gray Wooded (Luvisolic) Soils Management Publication**

Project Leader: Dick Puurveen, University of Alberta, Edmonton, AB, Canada. Email: puurveen@ualberta.ca

Project Cooperators: Miles Dick

Progress on the update of the publication “Gray Wooded (Luvisolic) Soils Management” went well in 2017. The scientists working on the project summarized agronomic yield data, and soil and plant analytical results taken and gathered over the last four decades, at the University of Alberta Breton Plots Long-term Research site. The last edition was published in 1971, and recent research results will better advise farmers growing crops on these soils. There has also been an updated literature search completed to compare the Canadian results to the research studies in Russia and Scandinavia on similar soil types.

During 2017, a first draft revised version was completed. This draft is being reviewed by cooperating scientists and a second draft will be completed by the early summer of 2018. It is planned to update and revise the publication and produce an additional e-publication version. This initiative is extremely relevant and needed as there is land in the Boreal Forest areas of northwest Alberta that is being logged, cleared, and developed for cropped agriculture. The recommendations for cropping systems and nutrient management from the Breton Plots research, on these formerly forested soils, will help farmers better manage and keep these soils healthy and productive. *IPNI-2016-CAN-AB38*

### **Supplemental Magnesium on Soils that Grow Crops Low in Magnesium**

Project Leader: Dianne Westurlund, Chinook Applied Research Assn, Oyen, AB, Canada. Email: cara-dw@telus.net

The cation exchange complex of many neutral to alkaline pH Great Plains soils in North America are dominated by the cations calcium ( $\text{Ca}^{+2}$ ), magnesium ( $\text{Mg}^{+2}$ ), potassium ( $\text{K}^+$ ), and sodium ( $\text{Na}^+$ ). These cations can interact, and an excess of one may interfere with crop availability and root absorption of another. Some consulting agronomists emphasize the use of recommended K:Mg ratios of 1:2 to help decide whether or not to apply K fertilizer. The use of these ratios is based on research from New Jersey by Bear in 1945 that suggested the ideal percentages of exchangeable cations be 65% Ca, 10% Mg, 5% K, and 20% H (hydrogen). Using this information, cation ratios of the following are Ca:Mg of 6.5:1, Ca:K of 13:1, and Mg:K of 2:1. However, the majority of agronomists and researchers suggest that plant availability based on part per million (ppm) values from regionally used soils tests, calibrated with regional field response trials is more useful. Even though most western Canada Prairie soils tend to have quite high Mg availability, there can be situations where fields receive repeated livestock manure applications, and high availability of K may interfere with Mg uptake by crops on these soils.

This project was conducted on such a soil, in the southwest area of the province of Alberta, near Stavely, AB. The available K, from soil test results, was estimated at 2,140 lb K/A in the top 18 in. of soil, compared to available Mg of 247 lb/A. A research experiment was conducted using two crops (canola and spring wheat), on a sandy loam textured, 6.4 pH, cation exchange capacity (CEC) of 11, and 3.9% organic matter soil. A randomized complete block experimental design was used with five treatments: 1) control with no Mg added; 2) granular KMag ( $\text{K}_2\text{SO}_4\text{MgSO}_4$ ) seed row-applied at 4 lb Mg/A; 3) granular magnesium sulfate ( $\text{MgSO}_4$ ) at 4 lb Mg/A seed row applied; 4) Foliar Mg at pre-elongation stage at 1 lb Mg/A; and 5) two foliar applications, each at 1 lb Mg/A, applied at pre-elongation and again at early flowering. The twice foliar Mg, and granular  $\text{MgSO}_4$  treatments resulted in the highest yields, respectively 28 and 27 bu/A compared to the check treatment of 24 bu/A for the canola, and 46 and 43 bu/A compared to 38 bu/A for the spring wheat, at 90% statistical confidence with LSDs of close to 7 bu/A. This research study will be expanded to two sites in the 2018 crop season, with the same crops, both sites on highly manured soils. *IPNI-2017-CAN-AB39*

### **Kenneth M Pretty Graduate Scholarship**

Project Leader: University of Guelph, Ontario Agricultural College, Guelph, ON, Canada. Email: oacinfo@uoguelph.ca

In memory of Kenneth M. Pretty (OAC, 1951), a scholarship of \$750 is awarded annually to a student in the School of Environmental Sciences, University of Guelph, who is conducting research in the area of plant nutrition or soil fertility. The recipient is selected on the basis of high academic achievement. The funds are provided jointly by the late Dr. K.M. Pretty and by the International Plant Nutrition Institute (IPNI). Application is not required.

In 2017, the award was presented to Pedro Machado, PhD candidate, who is doing research on nitrous

oxide emissions with IPNI 4R Research cooperators Dr. Claudia Wagner-Riddle. IPNI VP Dr. Tom Bruulsema attended the awards banquet and discussed IPNI's mission and 4R Nutrient Stewardship, with Mr. Machado and several other scientists and students in soil fertility and soil chemistry. *IPNI-1993-CAN-ON13*

### **Long-Term Optimum Nitrogen Rate for Corn Yield and Soil Organic Matter**

Project Leader: Bill Deen, University of Guelph, Dept. of Plant Agriculture, Guelph, ON, Canada.

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Project Cooperators: John Lauzon and Greg Stewart

Decisions on optimum nitrogen (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 using fertilizer application 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. Treatments include five application rates of N fertilizer ranging from 27 to 230 lb/A in a factorial arrangement with two times of application (pre-plant and sidedress) and differing levels of N applied the previous year.

Over the course of this trial so far, optimum N rates have ranged from 120 to over 230 lb/A, correlating directly to yields ranging from 115 to 220 bu/A. In seven of the eight years, optimum N application rates exceeded previous local recommendations. Based on results from this research, new Harmonized General (N Calculator) and Soil Nitrate (PSNT) Nitrogen Rate Recommendations for Ontario Corn were approved in December 2014 and have been implemented. The new recommendations allow the use of the pre-sidedress soil nitrate test, along with yield goal, to guide N recommendations. Yield results for the first six years up to 2014 were published in *Better Crops* 99(2):16-18.

Yield response to N in 2017 was similar to that of 2014, but achieved at greater efficiency in the sidedress treatment. Optimum yields of 193 bu/A were achieved with 155 lb/A of N applied as sidedress, or 195 lb/A applied pre-plant. Check plots continue to show little difference in yield, whether following corn fertilized with 130 lb N/A or 30 lb N/A.

Future work aims to integrate the information on soil N, soil organic matter, and yield resiliency to climate, using the DNDC model to assess sustainability impacts of N rate and timing decisions. This project has also received support from the Ontario Agri Business Association for sampling soil residual nitrate and soil organic carbon, and from Fertilizer Canada to measure nitrous oxide emissions. The study continues for its final year in 2018, at the end of which impacts on soil health will be assessed. *IPNI-2008-CAN-ON29*

### **Improving Phosphorus Efficiency in Crops Through the Management of Highly Effective Beneficial Soil Microorganisms**

Project Leader: Chantal Harmel, Agriculture and Agri-Food Canada, SPARC, Swift Current, SK, Canada.

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Arbuscular mycorrhizal fungi (AMF) forms a symbiosis with 80% of plant species. In the context of the Prairie Provinces of western Canada, this includes most field crops except for canola and mustard. Plants benefit from association with AMF by enhanced phosphorus (P) absorption. Plants supply photosynthetically produced carbon substrate to AMF as a food source for the fungi. The objectives of this research initiative are to assess the effects of using a commercial AMF inoculant (trade name MYKE®PRO) containing a reported superior AMF strain (sold for field crops since 2011), compared to an indigenous AMF community in the uninoculated treatments. Variable effects of this product on commercial crop yields have been reported in the prairie farming community, but its value in field crops has rarely been appropriately assessed through independent tests. In our study, its effects on nutrient (N and P) absorption, crop yield and microbial diversity, and its persistence in pulse-based rotation systems are being examined in 2-year crop sequence experiments. Trials are conducted on P-deficient soils, on two experimental farms, in Swift Current, Saskatchewan and Beaverlodge, Alberta, and on two commercial organic farms in the Swift Current area. These trials also test the value of P-containing fertilizer materials and the interaction between the inoculant and fertilization. Inoculation with the product or a sterilized inoculant at five different fertilization levels (0%, 75%, and 150% of the recommended rate of P), in the forms of composted manure, finely ground rock phosphate, and commercial mono ammonium phosphate fertilizer (11-52-0) has been applied to the pulse phase of the

rotations at the two Agriculture and Agri-Food Canada (AAFC) Research Stations over the past four years. The organic farms had only composted manure and rock phosphate.

During the four years of research, 2014 through 2017, inoculation with the commercial AMF inoculant had little effect on flax and pulse yields. An incompatibility of this inoculant with local soil biotic or abiotic conditions may limit its function at these sites. The agronomic data, including crop density, crop biomass, crop yield, and plant nitrogen (N), P, potassium (K) and carbon (C) content at blooming stage, soil moisture, and N and P concentrations in the spring at different depths have been collected and analyzed. However, the N, P, K, and C content of seed and straw at maturity and soil N and P concentrations are still being determined from the last year of research. Soil microbial analyses are also in progress. A final report will be prepared and available in late 2018. *IPNI-2014-CAN-SK43*

### **Seed Row Tolerance of 16-20-0-13 and 12-40-0-6.5S-1Zn in Western Canada**

Project Leader: Leader: Bryan Nybo, Wheatland Conservation Area Inc, Swift Current, SK, Canada.  
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The majority of phosphorus (P)-based fertilizers are either applied directly in the seed furrow (seed row) or side banded close to the seed row, for the growing of small grain cereals, canola, and lentils in the Western Prairie provinces of Canada. A research study assessing the effect of low and elevated application rates of 16-20-0-13S (sulfur) and 12-40-0-6.5S-1Zn (zinc), compared to monoammonium phosphate (MAP), placed in the seed rows of spring wheat, canola, and lentils was continued with a regional research association (Wheatland Conservation Area Inc) based in Swift Current, Saskatchewan. The research was conducted assessing seed row fertilizer effects on both canola and spring wheat during the crop seasons of 2015 and 2016. This research was continued in 2017 to assess the seed row fertilizer effects again on canola, and for 2017 switching to lentils from spring wheat. The change to looking at lentils instead of spring wheat was due to minimal adverse effect observed on the stand of spring wheat in the 2015 and 2016 research. Owing to the increasing amount of lentil acres grown, information on seed row effects is needed.

In 2017, the additional year of research was conducted on a low-P soil 45 km west of Swift Current, SK, near Gull Lake, SK. The canola crop stands were only slightly reduced going from the check treatment (zero P) up to 35 lb P<sub>2</sub>O<sub>5</sub>/A for the 16-20-0-13S, and even 40 lb P<sub>2</sub>O<sub>5</sub>/A using the 12-40-0-6.5S-1Zn or 11-52-0 fertilizers. There were 10.8 plants/m of row for the check treatment compared to a lowest measurement at 6.3 plants/m for one of the higher rates of P<sub>2</sub>O<sub>5</sub>. This lower plant stand did not adversely affect crop yield. For example, the 35 lb P<sub>2</sub>O<sub>5</sub>/A rate of 16-20-0-13S yielded 38.4 bu/A compared to a significantly lower yield of canola of 34 bu/A for the check treatment. There was a similar trend for the lentils, as fertilizer rates greater than 20 lb P<sub>2</sub>O<sub>5</sub>/A resulted in a slight reduction in crop stand, but yields were not adversely affected. In fact, for both the canola and lentils there was respectively a greater than 3 or 5 bu/A yield response to added P fertilizer for all P rates from 15 to 30 lb P<sub>2</sub>O<sub>5</sub>/A, compared to no P applied. This research shows that greater rates of seed row P can be tolerated to at least 30 lb P<sub>2</sub>O<sub>5</sub>/A, without significant adverse effects on crop yields. *IPNI-2015-CAN-SK46*

### **Developing Three Training Videos. Topic "Training Agriculture Retail Staff to Use 4R Nutrient Management with Farm Customers"**

Project Leader: Trish Meyers, Federated Co-operatives Limited, Saskatoon, SK, Canada. Email: [t.meyers@fcl.ca](mailto:t.meyers@fcl.ca)

The work on the development of training videos progressed well in 2017. Two days of video recording were completed with Federated Co-op Ltd. staff, one near Neerlandia, AB on July 4, 2017 and the second near Saskatoon, SK on Wednesday July 19, 2017. A professional videographer was contracted for the video and audio recording, and Tom Jensen, Director, IPNI North America Program, assisted with organization and interviewing of the Co-op staff. Four front-line crop advisers and one agronomy manager were interviewed and videotaped, discussing the following questions:

1. How did you learn about 4R Nutrient Management, and what do you do to learn more?
2. How do you introduce farm customers to using 4R principles in their fertilizer and manure applications?
3. How might farmers make changes in nutrient management by using 4R Principles?
4. How do you assess the success and usefulness of 4R Nutrient Management on the farms, and with farm customers?

The video editing and production of training videos is on-going. One general video covering all four questions noted above was edited and used at a Co-op agronomy training session held in Saskatoon, SK on February 7-8, 2018. Two hundred crop adviser staff were in attendance. The additional videos will be edited and produced in 2018 by the Co-op advertising group. *IPNI-2017-CAN-SK47*

## United States

### ***Variability in Soil Test Potassium and Crop Yield***

Project Leader: Antonio Mallarino, Iowa State University, Department of Agronomy, Ames, IA, USA.  
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The goal of this long-term research effort has been to improve the potassium (K) management of corn and soybean. Extensive research in the North Central region of the U.S. has investigated, separately, both nitrogen (N) and K fertilizer management for corn. However, there is scarce information available about how N and K interactions affect corn grain yield and nutrient uptake. The objective of this study was to evaluate the effects of various combinations of N and K rates on corn yield, N and K tissue concentrations, and N and K removed with grain harvest. Two trials with continuous corn were conducted from 2013 to 2016 at fields with Webster (northern Iowa) or Mahaska (southeast Iowa) soils, which were managed with chisel-plow/disk tillage. The annual combinations consisted of five N rates (0 to 300 lb N/A) and four K rates (0 to 72 lb K<sub>2</sub>O/A). Granulated urea was broadcast and incorporated into the soil in the spring at one site and a urea ammonium nitrate solution was injected at the V4 to V5 growth stage at the other site. Potassium chloride (KCl) was broadcast and incorporated into the soil in the spring at both sites. Leaves opposite and below the primary ear were sampled at the R1 growth stage and grain was sampled at harvest.

Fertilization with N increased leaf and grain tissue N concentrations, and fertilization with K increased the K concentration of both tissues. Potassium fertilization had no clear effect on leaf and grain tissue N concentrations. Nitrogen fertilization decreased or did not affect leaf and grain K concentrations when K was not applied and the soil K supply limited yield. Potassium fertilization alleviated or offset the effect of N application that reduced tissue K concentrations.

There was a large grain yield response to N fertilizer and a smaller response to K fertilizer at both sites, and there were significant N by K interactions. Corn yield and the yield response to N were higher with adequate K supply compared with K deficient treatments. Similar interactions were observed for N and K removed with grain harvest. The study demonstrated that K deficiency not only limits corn yield, but also limits its capacity to respond to N fertilization. *IPNI-1999-USA-IA9*

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

Project Leader: E. David Dickens, Warnell School of Forest Resources, University of Georgia, Statesboro, GA, USA.  
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Project Cooperator: David Moorhead

A fertilizer trial was established in Georgia in a thinned loblolly pine stand in 2014. The experimental design was three replications in a randomized complete block design using four fertilizer treatments. The treatments included: 1) a full dose of nitrogen (N) and phosphorus (P), and potassium (K) applied on February 18-19, 2014 and ½ dose NP or NPK application on February 18-19, 2014 with second ½ dose applied in February 2017 - all fertilizer treatment plots had a herbicide application in September-October 2013 prior to fertilizer treatments; 2) a herbicide-only treatment; 3) NPK-only treatment; and 4) an untreated control. The dominant soil series on the tract, based on Natural Resources Conservation Service (NRCS) soil maps is Eustis, a somewhat excessively drained loamy sand formed in coarse-textured marine and fluvial sediments. This soil series may not support good loblolly pine growth without NP or NPK fertilization as indicated by the current growth rate on the site through the early to mid 20-yr-old age class.

The major objectives of the study are to: 1) quantify the magnitude and duration of wood volume response to the fertilizer treatments; 2) determine changes in product class distribution; 3) determine the cash flow and rate of return for each fertilizer combination compared to unfertilized control plots; and 4) discern if ½ dose applications of NP or NPK fertilizers, applied three years apart, enhance growth compared to a single NP or NPK treatment on these sandy somewhat excessively well-drained soils. Baseline soil, foliage, tree measurements and one year post-application soil and foliage samples were taken in January 2015. Third-year

tree measurements and the second of the ½ doses of NP and NPK were taken/applied in February 2017 and are being summarized. In an earlier study, fertilized loblolly pines responded dramatically to the one-time fertilizer application. The NP treatment resulted in US\$1,301/A of wood and the NPK, sulfur and copper treatment produced \$1,605/A of wood. These values were compared to the control (herbicide only) which only resulted in \$890/A in the eight-year study period, showing gains from fertilization of \$411 and \$715/A. *IPNI-2004-USA-GA26*

### **Measuring the Nutrient Accumulation Rates of High-Yielding Potatoes and Sugar Beets**

Project Leader: Amber Moore, College of Southern Idaho, Twin Falls, ID, USA. Email: [amberm@uidaho.edu](mailto:amberm@uidaho.edu)

In-season accumulation and partitioning of dry matter, macro- and micro-nutrients by glyphosate-resistant sugar beet (*Beta vulgaris* L.) varieties in irrigated production systems are not well understood. A study was conducted to evaluate amounts and rates of dry matter, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B) accumulated by a high-yielding, glyphosate-resistant sugar beet variety (BTS 21RR25) on an irrigated Portneuf silt loam soil of southern Idaho. Nitrogen, P, and K fertilizers were applied at agronomic rates based on soil test values.

Whole plants were destructively sampled at 16-d intervals from June 9 (germination) to September 30 (full maturity), separated into tops (leaves, petioles, and crowns) and roots, and analyzed for dry matter amounts and nutrient concentrations to estimate amounts and rates of nutrient accumulation. Total mean accumulation at harvest over four replications was 67.5 t/ha (fresh beets), 268 (N), 69 (P), 529 (K), 200 (Na), 122 (Ca), 109 (Mg), 28 (S), 13 (Fe), 1.85 (Mn), 0.64 (Zn), 0.16 (Cu), and 0.68 (B) kg/ha (total dry plant). Distribution among tops and roots and daily rates of accumulation throughout the growing seasons were measured.

Amounts and rates of nutrient accumulation measured in this study provided information on the time of maximum nutrient uptake and total removal of nutrients at different growth stages. The study results can be used to develop pre-plant and in-season nutrient applications guidelines for glyphosate-resistant sugar beet varieties in high-yielding irrigated production systems. *IPNI-2013-USA-ID13*

### **Improving the Reliability of Soil Potassium Testing and Recommendations**

Project Leader: Antonio Mallarino, Iowa State University, Ames, IA, USA. Email: [apmallar@iastate.edu](mailto:apmallar@iastate.edu)

Project Cooperators: Ryan Oltmans and Michael Thompson

This project is in its final stages and the Potassium (K) Fellow is completing data management and statistical analyses. The study has two major objectives.

The first objective is to study the relationships among soil-test K, non-exchangeable K, and relevant properties of soils of the western humid Corn-Belt (those with large acreages dedicated to corn and soybean production). Chemical and mineralogical analyses were completed for 23 soils. Soil-test K concentrations ranged from 60 to 580 mg K/kg when samples were dried at 40° C prior to analysis. When samples were kept moist, values ranged from 44 to 466 mg K/kg, indicating that drying samples prior to analysis tended to increase soil-test K concentrations. Non-exchangeable K, the K in the interlayers of phyllosilicate minerals, ranged from 153 to 3,510 mg K/kg or 107 to 1,860 mg K/kg, depending on the analytical method used. The moist soil test K values correlated better with crop yield response to K. The short-term fixation of the soils was tested, and found to range from K-fixing to K-releasing. Minerals present across the samples were smectite (7 to 65%), vermiculite (2 to 39%), mica (8 to 27%), and kaolinite (20 to 70%).

The second objective is to study how K additions, crop removal, and leaching of K from crop residue influences changes in the ratio between soil K and non-exchangeable K for different soil sampling dates under field conditions. On average, soybean removed 68% more K than corn, averaging 74 kg K/ha. Initial residue samples taken at grain harvest averaged 81 kg K/ha for corn and 30 kg/ha for soybean. In the spring, at the time of the final residue sampling, 45 kg K/ha had been recycled back into the soil from corn residue and 24 kg K/ha had been recycled from soybean residue. Even with this recycling, soil tests from samples taken in the fall at harvest were higher than those taken in the spring for most trials. Non-exchangeable K increased or stayed nearly the same from fall to spring but decreased in the spring in soils from northern Iowa, which are poorly to very poorly drained and formed on glacial till. The Iowa soils internal drainage seems

to be as important or more important at determining differences than clay mineralogy. For both objectives, relationships among the measurements and other soil properties and precipitation are being examined at this time.

A final report will be completed during 2018. *IPNI-2013-USA-IA20*

### **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, KS, USA. Email: [schlegel@ksu.edu](mailto:schlegel@ksu.edu)

This long-term western Kansas study was initiated in 1961 to evaluate the response of irrigated continuous corn and grain sorghum to nitrogen (N), phosphorus (P), and potassium (K) fertilization. It remains one of the few continuous, long-term crop nutrition studies in the U.S.A. For both crops, N treatments were 0, 40, 80, 120, 160, and 200 lb N/A and P treatments were 0, 40, and 80 lb P<sub>2</sub>O<sub>5</sub>/A and 0 and 40 lb P<sub>2</sub>O<sub>5</sub>/A, respectively. The K treatments for grain sorghum were 0 and 40 lb/K<sub>2</sub>O/A.

Grain yields were 25% and 8% lower for corn and sorghum, respectively, in 2017 compared to the 10-year average. Nitrogen applied alone increased corn yield by 70 bu/A, while N and P applied together increased yield up to 130 bu/A (compared with unfertilized control). Phosphorus alone increased yield by less than 10 bu/A. Maximum yield for corn (174 bu/A) was obtained with the addition of 200 lb N and 80 lb P<sub>2</sub>O<sub>5</sub>/A. At this same N rate, 40 lb P<sub>2</sub>O<sub>5</sub> increased yield by 34 bu/A over no P application (P control), while 80 lb P<sub>2</sub>O<sub>5</sub> increased yield by 60 bu/A. The addition of P (either 40 or 80 lb P<sub>2</sub>O<sub>5</sub>/A) almost doubled apparent fertilizer N recovery in grain (from 31 to 56%) over the zero-P control and averaged across all N rates. At the highest fertilizer rates, the apparent fertilizer N recovery was 42%, whereas the apparent fertilizer P recovery in the grain was 61%.

Nitrogen fertilizer alone increased sorghum yield by 53 bu/A, while N plus P increased yield by up to 67 bu/A. Phosphorus alone increased sorghum yield by 9 bu/A, and P plus K increased yields by 10 bu/A. The application of K had no effect on sorghum yield in 2017 nor throughout the study period. Maximum sorghum yield for corn (137 bu/A) was obtained with the addition of 160 lb N, 40 lb P<sub>2</sub>O<sub>5</sub>/A, and no K. At this N rate, 40 lb P<sub>2</sub>O<sub>5</sub>/A without K increased yields by 17 bu/A. The addition of 40 lb P<sub>2</sub>O<sub>5</sub>/A fertilizer also increased the apparent fertilizer N recovery in grain from 36% (zero-P control) to 50% when averaged across all N rates. The addition of 160 lb N/A increased the apparent recovery of P fertilizer over the control from 18 to 70%. At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 32% for N, 66% for P, and 39% for K. *IPNI-1991-USA-KS23*

### **Characterization of Nitrogen Fixation in US Soybean Systems**

Project Leader: Ignacio Ciampitti, Department of Agronomy, Kansas State University, Manhattan, KS, USA.  
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The demand for nitrogen (N) in modern soybean production can be exceptionally high. A soybean crop that yields 70 bu/A may take up 320 lb N/A, with half accumulated after full-pod stage (R4). The primary sources of N for soybean are biological N fixation (BNF) and inorganic soil N. Fifty to 60% of plant N may be derived from BNF, which declines with increasing mineral N in the soil.

Nitrogen fixed by soybeans is assimilated and transported in the plant xylem in three forms: 1) ureides; 2) amino-N; and 3) nitrate. As nodulation activity increases, the ureide content in the xylem increases. Therefore, ureide concentration in the soybean stem represents an indirect measurement of how much N comes from fixation, and this approach is simpler and less expensive than the traditional <sup>15</sup>N isotope method (a more direct measure of BNF). The objectives of this project are: 1) to perform a regional characterization of soybean N fixation using the ureide technique; and 2) to explore the impact of exogenous soil N on seasonal BNF dynamics.

Thirty-three sites across the U.S. Corn Belt were established in 2016, and the experiment was replicated in 25 locations in 2017. Four soybean N treatments were imposed in a randomized complete block design: 1) zero N control; 2) 100 N lb/A applied at planting; 3) 100 N lb/A applied at V4 growth stage; and 4) 100 N lb/A applied at the R2 to R3 stage.

In 2017, grain yield ranged from 41 to 90 bu/A across sites and treatments, and yields were negatively correlated with protein concentration. Nitrogen fertilization had no effect on soybean yields, but significantly

affected the seasonal BNF profiles. The maximum attainable N fixation consistently decreased when N fertilizer was applied at planting or the V4 growth stage, compared with unfertilized soybean. In contrast, the effect of N fertilization at the R2 to R3 stage was variable. The application of fertilizer at the R2 to R3 stage resulted in the highest reduction in BNF of the high N-fixing soybeans, but this effect was not observed for the moderate and low-fixing soybeans. The later application of N fertilizer resulted in a similar reduction as the other N treatment for the moderate-fixing soybeans, but had no effect on BNF of low-fixing soybeans. The changes in BNF throughout the entire growing season, combined with its variability across environments, reinforce the importance of properly characterizing BNF, and reveals opportunities for breeding efforts aimed to improve BNF. *IPNI-2016-USA-KS43*

### ***Pushing the Limits of Fertilizer Nitrogen Recovery in a Semiarid Climate with Improved Nitrogen Management***

Project Leader: Richard Engel, Montana State University, Dept. of Land Resources and Environmental Sciences, Bozeman, MT, USA. Email: [rengel@montana.edu](mailto:rengel@montana.edu)

Project Cooperators: Carlos Romero, Rosie Wallander

A common goal of nitrogen (N) fertility programs should be to provide for the highest recovery of applied fertilizer N in the targeted crop species consistent with maximum yield and economic returns. To improve fertilizer N recovery in semiarid climates, such as Montana, consideration should be given to the use of NBPT (urease inhibitor) with urea or inclusion of nitrate-N sources. Previous research has shown that surface applications of urea made during the over winter period (December to March) are susceptible to volatile ammonia losses. This study was conducted to contrast fertilizer N recovery, yield and grain protein (or % N) of wheat from different N sources including urea, urea augmented with NBPT, urea augmented with a nitrification inhibitor (NI = nitrapyrin) and NBPT, ammonium nitrate, and sodium nitrate  $\text{NaNO}_3$ . The goal was to assess fertilizer N management strategies that would improve fertilizer N recovery.

In 2017, a winter wheat field trial was established at a rain-fed field site at the MSU-Central Agricultural Research Center (CARC) near Moccasin, Montana. The N fertilizers were applied as a spring surface application soon after re-growth of the wheat after breaking winter dormancy. Fertilizer N recovery was estimated using  $^{15}\text{N}$  isotope enriched (~5%) fertilizer materials. Growing season conditions were characterized by below normal rainfall that gave lower than normal crop yields. The winter wheat yield and grain N concentration were responsive to N fertilization as pre-plant soil tests revealed low indigenous soil nitrate concentrations (< 40 lb available N/A). We found that  $^{15}\text{N}$  fertilizer recovery in grain and total biomass, or fraction of N in the crop derived from  $^{15}\text{N}$ -labelled fertilizer was generally higher for  $\text{NaNO}_3$  compared to other N sources. We attributed this response to two factors: (1) volatilization of ammonia from the urea fertilizers; and (2) preferential microbial immobilization of N applied as ammonium compared to nitrate. The impact of volatility on  $^{15}\text{N}$  fertilizer recovery was evident from the addition of NBPT to urea. The addition of NBPT improved fertilizer  $^{15}\text{N}$  recovery in the above-ground biomass by almost 11%. The results of this trial were consistent with previous trials at N-responsive sites by finding that fertilizer N recovery from nitrate sources are often greater than from urea in Montana's semiarid climate. A final project report will be prepared in 2018. *IPNI-2016-USA-MT19*

### ***Documenting Nutrient Deficiency and Accumulation Rate in Vegetables***

Project Leader: Dharma Pitchay, Tennessee State University, Nashville, TN, USA. Email: [dpitchay@tnstate.edu](mailto:dpitchay@tnstate.edu)

This collaborative project between Tennessee State University and IPNI continues to result in high resolution photographs of nutrient deficiency symptoms of important horticultural crops. The primary accomplishment of 2017 was the documentation of deficiency symptoms of Russet Burbank potatoes growing in hydroponics. Symptoms of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, and zinc deficiency were induced in the greenhouse and carefully photographed. The collection of images was assembled into an e-book that is now available for purchase through the IPNI store (<https://store.ipni.net/>).

Plans for 2018 include the production of additional e-books documenting the nutrient deficiency symptoms of butterhead lettuce, Romaine lettuce, and cucumbers. This will augment the collection of previously completed e-books that currently includes broccoli deficiency symptoms. *IPNI-2012-USA-TN20*

## **Validating Weather and Sensor-based N Prediction Models for Michigan Corn Production**

Project Leader: Kurt Steinke, Michigan State University, East Lansing, MI, USA. Email: ksteinke@msu.edu

Project Cooperator: Jeff Rutan

Differences in weather, particularly the timing and amount of rain, cause variability in corn response to nitrogen (N) fertilizer from one year to another. The regional Maximum Return to Nitrogen (MRTN) approach used in seven midwestern states provides recommendations based on documented yield responses to N, and allows for economic optimization, but does not adjust for year-specific weather events. This trial compared two year-specific approaches as alternatives to MRTN. One was the use of a deterministic daily weather-based crop and soil model (Adapt-N<sup>®</sup>), and the other was a crop canopy sensor (Greenseeker<sup>®</sup>) using an algorithm developed in Minnesota. The trial was implemented at the Michigan State University research station near Lansing, Michigan in 2015 and 2016. Nitrogen fertilizer rates, ranging from 33 to 167% of the MRTN rate, were applied with 40 to 46 lb N/A as starter and the remainder as sidedress urea-ammonium nitrate (UAN) injected into the soil at the V4 growth stage. In comparison, the weather-based rates were determined just before the V8 growth stage, and applied at V8 using a surface band of UAN with urease inhibitor.

In 2015, a year wetter than normal in the first half of the growing season, the optimum N rate of 173 lb/A produced a corn yield of 165 bu/A. The MRTN rate was 140 lb/A, producing a yield of 150 bu/A. The Adapt-N model recommended a higher rate of 171 lb/A producing a yield of 154 bu/A, similar to but slightly below the yield expectation from the N response curve derived from V4 application timing. The crop canopy sensor recommended a rate of only 121 lb/A, resulting in a much lower yield of 138 bu/A.

In 2016, a year drier than normal in the first half of the growing season, the optimum N rate of 123 lb/A produced a corn yield of 208 bu/A. Owing to lower fertilizer prices, the MRTN rate was slightly higher than in 2015, and the Adapt-N model rate was lower. For both, 150 lb/A of N was recommended and this rate produced corn yields identical to those achieved at the optimum rate. The sensor-based N rate of 161 lb/A also produced the same yield.

The results from these two years demonstrated potential for a weather-based approach, and have been published in the *Journal of Crop Improvement*. DOI:10.1080/15427528.2017.1359715.  
*IPNI-2015-USA-MI14*

## **Documenting Nutrient Accumulation Rates in Four Barley Varieties**

Project Leader: Christopher Rogers, Aberdeen Research & Extension Center, University of Idaho, Aberdeen, ID, USA.  
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This project was designed to determine the “Right Time” aspect of nutrient accumulation of four distinct barley varieties (for animal feed, malting, human food, and adjunct). A study conducted in Idaho investigated the cultivar effects on barley grain yield, quality, nutrient concentrations, removal, and nutrient accumulation patterns under irrigated conditions for two-row barley cultivars.

Adjunct and feed barley cultivars produced the highest yields compared with the all-malt and food cultivars. Dry matter accumulation patterns were similar among cultivars, with maximum total nutrient uptake occurring between the soft dough stage and maturity. Protein,  $\beta$ -glucan, test weight, phosphorus (P), magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), and copper (Cu) concentrations were greater or equal in the food cultivar compared with the malt or feed cultivars. Variations in plant and grain nutrient concentrations were measured among the adjunct and all-malt cultivars, which could potentially affect the malting and brewing qualities. Total nutrient accumulation was greatest at either the soft dough stage or at maturity, where specific nutrients were greater at one stage compared to the other. Particular nutrients (e.g., K, Mg, and S) were largely accumulated in the plant (i.e., the stem plus leaves) compared to the grain spike. For other nutrients (e.g., P and micronutrient metals), they were translocated from the plant into the spike during the period between the soft dough growth stage and maturity. Results from these studies provide critical data for two-row barley under high-yielding conditions that can be used to improve future nutrient management decisions and can be used to more accurately predict nutrient cycling in barley cropping systems.

*IPNI-2015-USA-ID14*

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

Project Leader: Gaylon Morgan, Texas A&M University, College Station, TX, USA Email: gdmorgan@tamu.edu

Project Cooperators: Hunter Frame, Danny Fromme, Darrin Dodds, Keith Edmisten, Mike Jones, Randy Norton, Dale Monks, Andrea Jones, Bill Robertson, Randy Boman, Tyson Raper, Katie Lewis, and Mark Kelley

Potassium (K) plays a key role in several critical cotton plant processes, including photosynthesis, activation of protein enzymes, disease and drought stress mitigation, and fiber development. Across the United States Cotton Belt, K deficiency symptoms in cotton have increased over the past decade, which may be reducing lint yield and fiber quality in these areas. In 2015 a project was initiated at 12 locations across the Cotton Belt with the objectives of: 1) quantifying soil K concentrations (at depth) from major cotton production regions in the Cotton Belt experiencing K deficiencies; and 2) evaluating the impact of K application methods and rates on cotton lint yield, quality, and economic return on investment (ROI). Based on these results, the goal was to re-evaluate soil K recommendations and modify as appropriate to optimize yields. Both granular (0-0-60) and liquid (0-0-15) muriate of potash (KCl) sources of K were applied two to four weeks prior to planting cotton at rates of 0, 40, 80, 120, and 160 lb/A  $K_2O$ . In 2016, trial locations were divided, with nine being designated as new sites meaning that a new field location was selected each year of the study (Alabama, Arkansas, Louisiana, Mississippi, North Carolina, Oklahoma, Texas - Lubbock and Williamson Counties, and Virginia).

Discussion of results will include soil macronutrient concentrations at depths of 0 to 6 in., 6 to 12 in., and 12 to 24 in. and cotton lint yield. Locations other than Texas and Oklahoma generally had soil K concentrations less than 150 mg/kg (critical level of K, Mehlich 3), and as such, a yield response to applied K fertilizer was expected. In 2015 and 2016, a significant treatment effect was determined at three locations. Two of those, Williamson County, Texas, and Virginia, had lower yields than most other locations. A positive lint yield response to knife-injected K fertilizer (0-0-15) was measured in 2015 at the Lubbock County location. Inconsistent yield responses at locations with limited soil K or with soil K concentrations well above the critical level indicate that K dynamics in cotton are not well understood and deserve continued investigation. *IPNI-2015-USA-101*

## **Improving Nitrogen Fertilizer Management in Subsurface Drip-Irrigated Cotton**

Project Leader: Kevin Bronson, USDA-ARS, US Arid Land Agric Res Center, Maricopa, AZ, USA.

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Project Cooperators: Pedro Andrade-Sanchez, Doug Hunsaker

An irrigated cotton study was established in Maricopa, Arizona, on a Casa Grande sandy loam. The objectives of the study were: 1) compare lint yields and nutrient use efficiency (NUE) with soil test-based nitrogen (N) fertilizer management with canopy reflectance-based urea-ammonium nitrate (UAN)-N management approach in subsurface drip irrigated cotton; 2) compare lint yields and NUE for full and deficit irrigation in subsurface drip irrigated (SDI) cotton; and 3) construct N balances for subsurface drip irrigated cotton, i.e. quantify total N uptake, N recovery efficiency, nitrate leaching, and denitrification losses. Pre-plant soil nitrate-N (0 to 36 in.) averaged 51 lb/A. Our soil test-based N rate was 154 lb/A (225 lb N/A target minus 51 lb N pre-plant minus 20 lb N/A from irrigation water). We used the same soil test N rate for both the 100 and 75% ET irrigation level, in order to make these treatment comparisons strictly for water level.

Nitrogen deficiency in this study appeared rapidly in several vegetation indices as significant differences in N-fertilized plots vs. zero-N, on day 150, 15 days after the start of fertigation. Several vegetation indices for the reflectance-based N treatment fell significantly below soil test N plots, 29 days after fertigation commenced (N rates for reflectance were initially 50% of soil test target of 154 lb N/A). The last two weeks of the fertigation period, UAN injection rates were the same between the two treatments. Final reflectance-based N rate was 112 lb/A, a significant 42 lb/A less than the soil test treatment. In early August, first open boll biomass samples were taken. Biomass was high at 12,000 lb/A for soil test N and 100% irrigation, and 9,200 lb/A for soil test N at 70% water. Nitrogen and water effects on canopy height related very well to normalized difference vegetation index (NDVI). There was no yield reduction with reflectance-based management compared to soil test N, although biomass was less in the former. A significant savings of 42 lb/A less fertilizer N was achieved with reflectance-based N management. However, the lint yields of 1,600 lb/A were lower than the target of 2,000 lb/A. It is not clear why under SDI we are not obtaining the 1,800 lb/A lint yields we observed with furrow irrigation and overhead sprinkler in earlier studies. The high recovery efficiency of fertigated N of 90 to 92% in the soil test-based, 100% irrigation treatment was not unexpected but is a significant result that solidifies the hypothesis that NUE is very high in fertigated drip systems. *IPNI-2016-USA-AZ10*

## ***Do Critical Soil Phosphorus Concentrations Vary in Space and If So, Why?***

Project Leader: Joshua McGrath, University of Kentucky, Plant and Soil Sciences, Lexington, KY, USA.  
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Approximately 70% of agricultural service retailers offer variable rate nutrient application, with much of this likely based on grid soil sampling. However, research indicates that grids greater than 1/4 acre cannot be accurately interpolated to make variable rate prescriptions. Furthermore, not only does soil phosphorus (P) concentration vary across fields, but it is likely that threshold soil P concentration for crop response (the critical level) varies as well. This project investigates spatial and temporal variability in soil P critical concentrations and P supply for grain crop production as they relate to soil chemistry, soil biology, and rhizosphere interactions that influence crop P requirements.

The methodology relies on numerous sample points covering the variation within fields and between fields and across time. To date, variable rate P management relies on the interpolation of grid sampled soil data and the relationship between covariance and distance, where it is assumed that the greater the distance between points, the less similar their behavior or the lower their covariance. This project evaluates the covariance of yield response at both field and regional scales in order to evaluate fertilizer recommendations for different soil test values. Small plots were randomly established in each field site and then split into subplots that either received P or did not receive P. The difference in yield between the fertilized and unfertilized subplots provides the spatial distribution of yield response at various soil P levels across both the field and sites.

Two field sites were established in Kentucky during 2016. At both sites the the soil P concentration in the majority of plots fell below the University of Kentucky critical level, where a response to P fertilizer would typically be expected. Regardless of soil P concentration, a yield response to P fertilizer application was observed in about 50% of the plots. These preliminary results seem to support the hypothesis that critical level varies spatially across fields. In 2017, an additional field site was added near Blacksburg, Virginia.

In 2018, three additional sites are proposed, one located in Ohio and two in Texas. To date the focus has been on yield and biomass response to P. The next phase of the project focuses on more detailed soil and rhizosphere analysis to understand the mechanisms influencing differential response within narrow soil P concentration ranges. *IPNI-2016-USA-KY13*

## ***Improving Nitrogen Fertilizer Management in Subsurface Drip-Irrigated Cotton***

Project Leader: Tracy Wilson, Central Oregon Ag. Res., Madras, OR, USA. Email: tracy.wilson@oregonstate.edu  
Project Cooperators: Amber Moore

Central Oregon produces 85% of the carrot seed grown in the United States. Very little research is available regarding the nitrogen (N) response of carrots and carrot seed production in this region.

This field project is underway at two farmer fields in Central Oregon to refine fertilizer recommendations for carrot and carrot seed production. A second objective is to measure nutrient uptake and partitioning in both the aboveground (including seeds) and below ground carrot biomass during the growing season that extends over two years. This work will provide new information on the “Right Time” aspect of 4R Nutrient Stewardship for carrot fertilization to more appropriately meet peak nutrient uptake demand periods.

Hybrid carrot seed was planted in 2017 at two low-N sites and irrigated through furrows (Colman site) or drip (Weigand site). Nitrogen fertilizer was basally applied, and additional N was applied at three rates (0, 75, or 110 lb N/A) at bolting. Carrot roots and tops from both female and male plants are harvested twice a month, then weighed, cleaned, dried at 60° C, and then weighed again to determine plant dry matter. Ground plant tissue samples are now being analyzed to evaluate nutrient accumulation patterns during the growing season.

Additional sampling of soil and plant tissue will continue in 2018 during the seed-production phase of carrot cultivation. Plant tissue and soil samples will be used to monitor N movement and accumulation. The quantity and quality of the carrot seeds will also be evaluated to measure the influence of nutrient management practices. *IPNI-2016-USA-OR17* ❖



# China Program

**Dr. Ping He, Director**

**Dr. Shutian Li, Deputy Director**

**Dr. Fang Chen, Deputy Director**

## ***Field Validation of Nutrient Expert® for Single Season Rice in China***

Project Leader: Yuying Li, Hebei Academy of Agricultural and Forest Sciences, Soil and Fertilizer Institute, Hebei, China. Email: [yyli@ipni.ac.cn](mailto:yyli@ipni.ac.cn)

Project Cooperators: Liu Shuquang, Gao Qiang, and Xie Jiagui

Nutrient Expert® (NE) field validation continued for single-season rice in 2017 through 10 on-farm experiments in Jilin and Heilongjiang Provinces of China. The objective was to compare the NE-based fertilizer recommendation method with traditional soil test-based fertilizer recommendations and farmers' practice (FP), in terms of rice grain yield and nutrient use efficiency.

Each individual field site received a site-specific fertilizer application based on the NE tool and soil test results. The average nutrient application rates in the NE-based plots were 171-61-98 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha, the soil test-based plots received an average of 167-63-84 kg/ha, while the FP plots received 175-63-71 kg/ha in Heilongjiang. Average rice grain yield in the NE treatment (9.3 t/ha) was higher than the soil test (8.8 t/ha) and FP treatments (8.1 t/ha), but the values were not significantly different. The average agronomic efficiency (AE) and partial factor productivity (PFP) of nitrogen were 22.9 kg/kg and 54.4 kg/kg in the NE treatment, 20.5 kg/kg and 53.0 kg/kg in the soil test-based treatment, and 15.9 kg/kg and 47.6 kg/kg in the FP treatment, respectively.

For Jilin, the average N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O application rates were 167-65-94 kg/ha in the NE-based plots, 176-69-93 kg/ha in the soil test-based plots, and 182-74-92 kg/ha in the FP plots. There was no significant difference in rice grain yield between the NE (8.8 t/ha), soil test (8.8 t/ha) and FP treatments (8.6 t/ha). Similarly, the AE and PFP values of N among the treatments were not different.

The NE tool provided fertilizer recommendations that improved yield and nutrient use efficiency in single-season rice and it could be useful when soil testing is not available or timely. *IPNI-2014-CHN-NESR*

## ***Field Validation of Nutrient Expert® Soybean in China***

Project Leader: Dan Wei, Heilongjiang Academy of Agricultural Sciences, Soil and Fertilizer Institute, Heilongjiang, China. Email: [wd2087@163.com](mailto:wd2087@163.com)

Project Cooperator: Wei Wang

The Nutrient Expert® (NE) fertilizer decision support system for soybean was calibrated based on collected data from Henan, Anhui, Jiangsu, and Sichuan Provinces in China. The objective was to compare the NE-based fertilizer recommendation with traditional soil test (ST)-based fertilizer application and farmer's practice (FP) on soybean yield and nutrient use efficiency. Additionally, nitrogen (N) and phosphorus (P) rate experiments were conducted to test the N and P application rates for soybean in Henan and Heilongjiang.

The average nutrient application rates in the on-farm comparative studies were 62-43-60 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha, 26-9-9 kg/ha, and 44-54-54 kg/ha for the NE, FP, and ST treatments, respectively. Soybean yield responses to N, P, and K based on the NE treatment were 260 kg/ha, 166 kg/ha, and 300 kg/ha, respectively. The average highest grain yield was obtained in the NE treatment (2,840 kg/ha), but there was no significant yield difference between the NE, FP (2,760 kg/ha), and ST (2,590 kg/ha) treatments. Based on the experiment with various rates of N and P fertilizer, the application of 40-50 kg N/ha and 25-50 kg P<sub>2</sub>O<sub>5</sub>/ha can ensure high soybean yield, and the addition of rhizobium can increase yield by 200 to 450 kg/ha.

Results indicated that NE can maintain or improve soybean yields with appropriate fertilizer application rates. Rhizobium inoculation was a recommended practice, which should be integrated into NE for Soybean systems. *IPNI-2014-CHN-NES*

### **Field Validation of Nutrient Expert® for Early and Late Rice in China**

Project Leader: Jun Nie, Hunan Academy of Agri. Sci., Soil and Fertilizer Institute, Hunan, China.  
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Project Cooperators: Yulin Liao and Shuanhu Tang

Field validation of Nutrient Expert® (NE) fertilizer decision support tool in early and late rice systems in Jiangxi and Hunan Provinces continued in 2017. The objective was to test the NE-based fertilizer recommendation method (NE) against traditional soil testing (ST) and farmers' practice (FP). Field experiments were conducted on five and seven sites each in Hunan and Jiangxi respectively in early rice and late rice.

In Hunan, the highest grain yields were observed for both early rice (6.9 t/ha, with application of 138-53-84 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha) and late rice (7.9 t/ha with 154-53-96 kg/ha) in the NE-based treatment. These yields were significantly higher than those of ST (5.6 t/ha with 145-56-79 kg/ha for early rice, and 7.1 t/ha with 186-40-78 kg/ha for late rice) and FP (5.4 t/ha with 105-49-76 kg/ha for early rice, and 6.8 t/ha with 120-67-76 kg/ha for late rice). The net income from the NE-based recommendation increased by 24% and 26% for early rice, and 11% and 16% for late rice, as compared to FP and ST, respectively.

In Jiangxi, the NE treatment achieved higher yield, but without significant differences as compared to ST and FP treatment for both early and late rice. The NE, ST, and FP treatments received 154-87-72, 144-71-120, and 190-89-180 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha for early rice, and 142-55-60, 176-64-133, and 216-100-231 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha for late rice, respectively. Net income in the NE plots increased by 9% and 11% for early rice, and 6% and 13% for late rice, over the FP and ST.

Results of both early and late rice trials indicated that NE can maintain or improve grain yields with less nitrogen (N) or less phosphorus (P) fertilizer inputs, and more balanced fertilizer application. Besides changing the rates, NE also recommends a second N application at a later stage of crop growth than FP for both early and late rice crops. The higher yield and profitability achieved by the NE-based fertilizer recommendation were due to the application of the right fertilizer source, at the right rate and time. *IPNI-2014-CHN-NEER*

### **Field Validation of Nutrient Expert® for Middle Season Rice in China**

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Project Cooperators: Donghai Liu and Lujiu Li

The Nutrient Expert® (NE) field validation study continued for middle season rice in 2017. Field experiments were set up in the Anhui and Hubei Provinces of China to compare the NE-based fertilizer recommendation method to the recommendations based on soil testing (ST) and farmer's practice (FP).

In Anhui, the average nitrogen, potassium, and phosphorus (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O) recommendations were 154-54-105 kg/ha, 195-69-93 kg/ha, and 208-67-67 kg/ha for the NE-based, ST-based, and the FP plots, respectively. Rice grain yield in the NE treatment (8.9 t/ha) was not significantly different from the ST recommendation (8.9 t/ha) and FP treatment (8.2 t/ha). The average agronomic efficiency (AE) and partial factor productivity (PFP) values of N were 14.3 kg/kg and 57.7 kg/kg in the NE treatment. The average AE and PFP in the ST-based and FP treatments were 11.6 kg/kg and 46.0 kg/kg, and 7.5 kg/kg and 39.7 kg/kg, respectively.

In Hubei, the average N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O recommendation for the NE plots was 159-70-64 kg/ha, for the ST-based plots was 158-62-90 kg/ha, while the FP plots received an average of 163-117-117 kg/ha. No significant grain yield difference was observed between the NE-based, ST-based, and FP (7.4 t/ha, 7.6 t/ha, and 7.4 t/ha, respectively) nutrient applications. The AE and PFP values also did not show any significant difference among NE, ST, and FP treatments.

The on-farm trials suggest that the NE could be used as an effective tool for providing 4R-based site-specific fertilizer recommendations when the soil test is not available or timely. *IPNI-2014-CHN-NEMR*

### **Best Management Practice of Potassium for Sunflower in Northwest China**

Project Leaders: Tianwen Guo, Institute of Dryland Farming, Gansu Academy of Agricultural Sciences, Gansu, China.  
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The effect of potassium (K) fertilization at various water regimes on oil sunflower yield and quality was studied during 2015 to 2017 in Dingxi County of Gansu Province. The experiment was a randomized complete block designed with three replicates. There were three irrigation regimes: 1) rain-fed without plastic mulch (R); 2) double ridges of plastic-mulched furrows added at sowing (PM); and 3) PM plus irrigation (PMI). Four rates of potassium chloride (KCl) were applied at 0, 48, 84, and 120 kg K<sub>2</sub>O/ha. In the PMI water regime, sunflower was irrigated at budding, early flowering, and later flowering with 60 to 108 mm water each time. The average precipitation during the growing stage from April to September in three years was 270 mm. The sunflower variety was Longkuiza No. 3 and the plot area was 33 m<sup>2</sup>. All the plots received the same amount of recommended N at 150 kg/ha and P<sub>2</sub>O<sub>5</sub> at 90 kg/ha. All N, P, and K fertilizers were applied basally.

The results from the three years of the study indicated that the water regime significantly influenced total dry matter, achene yield, and thousand-achene weight of oil sunflower. These parameters were further improved with better water availability. Compared with R, the PM and PMI water regimes increased total dry matter by 72% and 98%, increased achene yield by 63% and 104%, increased thousand-achene weight by 24% and 39% respectively, and improved fertilizer K use efficiency. Water regimes also influenced sunflower grain quality. The grain oil content resulting from PM and PMI was 2% more than that of R.

Compared with zero-K control plots, K fertilization increased achene yield by 4 to 9% with a mean of 6% with the R water regime, increased achene yield by 9 to 20% with average of 15% with the PM water regime, and increased achene yield by 12 to 20% with mean of 16% with the PMI water regime. Thus, the effect of K fertilization on achene yield was increased by the improvement of water conditions. Achene yield increased with increasing K application rates, and the highest achene yield was observed at 120 K<sub>2</sub>O/ha under the three water regimes. Potassium fertilization also improved grain quality of oil sunflower. The average oil content in sunflower grains by K fertilization was 1.2, 2.5, and 3% over that of the K control treatment at R, PM, and PMI water regimes respectively, and this effect increased with K rate increase. Potassium fertilization also decreased saturated fatty acid content and improved the unsaturated fatty acid content of the grains, increased the oleic acid and linolenic acid content, all of which also increased with improved of water conditions. Based on these results, applying KCl at a rate of 120 K<sub>2</sub>O/ha under PMI water management was the best management practice in oil sunflower production in Gansu. *IPNI-2015-CHN-C14*

### **Effect of Different N Rates on Yield and Benefit of Edible Sunflower in Inner Mongolia**

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Project Cooperators: Jun Zhang

Inner Mongolia Autonomous Region (IMAR) is the main sunflower-growing region, with area and production accounting for over 50% of the total in China. In IMAR, 80% of the sunflower is produced for edible nuts. The amount of nitrogen (N) required for producing 100 kg achenes is 3.8 to 4.9 kg N/ha. Farmers frequently over apply N fertilizers, resulting in low N use efficiency and low benefit. Therefore, the purpose of this project was to study the effect of various N rates on sunflower yield and benefit, providing the scientific basis for selecting the right rate of N in sunflower production.

Field experiments were conducted in Wuchuan, Jining, and Linhe Counties of IMAR. The edible sunflower species used in the experiments in Wuchuan, Jining, and Linhe were 3638, SH363, SH361, respectively. Sunflower was planted using plastic mulch with five N fertilizer application rates of 0, 100, 150, 200, 300 kg N/ha, and three replicates for each treatment. The replicates of 36 m<sup>2</sup> each were randomly arranged in the field. All treatments received the same amount of phosphorus (P) and potassium (K) fertilizers at 90 kg P<sub>2</sub>O<sub>5</sub>/ha and 90 kg K<sub>2</sub>O/ha. All P and K, and 30% of N fertilizers were row-banded basally before sowing and the remaining 70% of N was topdressed with irrigation. The crop was under drip irrigation in the Wuchuan and Jining trials, while flood irrigation was used in Linhe.

Nitrogen fertilization significantly increased achene yield. The maximum yield was obtained in the 200 kg

N/ha treatment at all the three locations. Achene yield increased from 15.5 to 28% at Wuchan, 11 to 23% at Jining, and 14 to 23% at Linhe, over the N control plots. Agronomic efficiency was 2.5 to 6.8, 1.5 to 5.5, and 1.8 to 5.7 kg achene/kg N; and N recovery efficiency was 17 to 41%, 15 to 44%, and 16 to 44% at the three sites, decreasing as the N application rate increased. Based on the relationship between N rates and achene yields, the N rate for maximum achene yield was 194 kg/ha in Wuchuan, 183 kg/ha in Jining, and 190 kg/ha in Linhe, with the corresponding yields being 5,970, 4,740, and 4,805 kg/ha, respectively. The economic optimum N rate, at which the marginal seed value equals the marginal fertilizer cost, was 183 kg N/ha in Wuchuan, 168 kg N/ha in Jining and 175 kg N/ha in Linhe, resulting in the maximum profits of US\$940, 635, and 665/ha, respectively. *IPNI-2017-CHN-NM01*

### **Better Nutrient Management Strategy for Rice-Wheat, Rice-Rapeseed and Rice-Rice Cropping Systems**

Project Leader: Yi Liu, Chinese Academy of Sciences, Wuhan Botanical Garden of CAS, Moshan, Wuchang, Wuhan, China. Email: lyle3521@126.com

Project Cooperators: Chen Shusen, Liu Chuang, and Yang Yongcheng

The agricultural regions of China under rice-upland crop rotations are important for grain crop production, commercial fertilizer use, and ecological sustainability. Therefore, research on the technology and strategies of better crop fertilization in this region are important to help achieve the goal of optimizing fertilizer use to increase fertilizer use efficiency in the country. Under the support from IPNI China program and the Special Fund for Agro-scientific Research in the Public Interest of the MOA China, the project cooperators from Wuhan Botanical Garden of CAS carried out a series of field experiments with rice-wheat, rice-rapeseed, and early rice-late rice rotations for key technologies and strategies of efficient fertilization in Jinmen County of Hubei Province, and Changsha County of Hunan Province.

The results from 2017 showed that compared to urea, the application of controlled-release urea significantly increased nitrogen (N) fertilizer use efficiency by 36 to 93%, and slightly increased rice yield. Rice straw-return treatments showed some negative effect on late rice yield and N use efficiency, but the effect was not significant. The fertilizer recommendations from the Nutrient Expert® fertilizer decision support tool (NE) significantly increased the economic efficiency of fertilization, increased the fertilization output/input ratio from 9.8 to 11.5 kg/kg, and increased N use efficiency from 36 to 55% for rice, wheat, and rapeseed.

A large amount of commercial fertilizer is used for rice cultivation in China, however, the use efficiency is rather low. Researchers from the IPNI southeast China Program collected data from the rice fertilization field experiments from 2001 to 2012. Using the data, the researchers established a novel approach for rice fertilizer recommendation based on the fertilization for Agronomic Efficiency (AE) and Sustainable Yield Index (SYI). This approach was able to better estimate fertilizer rates, thereby significantly increasing rice yield, economic benefit, and agronomic efficiency of fertilizer use. It is an effective approach for improving fertilizer recommendations in rice, and potentially to other crops. The experimental results have been published in Chinese and English scientific journals during 2015 to 2017. *IPNI-2015-CHN-HB45*

### **Combination of Right K and P Source on Apple Fruit Yield and Economic Income in Shaanxi**

Project Leader: Yan'An Tong, Northwest A & M University, Department of Agricultural Resources and Environment, Yangling, Shaanxi, China. Email: tongyanan@nwsuaf.edu.cn

The purpose of this study was to compare the effect of the combinations of potassium (K) and phosphorus (P) fertilizer sources on apple yield and their economic benefit to provide the scientific basis for selecting the right P and K source for apple production. Two P sources, MicroEssentials®(SE, N-P<sub>2</sub>O<sub>5</sub>-S-Zn 12-40-10-1) and diammonium phosphate (DAP), and three K sources, crystal granular potassium chloride (CGMOP), potassium sulfate (K<sub>2</sub>SO<sub>4</sub>), and MgK<sub>2</sub>(SO<sub>4</sub>)<sub>2</sub> were studied.

The experiment was conducted in Fuping County of Shaanxi Province where the average temperature and annual rainfall was 11.4 to 15.2°C and 460 to 685 mm, respectively. The experiment was located at a 3-year old Fuji apple tree orchard with a density of 2,500 trees/ha. There were five treatments: 1) DAP without K; 2) DAP + K<sub>2</sub>SO<sub>4</sub>; 3) DAP + CGMOP; 4) SE + CGMOP; and 5) SE + MgK<sub>2</sub>(SO<sub>4</sub>)<sub>2</sub> + CGMOP. All treatments received urea at 300 kg N/ha, 150 kg P<sub>2</sub>O<sub>5</sub>/ha, and 200 kg K<sub>2</sub>O/ha, except for the K control treatment. All of the P, 40% of N, and 40% of the K was applied basally during the previous fall after harvest, and the remaining 60% N and K fertilizers were topdressed at the fruit expanding stage.

Compared to the K control treatment, K fertilization increased fruit yield and single fruit weight but the difference between K treatments was not significant. Economic analysis showed that the application of DAP

with CGMOP resulted in the highest benefit from K application (US\$575/ha), followed by the treatment of SE with CGMOP (US\$475/ha), that were US\$465 and US\$370 more than the benefit from applying DAP with  $K_2SO_4$ , respectively. The treatment of SE combined with  $MgK_2(SO_4)_2$  and CGMOP resulted in no benefit due to high fertilizer cost. Thus, the combination of DAP with CGMOP or the combination of SE with CGMOP can be recommended in apple production in Shaanxi. *IPNI-2017-CHN-SN01* ❖



# South Asia Program

**Dr. T. Satyanarayana, Director**  
**Dr. Sudarshan Dutta, Deputy Director**

## India

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

Project Leaders: 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

This study was aimed at evaluating 4R nutrient management guidelines in the rice-maize-green gram cropping system in a strongly acidic soil in Odisha. The experiment consisted of ten treatments: 1) Site-Specific Nutrient Management (SSNM) with application of all limiting nutrients based on 4R principles; 2) SSNM with no nitrogen (N); 3) SSNM with no phosphorus (P); 4) SSNM with no potassium (K); 5) SSNM with no sulfur (S); 6) SSNM with no boron (B); 7) SSNM with no zinc (Zn); 8) SSNM with no calcium (Ca); 9) absolute control with no fertilizer; and 10) farmers' practice.

The experiment, conducted over a period of three years, revealed that the cumulative biomass production and the economic yield in terms of rice equivalent yield (REY) with SSNM were 98 and 49 t/ha, respectively. Omission of N, P, K, S, B, Zn, and Ca from SSNM resulted in a cumulative yield loss of 40, 25, 15, 26, 14, 11, and 19% respectively in three years, indicating that omission of any of the limiting nutrients could significantly reduce the productivity of the rice-maize-green gram system. No addition of fertilizer (absolute control) resulted in 58% yield loss, while farmers' practice of unbalanced and inadequate application of fertilizers resulted in a yield loss of 28% over SSNM.

The agronomic efficiencies (kg grain/kg of nutrient applied) across the treatments ranged between 19 to 35 for N, 50 to 161 for P, and 24 to 79 for K, while the apparent recovery efficiencies of N, P, K, and S varied from 39 to 70, 21 to 71, 49 to 139, and 6 to 19%, respectively. Both the agronomic efficiency and apparent recovery efficiency of nutrients were highest in SSNM. Post-harvest soil properties indicated an improvement in soil pH as a result of lime addition under SSNM, which also reported a slight increase in organic carbon status from 0.41 to 0.49%. However, post-harvest assessment of soil fertility under SSNM indicated a decline in the available K fertility status and reported a net negative balance of K by 428 kg/ha, while the negative balance of N and P were 90 and 20 kg/ha, respectively.

The study conducted over three years indicated that SSNM practice based on the 4R Nutrient Stewardship principles exhibited overall net return of Rs. 60,000/ha, which was four times higher than the farmers' practice (Rs. 15,000/ha). The K rates suggested under SSNM practice was inadequate for the three crops sequence, and may require application of K fertilizer in green gram that was previously grown on residual fertility, in order to overcome K depletion from soil. The study was concluded in 2017. *IPNI-2014-IND-525*

### ***Indigenous Nutrient Supplying Capacity of Vertisols under Cotton and Soybean***

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This project was aimed at determining the response of cotton and soybean to major nutrients, and understanding the extent of spatial and temporal variability of yield responses across the soybean and cotton-growing regions of Maharashtra. The study compared four treatments: 1) ample NPK (nitrogen, phosphorus, and potassium) and other limiting nutrient application; 2) omission of N from the ample treatment; 3) omission of P from the ample treatment; and 4) omission of K from the ample treatment. The study determined the nutrient uptake pattern, nutrient use efficiency and residual soil fertility through the nutrient omission technique. The results of the study contributed to the development of the Nutrient Expert<sup>®</sup> (NE) fertilizer decision support tools for cotton and soybean.

Average yield data pooled over three years indicated that the ample NPK treatment produced the highest soybean (2.1 t/ha) and cotton (2.4 t/ha) yields. The lowest soybean yield was recorded with the P omission (1.6 t/ha), a yield reduction of 22% over the ample treatment. The yield reductions due to N and K omission were 18% and 9%, respectively. The lowest seed cotton yield was recorded with N omission (1.9 t/ha), and the yield reductions over the ample treatment were 19% for N omission, followed by K (13%) and P (9%) omission. The highest soybean and seed cotton yields in the ample NPK treatment was associated with high N, P, and K uptake, 132.7, 22.8, and 59.6 kg/ha and 85.4, 23.9, and 92.3 kg/ha, respectively.

Agronomic efficiency (AE: kg grain per kg nutrient applied) of N, P, and K were 12.3, 4.6, and 2.4 for soybean; and 2.4, 2.9, and 3.3 for cotton, respectively. The low agronomic efficiencies observed is typical for omission plot studies where nutrients are applied in ample quantities to ensure none of the nutrients are limiting except the intended ones. The study was concluded in 2016 and the results of the study were used for the development of NE for soybean and cotton. *IPNI-2013-IND-526*

### ***On-Farm Precision Nutrient Prescription Under Predominant Cereal-Cereal Systems Using Nutrient Expert®***

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Project Cooperator: R.P. Mishra

This study compared a Nutrient Expert® (NE)-based nutrient recommendation with the official state recommendation (SR) and farmers' fertilizer practice (FFP) in the rice-wheat cropping system across five locations of Amritsar, Modipuram, Kanpur, Faizabad, and Nainital. Ten on-farm sites were selected at each of the locations, and the three nutrient management options were evaluated for agronomic, economic and environmental benefits through yield, net returns, and nutrient use efficiency estimations. Soil pH was generally alkaline (>7.5) except in Nainital (pH 6.7), and electrical conductivity (EC) was within the safe limits (<0.4 dS/m), except in Modipuram (0.48). Organic C was low (<0.5%) in Amritsar, Kanpur, and Faizabad, while medium at Modipuram (0.57) and high at Nainital (0.77). All locations had low available nitrogen (N) (<280 kg/ha), medium to high available phosphorus (P) (12.5 to 32.5 kg/ha), and medium (135 to 335 kg/ha) available potassium (K).

The NE-based recommendations produced 5.2 to 7.1 t/ha of rice yield, with an average of 6.1 t/ha, which was 8 and 25% higher than SR and FFP, respectively. Similar observations were also reported in wheat where yield ranged from 3.5 to 5.0 t/ha, with an average of 4.4 t/ha, that was 8 and 16% higher than SR and FFP, respectively. The rice-equivalent yield (REY) of the rice-wheat system was 10.9, 10.0, and 9.0 t/ha for NE, SR, and FFP respectively. The average REY in the NE plots were 8 and 20% higher than SR and FFP, respectively. The higher yields of rice and wheat with NE was due to high nutrient uptake and high nutrient use efficiency. The average N (114 kg/ha), P (26 kg/ha), and K (122 kg/ha) uptake of rice in the NE plot was 11, 16, and 10% higher than SR, and 30, 58, and 38% higher than FFP, respectively. Similarly, partial factor productivity (PFP) of N, PFP-P and PFP-K in the NE treatment were 53, 391, and 128 kg/kg, respectively. The PFP-N in the NE treatment was 13 and 46% higher than SR and FFP, while PFP-P was higher than SR and FFP by 82 and 46%, respectively. The PFP-K for NE was 27 and 24%, less than SR and FFP, indicating that the NE tool helped suggest adequate rates of K, which was under-applied in the SR and FFP treatments. The added net return over FFP was Rs.18,710 for the NE treatment and Rs.15,100 for the SR treatment. The performance of the NE-based nutrient recommendations are currently being analyzed for other cropping systems such as rice-rice, rice-maize, and maize-wheat systems. *IPNI-2014-IND-528*

### ***Assessing the Indigenous Nutrient Supplying Capacity of Soils to Soybean in Vertisols of Northern Karnataka***

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The study was aimed at validating the Nutrient Expert® (NE) fertilizer decision support tool for soybean with the existing nutrient management practices, and determine soybean response to applied nutrients and seed inoculation in the Vertisols of northern Karnataka. Replicated on-station experiments were conducted at the Agricultural Research Station (ARS) of the University of Agricultural Sciences, Dharwad. The study consisted of nine treatments: 1) NE (27-51-51 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha) plus seed inoculation with Rhizobium; 2) NE minus seed inoculation with Rhizobium; 3-4) two treatments with omission of N from the NE recommendation, but one with seed inoculation and the other without seed inoculation; 5-6) two treatments with omission of phosphorus (P), and potassium (K) from NE; 7) State Recommendation/RDF (40-80-25 kg/

ha); 8) farmer practice/FP (23-58-0 kg/ha); and 9) an absolute unfertilized control.

The average grain yield of soybean in the NE treatment was 2,040 kg/ha and yield response to application of nitrogen (N), P, and K was 470, 395, and 260 kg/ha, respectively. The yield reduction due to omission of N, P, and K was 23, 19.4, and 12.7%, indicating that N followed by P and K are the most limiting nutrients for growing soybean on these medium deep black soils. The average yield recorded for the RDF was 2,170 kg/ha, which was 6% higher than NE. The yield recorded for FP and absolute control were 1,560 and 1,195 kg/ha, which were 24 and 42% lower than the NE treatment. The higher grain yield of soybean in NE treatment was attributed to significantly high dry matter per plant, more number of pods per plant, high test weight of seed, taller plant height, and an increased number of nodules per plant.

The study also offered interesting observations on the effect of omitting N from the rhizobium-inoculated and the non-inoculated treatments. The results indicate that skipping rhizobium inoculation from NE, reduced yield by only 3% (66 kg/ha). However, omitting N from inoculated and non-inoculated plots showed a yield decline of 470 and 660 kg/ha, with yield reduction of 23% due to N omission and 32% due to combined omission of N+seed inoculation, indicating that an additional 190 kg/ha of yield was reduced due to omitting seed inoculation. The study also indicated that contribution of N from biological N fixation due to inoculation could be significant with application of N, and skipping both N and seed inoculation could drastically reduce the yield. The higher yield recorded with RDF (40-80-25 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha) in comparison to NE (27-51-51 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha), also suggests further investigations on variable rate and time of N and P application to soybean. *IPNI-2014-IND-531*

### ***Agronomic, Economic, Social and Environmental Benefits of Improved Nutrient Management Practices in Maize Production Systems Under Variable Farm Size, Climate, Soil Fertility Conditions and Farmer Resource Endowment in Telangana, India***

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This study was aimed at understanding the maize-growing ecology in the state of Telangana, and to determine the benefits of improved nutrient management practices for maize production. The study covered two traditional (Karimnagar and Medak) and two emerging (Nizamabad and Mahabubnagar) maize-growing districts in the State.

In Karimnagar, maize was grown on an irrigated fertile soil (mixture of loamy and black cotton soils), where 70 and 50% of farmers apply organic manure and potassium (K) fertilizer to maize, respectively. The prevailing maize yields varied from 6.3 to 10 t/ha. In the Medak district, soils varied from loamy red earth to red sandy and black cotton soils, and maize is grown under rain-fed condition with only 10% of farmers applying both manure and K fertilizers, and maize yields range from 2.5 to 7 t/ha. Maize is grown under an irrigated condition in the Nizamabad district with loamy black cotton soil, and the yield varies from 6 to 7.5 t/ha. The average NPK application in this district was 343 kg/ha, and 70% of the farmers use manure while 100% of them apply K fertilizer. In Mahabubnagar district, maize was grown in red soils under rain-fed conditions and only 10% of the farmers apply both manure and K fertilizer. The average NPK application rate is 308 kg/ha and yields ranged from 1.2 to 6.3 t/ha.

The Nutrient Expert<sup>®</sup> (NE) fertilizer decision support tool and soil test crop response (STCR) equation-based fertilizer recommendations were considered as improved nutrient management strategies, which were compared with state recommendation (SR) and farmers' practice (FP). Ten on-farm experiments were conducted in each district comparing all the four nutrient management options. Average results of all the four districts indicated that highest maize yields were achieved with STCR (5.8 t/ha), SR (5.7 t/ha), and NE (5.4 t/ha) were not significantly different, but were higher than FP (4.9 t/ha). The 7% higher yield in STCR was a result of 24% higher nutrient application rates (248, 59, and 68 kg/ha N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O), than in the NE-based nutrient application (167, 60, and 56 kg/ha N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O). Among the four nutrient management options tested, NE-based site-specific 4R fertilizer recommendation showed a Benefit:Cost ratio of 8.1, which was 43, 26, and 29% higher than STCR, SR, and FP, respectively, indicating that even though yields achieved with NE-based fertilizer recommendations were slightly lower than STCR and SR, the economic benefit achieved with NE was significantly greater than STCR and SR. The project was concluded in 2017.

*IPNI-2015-IND-532*

## ***Yield Maximization in Cotton through Targeted Yield Approach and Omission Plot Techniques in Vertisols of Karnataka***

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The current project was aimed at assessing the yield responses to application of nitrogen, phosphorus and potassium (NPK) in transgenic cotton grown in the black soils of northern Karnataka. The on-station replicated experiment was conducted at the agricultural research station at the University of Agricultural Sciences, Dharwad, Karnataka. Cotton was grown under a rain-fed environment with the support of supplemental irrigation during the monsoon season of 2017. The soil reaction was alkaline (pH 7.2), with low available N (163 kg/ha), high available P (52 kg/ha) and high available K (362 kg/ha). The experiments consisted of four treatments including: ample NPK (180-70-80 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O kg/ha), N omission, P omission, and K omission from the ample NPK treatment.

Seed cotton yield (SCY) in the ample NPK treatment was 3,615 kg/ha, which was highest among the four treatments. Omission of N, P, and K resulted in 47, 3, and 13% reduction in SCY as compared to ample NPK application, while yield response to the application of N, P, and K was 1,680, 125, and 485 kg/ha, respectively. The results indicated that N followed by K were the important nutrients limiting the yield of cotton grown in the Vertisols of this region. With the ample NPK treatment, the superior yield characteristics such as plant height (110 cm), number of bolls per plant (44), boll weight (6.6 g), dry matter yield (283 g/plant), and seed cotton yield (260 g/plant) resulted in significantly higher economic yield over the respective nutrient omission treatments. Nutrient uptake and post harvest soil analysis are currently being analyzed.

The data recorded from this study will be utilized for developing the Nutrient Expert® fertilizer decision support tool for cotton, which will help in providing individual field-specific fertilizer recommendations for improving the productivity and profitability of farmers growing cotton. *IPNI-2015-IND-533*

## ***Optimising Nutrient use Efficiency under Zero Tillage Operations in Rice - Maize Cropping System in Coochbehar and Malda District of West Bengal***

Project Leader: Abhas Sinha, Dept. of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya.

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The objective of the project was to determine the nutrient requirement of HYV (high-yielding variety) rice-hybrid maize cropping system, cultivated under zero tillage. The project was initiated in 2015 in two districts of West Bengal, namely Coochbehar and Malda, having differences in agro-ecological characteristics. The Coochbehar district has Terai foothill soils, while Malda has predominantly old alluvial soils. During kharif season, rice was grown followed by maize on the same field after harvest of rice. The treatments for both of the crops included application of different doses of fertilizer such as: 1) ample nitrogen (N), phosphorus (P), and potassium (K); 2) ample minus N; 3) ample minus P; 4) ample minus K; and 5) farmer's fertilizer practice (FFP) for the HYV rice - hybrid maize cropping system. The nutrient recommendation for the ample NPK plot was based on the Nutrient Expert® (NE) fertilizer decision support tool for rice and maize.

Fifteen farmers' fields were chosen in each district for conducting field experiments on rice during 2016 rainy season, followed by maize in the following winter (2016) season. An area of 0.13 ha was allotted for each treatment. The average rice yield for the NPK plot was over 5.5 t/ha in Coochbehar district and 5 t/ha in Malda. Across both the districts, N was the most yield-limiting nutrient, followed by P and K. In the case of maize, the average productivity in the Coochbehar and Malda districts was 8.5 and 7.5 t/ha, respectively. Similar to rice, N was the most yield-limiting nutrient followed by P and K in both districts.

Overall this study has developed background information that will be useful for improving NE-based fertilizer recommendations, particularly for this area in West Bengal. *IPNI-2015-IND-536*

## ***Study of Variable Nutrient Responses in Soybean Grown at New Alluvial Soils of Bihar***

Project Leader: Sudarshan Dutta, International Plant Nutrition Institute (IPNI), South Asia Program, Kolkata, West Bengal, India. Email: sdutta@ipni.net

Soybean is emerging as a major oilseed crop of India. The total area under soybean production in India is over 10 million ha. However, the average soybean productivity of the country is about 0.8 t/ha. Inappropriate nutrient management is considered as one of the constraints for productivity enhancement of soybean,

which is grown on poor fertility soils with limited fertilizer use. Along with an increase in acreage, improved productivity of the crop with 4R-based fertilizer management can help boost the economics of production and total production of the country.

Following the successful development and dissemination of Nutrient Expert® (NE) maize, wheat, and rice for small holder farmers of India, developing a decision support tool for promoting balanced fertilizer application in soybean became a priority. Data collected from a pan-India nutrient response study was utilized, along with legacy data from national partners, to develop a beta version of the NE soybean fertilizer decision support tool. The NE soybean tool was validated in 14 different locations in four districts of Bihar during 2017, that compared the NE-based recommendation with the farmers' fertilizer practice (FFP). The average nitrogen (N), phosphorus ( $P_2O_5$ ), and potassium ( $K_2O$ ) application rates in the FFP and the NE-based recommendations for soybean were 11-14-0 and 26-39-38 kg/ha respectively across all the locations. Balanced nutrient application recommended by the NE-Soybean tool significantly improved the average soybean grain yield (1.80 t/ha) over FFP (1.60 t/ha). Moreover, the gross return over fertilizer cost was significantly higher for the NE plots (Rs.49,870) compared to the FFP (Rs.45,184). The NE-soybean tool has been improved based on preliminary results, and will be used for further on-farm validation in several locations in 2018.  
*IPNI-2013-IND-538*

### **Nutrient Expert® Soybean Validation Trial at Red and Lateritic Soil of Jharkhand**

Project Leader: Rakesh Kumar, Birsa Agricultural University, Soil Science and Agricultural Chemistry.

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Soybean is one of the most promising crops in improving farmers' economic status in many parts of India. Soybean is also gaining popularity in eastern Indian states like Jharkhand. However, there is no modern and balanced nutrient recommendation protocol for soybean, especially for small and marginal farmers of eastern India.

The Nutrient Expert® (NE) soybean fertilizer decision support tool was co-developed with local partners to facilitate on-farm application of improved nutrient management practices. The NE soybean was validated on-farm in five different locations of the state of Jharkhand, India, where the NE-based fertilizer recommendations were compared with State Recommendation (SR) and Farmers' Fertilization Practices (FFP). The one year of on-farm trial data highlights that the NE soybean-based recommendations significantly improved the average soybean grain yield (4.5 t/ha) compared to that of FFP (2.8 t/ha) and SR (3.4 t/ha). This could be attributed to the balanced fertilizer application, as the average N and  $K_2O$  applications were significantly higher in the NE-based recommendations compared to that of FFP and SR, and better timing of fertilizer application. However, there was no significant change in  $P_2O_5$  application.

The average net income improvement resulting from use of NE soybean was more than Rs.40,000/ha (US\$620 approximately) over FFP, and Rs.25,000 (\$390 approximately) over SR. Overall, NE soybean produced higher soybean productivity through balanced fertilizer application along with better economics.  
*IPNI-2016-IND-539*

### **Ecological Intensification for Climate Resilient Maize Based Cropping Systems**

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Project Cooperators: Narendra Singh Bagri, Mahesh Kumar, Vijay Pooniya, Vinod Sharma, Amit Kumar Singh, Bashir Ahmad Alaie, Dilip Singh, V.K. Paradkar, Hargilas, Mritunjay Kumar, Sonali Biswas, Pramila Naik, C.S. Singh, A.K. Sinha, D. Sreelatha, E. Rajnikantha, A.P. Sivamurugan, and P. Thukaiyannan

This project is an outcome of the IPNI Global Maize initiative, where the national maize research group of India (ICAR-Indian Institute of Maize Research) adopted the concept of ecological intensification (EI) and initiated a multi-location project on "Ecological intensification for climate-resilient maize-based cropping systems." The project was aimed at developing EI practice to improve over the current farmer practice in the six major maize-based cropping systems and determine the role of EI in improving crop yield, farmer profitability, and environmental sustainability. The study will quantify the role of the individual components of EI, alone or in combination, on climate resilience across varying growing environments in the predominant maize systems.

The study was initiated at 23 experimental stations, representing 15 maize-growing states of India covering

six predominant maize cropping systems (Maize-wheat-greengram; Rice-maize; Maize-chickpea, Maize-mustard/oats; Soybean-maize/Legume-maize; Maize alone). The study consisted of eight treatments replicated three times over a randomized block design. The EI treatment (T1) included best practices for crop and nutrient management. The best practices for crop management included using the best genotypes, right planting density, ideal tillage, and improved water, weed, and pest management. The nutrient management in the EI treatment used the Nutrient Expert®-based precision nutrient recommendations for rice, maize, wheat, and soybean, whereas 4R nutrient management guidelines were followed in the other crops. The second treatment was farmers' practice (T2), which was determined through a survey of crop and nutrient management practices followed by 50 farmers from the surrounding villages of the identified location, and the mode value was selected as the farmers' practice. The other six treatments consisted of omission of individual crop management practice from the EI treatment: (T3) EI minus tillage+residue; (T4) EI minus nutrient management; (T5) EI minus planting density; (T6) EI minus water management; (T7) EI minus weed management; and (T8) EI minus insect and disease management, for quantifying the contribution of individual components of the EI treatment towards achieving climate resilience under varying weather and growing environment.

The experiments were initiated during the monsoon season of 2017. Observations on yield and agronomic parameters, weather data, and nutrient uptake were recorded for the first cropping cycle, and the data is currently being analyzed for determining the economic benefit due to EI over the farmer practice at each of the research locations. *IPNI-2017-IND-540*

### ***Bridging Yield Gap of Soybean through Site-Specific Nutrient Management***

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Project Cooperators: S.A. Jaybhay, D.S. Meena, Arvind Kumar Singh, Toijam Sunanda Devi, Sher Singh, R.N. Katkar, S.C. Saxena, Anchal Das, Rajendra Lakpale, Gouranga Charan Mishra, C. Sreedhar, Harpreet Kaur, M.S. Dandge, M.D. Vyas, Engrala Ao, G.J. Patel, Sangashetty G. Blkunde, and Shri M. Chandrappa

This project, focused on bridging the yield gap of soybean through site-specific nutrient management, is an outcome of the partnership established by IPNI South Asia program with the national soybean research system of India (ICAR-Indian Institute of Soybean Research). The study was aimed at determining yield response of soybean to nitrogen, phosphorus, and potassium (N, P, and K) application through nutrient omission trials in 18 major soybean-growing states of India. The study will also compare fertilizer recommendations from the Nutrient Expert® fertilizer decision support tool for soybean, official state recommendation, and the farmer fertilizer practice in terms of yield and profitability of soybean production.

The study consisted of on-station experiments with seven treatments replicated three times arranged in a randomized block design at 18 AICRP (All India Coordinated Research Project) soybean centers in India. The seven treatments used at each location were: Site-Specific Nutrient Management (SSNM) based on: T1) NE fertilizer recommendation; T2-T4) omissions of N, P, and K from T1; T5) an absolute (unfertilized) control; T6) state recommended dose of fertilizer (RDF); and T7) the farmers' fertilizer practice (FFP). The farmers' fertilizer practice was determined through a survey of 10 farmers at each location.

Initial soil samples were collected from each location and analyzed for physico-chemical characteristics and available nutrient status. The soybean grain yield and different yield attributes were recorded for all seven treatments. Post-harvest plant and soil samples were collected from each treatment to determine the N, P, and K uptake, and the soil nutrient concentration after the soybean harvest. All the soil and plant samples were gathered at a common testing facility arranged by IPNI, and the analysis is currently underway. The results of the study will be presented by the cooperators from the 18 AICRP centers at the annual soybean workshop scheduled for March 2018, and will be available for reporting by IPNI. *IPNI-2017-IND-541*

### ***Efficiency of Nitrogen Carriers in Calcareous Soil under Hybrid Rice-Wheat-Green gram Cropping System: a step towards Nutrient Expert® based 4R Stewardship plant nutrition approach***

Project Leader: Sudarshan Dutta, International Plant Nutrition Institute (IPNI), South Asia Program, Kolkata, West Bengal, India. Email: Sdutta@ipni.net

Project Cooperator: S.P. Singh

Nitrogen (N) fertilizers play an important role in regulating N transformations, changing N loss patterns,

and influencing N use efficiency (NUE) in crop production. There is ample opportunity to improve the productivity and economics of hybrid rice-wheat cropping system through the application of right N sources under the different agro-ecological regions of India. The Nutrient Expert® (NE) fertilizer decision support tool, based on the concept of 4R Nutrient Stewardship and principles of site-specific nutrient management (SSNM), offers solutions for providing field-specific fertilizer recommendations to improve yield and economics of rice-wheat growing farmers in the region. Recently several N sources have been introduced in the market such as neem-coated urea, sulfur-coated urea, and others. Thus, for determination of right source of N under varied climatic regions, NE-based fertilizer recommendations with locally available N sources were tested in a field experiment in hybrid rice-wheat-green gram cropping system at the experimental farm of DRPCA, Pusa, Bihar. The study was initiated in Kharif 2016 and has continued.

The treatments included application of N, phosphorus (P) and potassium (K) fertilizers in all the of research plots based on the NE recommendations for maize and wheat. The different sources of N fertilizer included prilled urea, neem-coated urea, ammonium sulfate, calcium nitrate, diammonium phosphate, sulfur-coated prilled urea, and sulfur with neem-coated urea. The effect of the sources was compared within treatments as well as with N omission plots. The study reported highest rice equivalent yield resulted from fertilization with sulfur-coated prilled urea (11.5 t/ha), followed by calcium nitrate (11.3 t/ha), compared to the other treatments. The lowest cropping system yield was observed when sulfur and neem-coated urea was used as a N source. The study will be continued for three years to understand the trend and impact of different sources. *IPNI-2016-IND-542*

## Nepal

### ***Transfer, Evaluation and Dissemination of an Innovative Fertilizer Management Tool (Nutrient Expert®) for Increasing Crop Yields and Farmers' Income in Eastern Nepal***

Project Leader: Netra P. Sen, FORWARD, Nepal. Email: [npsen@forwardnepal.org](mailto:npsen@forwardnepal.org)

The study was aimed at developing and disseminating improved fertilizer recommendations, using the Nutrient Expert® (NE) fertilizer decision support tool, for the farmers of Nepal in collaboration with FORWARD, a leading non-governmental organization in Nepal, and the Non-Resident Nepalese Association of Australia (NRNA). The NE fertilizer recommendations were compared with official government recommendations and farmers' fertilizer practice with 600 farmers growing rice, maize and wheat in Zhapa and Morang districts of eastern Nepal.

The results revealed that NE-based fertilizer recommendations improved the yield of rice, maize, and wheat by 16, 47, and 42% over the farmer practice. The corresponding increase of yield over the official recommendations in wheat and maize was 18 and 21%, respectively. The increased yield also raised farm income by an additional Nepalese Rupees (NR) 18,100 to 19,050/ha in rice, NR 12,040 to 28,860/ha in wheat, and NR 43,525 to 73,650/ha in maize. The study indicated that Nepalese farmers are able to significantly improve the yields of rice, wheat, and maize, and also raise their income through the use of site-specific fertilizer recommendations generated by NE.

The research project organized 4R Nutrient Stewardship training programs for the scientists of the Nepal Agricultural Research Council, local government extension, students and researchers from the Institute of Agriculture and Animal Science, and agronomists from FORWARD and helped in capacity building of stakeholders on the use of NE. The study also organized a field tour of national government officials, university scientists, FORWARD staff, and farmers from Nepal to the farmer fields and on-farm research stations in Begusarai, Samastipur, and Muzzafarpur districts of Bihar in India, and helped in capacity building and knowledge exchange between the farmers of two neighboring countries. The study was concluded in 2016. *IPNI-2014-NPL-1* ❖



# Southeast Asia Program

**Dr. Thomas Oberthür, Director**

**Dr. Mirasol Pampolino, Deputy Director**

## Indonesia

### ***Cocoa Intensification in Indonesia - IPNI Cocoa Care Program***

Project Leader: Thomas Oberthür, International Plant Nutrition Institute. Email: toberthur@ipni.net; Noel Janetzki, PT Community Solutions International, Cocoa Care Program. Email: kjnatski@gmail.com

Project Cooperators: IPNI Southeast Asia Program, Cocoa Care, Indonesia, Lautan Luas, Indonesia, and Uralkali Trading, Singapore

There has been an ongoing decline in quality and productivity of cocoa in Indonesia since the early 2000's. This decline, while the global cocoa markets are strong, has undermined farm profitability and presents a substantial risk to the survival of the industry in Indonesia. This project, initiated in 2013 and scheduled to run until 2019, will identify and support cacao-farming families with the necessary land and family resources to become sustainable family businesses by deploying good agricultural practices, and fertilizer application based on the 4R Nutrient Stewardship Principles. Project information will also be used to estimate and project fertilizer market demand for Sulawesi and guide market development.

The cacao farmers were 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 were rehabilitated or replaced with the best available planting materials. Soil and leaf sampling were undertaken within the farms to establish nutritional and other soil needs. These data were analyzed and ideal soil management practices and fertilizer regimes were developed (including potash fertilizers) to achieve the optimum soil condition and nutritional levels for cacao farming. Test plots were established within each farm to monitor the impact of these interventions.

IPNI and PT Community Solutions International Cocoa Care program jointly managed the project. The Cocoa Care team conducted farmer identification, procurement, field trials implementation and monitoring while IPNI provided guidance on scientific methods, statistical analysis of results and managerial oversight.

Dry bean yield, bean size, and economics of production from 73 participating farms from July 2013 to September 2016 have been analyzed, summarized, and synthesized into two journal articles and submitted for publication. A cocoa seedling nursery trial was established in August 2017 to evaluate the effect of different levels of fertilization on the growth of the seedling. Seedlings from this nursery will be used for the model farm to be established in April 2018. A second nursery will be set up in early 2018 to fine-tune fertilizer recommendations for seedlings. Importantly, this project will demonstrate to farmers the benefits of good agricultural practices, including fertilization, and thereby provide motivation to growers for management change. *IPNI-2013-IDN-27*

### ***Estate-Scale Experiments (ESE) in Oil Palm: Supporting the Oil Palm and the Fertilizer Industry to Meet the Demands of Sustainable Intensification***

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

This project builds on the analytical approaches of Plantation Intelligence™ to guide the establishment of Estate-Scale Experiments (ESE) in commercial palm oil production systems, and to analyze and distill the results generated within such ESE for fertilizer use decisions that lead to higher returns on investment in fertilizer. The implementation of the project is from 2015 to 2019 in Central Kalimantan, Indonesia.

This 6,000 ha trial began in January 2015 to enable the full integration of fertilizer recommendations and application into the partner plantations. Three treatments of nitrogen, phosphorus, potassium, and magnesium (NPKMg) were assessed: 1) normal (the rate that would be applied conventionally); 2) +25%; and 3) -25% of the conventional rates. This is a low risk design that will provide good insight about fertilizer productivity. The total fertilizer application, hence cost, will be almost the same as ‘normal’ (a slight deviation could occur due to unequal block size). The treatment is varied block-by-block and fertilizer is applied in the normal way (i.e., hand/machine). IPNI and the agronomic research and development team of the partner plantation jointly adjusted recommendations when leaf analysis results were available, and regular rates were

defined. Fertilizer rate adjustments are only made for KCl, urea, NPK, and ammonium sulphate. The rates for rock phosphate, dolomite, kieserite, and borate remain unchanged.

Project field implementation started in February 2015. The project has now generated two years of data and analysis is ongoing. Importantly, analytical techniques and methods for the interpretation of large scale on-farm experiments have been developed, including an approach that quantifies the impact of soils, weather, and topography on yields, and thereby provides understanding of the impacts of nutrition. Key publications produced include “Learning from commercial crop performance: Oil palm yield response to management under well-defined growing conditions” in *Agricultural Systems* 149 (2016) 99-111, “Plantation Intelligence Applied Oil Palm Operations: Unlocking Value by Analyzing Commercial Data” in *The Planter*, Kuala Lumpur, 93 (1094): 339-351 (2017), and “Estate Scale Experiments (ESE): Continuously improving response to fertilizer in large commercial oil palm operations” in *Fertilizer FOCUS | NOV/DEC 2017*, 32-36. Currently, training course materials are being prepared for wide scale dissemination of principles and lessons learnt.

Fertilizer remains the single largest variable cost to plantation managers, but the actual effects of the fertilizer applied are largely unknown at the estate scale. Should managers reduce or increase rates, where, and by how much? The estate-scale experiments embedded within the commercial production system answers these questions, because the experiment occurs at the scale at which the managers’ decisions are implemented. *IPNI-2015-IDN-28*

### ***The Role of Boron in Sustainable Intensification of Smallholder Cacao Systems in Sulawesi, Indonesia***

Project Leaders: Noel Janetski, PT Community Solutions International, Cocoa Care program. Thomas Oberthur, International Plant Institute, Penang, Malaysia. Email: toberthur@ipni.net. Weng Kee Ch’ng, Rio Tinto Minerals

The overall purpose of this project is to strengthen and add additional value related to the micronutrient boron (B) in the current efforts on sustainable intensification of cacao production systems. This was aimed at increasing the yield and profitability of smallholder cacao farms in Indonesia and elsewhere in Southeast Asia. The provided resources would enable the generation of B nutrition information and knowledge dissemination processes that help farmers and the fertilizer industry to benefit from the strong markets for cocoa. It would also facilitate effective agronomic nutrient management in intensive cacao smallholder production systems through the development and deployment of 4R Nutrient Stewardship practices related to B. The project commenced in September 2016 and will run until August 2019. Importantly, the project will demonstrate to farmers the benefits of good agricultural practices, including fertilization with B, and thereby provide motivation to growers for management change.

The project supported on-farm trials that included B nutrition with 15 smallholder cacao farmers in the Soppeng/Bone area. Smallholders were identified and integrated into ongoing IPNI Cocoa Care™ work. Where necessary, dead or non-productive cacao trees in the selected farms were rehabilitated or replaced with the best available planting materials. These 15 cacao farmers were trained both “in class” and “in field” on how to implement good agricultural practices on their farms for maximum productivity at the Mars Cocoa Academy. Baseline soil, leaf, and fruit sampling was undertaken within the farms to establish nutritional and soil needs. The concept of 4R Nutrient Stewardship was used to implement the nutrition program. There were three treatments: 1) general good agricultural management practices, with no fertilizer applications (GAP only); 2) good agricultural management practices, plus B-containing fertilizer applications (GAP fertilizer + B); 3) good agricultural management practices, with no B-containing fertilizer applications (GAP fertilizer without B).

The first application of fertilizers was completed according to plan. A preliminary data analysis of the 2017 yield and bean quality has not yet produced statistically significant findings but it indicated clear trends that we will consolidate with the 2018 data. These trends showed that: 1) the overall yields are generally still low; 2) there is currently a large yield variability between farms; 3) the benefit of B seems larger in well-managed farms; 4) in more than half of the farms, B treatment yielded the highest; and 5) bean size was largest in the B treatment in more than half of the farms. *IPNI-2016-IDN-29*

### ***IPNI Southeast Asia’s International Publication Partnership on Oil Palm Nutrition***

Project Leader: Thomas Oberthür, International Plant Nutrition Institute (IPNI), Southeast Asia Program, Penang, Malaysia. Email: toberthur@ipni.net

Project Cooperators: Klaus Dittert, Munir Hoffmann, Reimund Roetter, Hsiao Hang Tao, and Heike Thiel

Through publishing a field manual on 4R oil palm nutrition and scientific journal papers, this project aims

to promote adequate and wide-scale use of responsible nutrient management, based on IPNI's 4R Nutrient Stewardship concept (right source, right rate, right time, and right place), for high yield and profit, and environmental sustainability in the oil palm sector of Southeast Asia. In addition to the purpose of market development, the publications aim at highlighting the importance of scientific research and technological development on sustainable intensification of oil palm. This project was implemented from 2016 to 2017.

IPNI implemented the Southeast Asia - 05 project from 2011 to 2015 that focused on improved nutrient management in oil palm plantations in Central Kalimantan, Indonesia, with support from Kali GmbH. The field trials generated a significant amount of valuable information that will be analyzed and published under this project through a post-doctoral fellowship partnership between K+S Kali GmbH, the Institute of Applied Plant Nutrition (IAPN), and the Department for Crop Sciences, Crop Production Systems in the Tropics at the Georg-August-Universität Göttingen. The project will produce 1) a field handbook on 4R oil palm nutrition for use by practitioners in the industry, and 2) scientific publications for the scientific knowledge domain.

A scientific journal paper on “Effects of best management practices on dry matter production and fruit production efficiency of oil palm” was submitted to and accepted by the European Journal of Agronomy (2017, 90:209-215). Results were also presented at a seminar on July 4, 2017 at the TROPAGS Institute, University of Göttingen. A second publication on “Fertilizer management effects on oil palm yield and nutrient efficiency on sandy soils with limited water supply in Central Kalimantan” was submitted to Nutrient Cycling in Agroecosystems, and was accepted assuming satisfactory revision, which is ongoing. The third publication is currently under development. Furthermore, a two-day annual review was held in Penang in December 2017, to outline the 2018 publication schedule, including the development of two peer-reviewed papers and an Oil Palm 4R Nutrition Handbook.

Preliminary results suggest that nutrient management practices play an important role in determining oil palm production in our project plantations in Central Kalimantan. The outputs from this project would be useful for agronomists at plantations and planters of smallholder oil palm systems, to identify better ways to implement nutrient best management practices for sustainable intensification of oil palm. *IPNI-2016-SEAP-7*

### **Publication Development and Knowledge Sharing**

Project Leader: Sandra Leng, International Plant Nutrition Institute, Southeast Asia Program, Penang, Malaysia.  
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Project Cooperators: Benjamin Ngiam and Tran Minh Tien

This objective of this project is to engage scientific authors, consultants, service providers, and other partners to identify suitable collaborators for IPNI Southeast Asia Program, and establish partnerships that can add value to research and market development undertakings in the region. This permanently ongoing project, based on available resources, synthesizes and disseminates findings and results through production and/or distribution of publications and program communications.

The project uses various approaches and methods related to publication development and communication, including website content, webinars, press releases, book distribution, and conventional writing of publications. Scientific publications are not dealt with here, but under the respective projects. The results of the project to date:

- Conducted seven webinars, each with 50 to 200+ participants
- Published eight press releases, four quarterly newsletters, one manual (*4R Plant Nutrition Manual* in Bahasa Indonesia), and one *Planters' Diary 2018*
- Published three articles in external popular magazines (*Media Perkebunan*, *Fertilizer Focus*)
- Developed eight 4R logos in Southeast Asian languages (Lao, Thai, Bahasa Malaysia, Bahasa Indonesia, Khmer, Burmese, Vietnamese, Tagalog)
- Uploaded 76 web pages and 18 events to the IPNI SEAP regional website
- Uploaded 3,055 images to IPNI Image Database
- Entered 1,168 publications into IPNI SEAP library
- Mailed out 2,052 copies of *Better Crops*
- Fulfilled 53 book orders

The fundamental aim of this project is in line with IPNI's general mission: the dissemination of information related to the responsible nutrition of crops. The project raises the awareness of the general public and specifically targeted focus groups on critical issues in plant nutrition. *IPNI-2017-SEAP-09*

### **Seed Project and Incubator Program**

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Project Cooperators: Mr. Noel Janetski, Dr. Tin Aye Maung, Ms. Marianne Samson, Dr. Tassilo Tiemann

The IPNI Southeast Asia Program seed fund is used to support promising market development and research ideas that have a high likelihood of leading to a larger project engagement. Such innovative ideas may include review of publications, preparing the ground for later projects, proof of concept trials in the field, market assessment studies, or amongst others, the generation of land use, crop production, and fertilizer use statistics based on public and other information sources. The implementation of this project is permanently ongoing depending on resources. In 2017, the Seed Fund was used to:

1. Develop a database of land use and crop productivity statistics for major crops in Southeast Asia, which was then used to calculate nutrient uptake and removals, and fertilizer forecasts. The database has been shared with interested member companies, and components have been presented in webinars, publications, and at conferences.
2. Produce a review of fertilizer use trends in Southeast Asian countries.
3. And finally, initiate a literature review on plant nutrition in Black Pepper. This literature review is the starting point for the development of a field trial and supply chain project on improved pepper crop nutrition with Olam International and Yara International.

This program will generate significant return to IPNI and its member companies through systematic identification and conceptualization of targeted and specific market development and research opportunities.  
*IPNI-2017-SEAP-00*

## **Philippines**

### **Sustainable Yield Intensification in Philippine Cassava Systems**

Project Leaders: Mirasol Pampolino, International Plant Nutrition Institute, Metro Manila, Philippines.

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Project Cooperators: IPNI Southeast Asia Program, Universal Harvester Inc., Philippines, Uralkali Trading, Singapore, and University of the Philippines Los Banos, Philippines

This project generates the scientific information that is required to establish the nutrient uptake and yield relationships for cassava, determines the agronomic use efficiency for individual nutrients to aid in the development of fertilizer recommendations, and establishes 4R-consistent nutrient management practices for smallholder growing systems. The implementation of this project is between 2015 and 2018 in the Philippines.

The project uses an approach that successively reduces the risk for growers to invest in fertilizers, and consists of: 1) an analysis of the existing data to derive nutrient uptake functions for cassava; 2) supporting the existing information with data from on-station trials and trials in commercial fields that demonstrate economic viability and validate nutrient uptake functions; and 3) development of a Nutrient Expert® (NE) Cassava fertilizer decision support tool for the Philippines. Therefore, we will: 1) determine the parameters for internal nutrient efficiency, response to individual nutrients and attainable yields from nutrient omission trials on stations; 2) verify the parameters in trials at farmers' fields and develop a Beta version of NE Cassava; 3) use the Beta version to generate fertilizer recommendations for a selected number of farmer's fields; and 4) examine the field results jointly with stakeholders and refine the model as needed.

In 2015-2017, results of one to two years of cassava cropping at four on-station sites (two sites in Laguna, one in Isabela, one in Bukidnon), and three on-farm sites in Agusan del Norte indicated positive response to fertilization, with attainable yields of 20 to 58 t/ha of fresh root yield. In 2017, the beta version of NE for Cassava was developed and subsequently used to generate 4R-based fertilization rates for the individual trial sites. Yield, fertilizer use, and nutrient uptake data from harvested trials have been added to the cassava database. Four on-farm cassava fertilization trials for the optimization of NE Cassava were established in the province of Zambales.

Cassava attainable yields and yield response to nitrogen, phosphorus, and potassium application varied across locations and varieties. Large amounts of nutrients are required by cassava to produce high yields. Fertilizer recommendations based on 4R principles will help farmers improve their yields and profit and prevent severe nutrient mining that could lead to land degradation. *IPNI-2014-PHL-5*

### **Scaling of Maize Fertilizer Recommendations Philippines**

Project Leaders: Mirasol Pampolino, International Plant Nutrition Institute, Metro Manila, Philippines.

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The first objective of this project was to test a model for scaling 4Rs in maize through the use of recommendation based from the fertilizer decision support tool, Nutrient Expert® Maize (NE). The second objective was to building the capacity of farmer leaders within smallholder cooperatives to use the NE tool. The project was implemented from October 2016 to December 2017 in the Philippines.

Field validation of NE for Maize in the Philippines, through the regional offices of the Department of Agriculture, has demonstrated that it is an effective tool in providing fertilizer recommendations that help farmers improve maize yields and farming profitability. The NE recommendation is tailored to field-specific conditions and includes prescriptions on the 4Rs of fertilizer application (right source, rate, time, and place). The participating cooperatives have been identified/nominated by the project sponsor, Universal Harvester Inc. (UHI), who is supplying fertilizers to the cooperatives. The project included: 1) training of lead farmers in the cooperatives and the agronomic staff of UHI on the use of NE, and enabling them to develop recommendations for the members of the cooperatives; and 2) monitoring of the impact of the NE recommendations on maize yield, nutrient use, and fertilizer sales.

In 2017, we conducted seven field visits to monitor field trials and discuss project activities; three co-op partner meetings to present field results; three farmer meetings to introduce 4R and NE; and three educational activities that trained 29 co-op staff on the use of NE. We collected 92 fertilizer and yield data from field trials by farmers, presented one poster at a national scientific conference, and provided one project update to the project sponsor. Eight task reports and four quarterly reports were also submitted to the project sponsor. A scaling model has been tested with three smallholder cooperatives. Observations and findings will be compiled in a final project report. *IPNI-2016-PHL-6*

## **Myanmar**

### **Myanmar 4R Nutrient Stewardship Program**

Project Leader: Thomas Oberthür, International Plant Nutrition Institute (IPNI), Southeast Asia Program, Penang, Malaysia Email: toberthur@ipni.net

Project Cooperators: IPNI Southeast Asia Program, Wilmar International, Canpotex International IJM Plantations, Wilmar International, and Canpotex International

Myanmar's recent economic opening has provided new opportunities, including those for the fertilizer industry and their supply chain partners. In this project, we will conceptualize and implement a market development program for Myanmar, together with one of IPNI's member companies. This project began in 2014 and will continue through 2018.

During the first two years of the study (2014 and 2015), the program encompassed the production of educational 4R Nutrient Stewardship materials and conceptualized, prepared and delivered a 4R seminar series in Myanmar. Initially, the direct impact was generated for the local business partners of IPNI member companies by developing materials that support both fertilizer market and sustainable agricultural development. Eventually, we expect our work to generate yield and income increases for farmers who deploy the 4R concepts. Furthermore, the program engagement strategy has a large-scale outreach into various commodities and will increasingly engage diverse key stakeholders in the agricultural sector.

For 2017, we undertook a fertilizer market assessment to identify the most significant 4R Research and Development opportunities in terms of regions, commodities, processes, and fertilizer industry demands. For this assessment, we developed a rapid field approach to generate deep market intelligence, executed three regional field missions in which the rapid approach was deployed. A final report "Supporting Responsible and Profitable Use of Fertilizers in Myanmar" was written to outline market development opportunities identified during the field missions. A presentation was prepared based on the report was delivered in Myanmar to the supporting IPNI member company and its national business partners. The project is now complete.

We expect this program to generate significant benefits for the farming and agricultural business community in a country that is considered as a potential agricultural powerhouse, but where currently little information is available to realize this vision. IPNI and partners will make a difference in this ambitious process.  
*IPNI-2015-MMR-4*

## Vietnam

### ***Improving Coffee Crop Nutrition in Vietnam***

Project Leader: Thomas Oberthür, International Plant Nutrition Institute (IPNI), Southeast Asia Program, Penang, Malaysia Email: toberthur@ipni.net

Project Cooperators: Ezio Nalin de Paulo, Tien Bac Thong

The main objective of this project is to understand current crop nutrition practices in Robusta Coffee in Vietnam, the world's second largest coffee-producing country. The findings of the study will be used to develop field trials that support and promote adequate and wide scale use of responsible nutrient management for high yield, profit, and environmental sustainability in the coffee sector of Vietnam. The project is currently in Phase 1 for 2018, followed by a planned implementation of Phase 2.

Specifically, the project will produce the following outputs until the end of April 2018:

1. A report with the review findings (maximum 25 pages)
2. A manuscript (1,500 to 2,000 words) submission for IPNI's *Better Crops Journal*
3. A two-page outline for a field trial to improve coffee crop nutrition in Vietnam
4. Repository of images, graphs and tables that can be used for presentations

The following milestones and deadlines are used to produce the outputs:

1. Literature (grey, older, rare) collected from Vietnamese institutions: January 10, 2018
2. Key literature translated from Vietnamese into English: January 25, 2018
3. Field data and focus group discussion results compiled: February 10, 2018
4. First report draft including literature review and field data: February 28, 2018
5. Field work design draft: March 12, 2018
6. Journal manuscript draft: March 31, 2018
7. All final products: April 15, 2018.

The field surveys from in the most important Vietnamese Robusta coffee regions have been completed. The databases with field results are currently being developed. The literature review, as well as writing the first manuscript are ongoing. IPNI has been instrumental in the initial establishment of crop nutrition management practices in Vietnam between 1990 and 2000. This project will build on the achievements and further improve the current management practices. *IPNI-2017-VNM-01*

## Multi-Country

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

Project Leader: Chris Donough, International Plant Nutrition Institute, Penang, Malaysia.  
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Project Cooperators: IJM Plantations, Wilmar International, and Canpotex International

The objective of this project is 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 of oil palm including nursery, immature, and mature development phases of the crop. This project is implemented between 2011 and 2019, and may even be extended until 2021 if monitoring requires it.

The BMP treatments are developed in full-sized management blocks in two collaborating plantations in Sumatra (Indonesia) and Sabah (Malaysia), involving re-planting of previous crops by IPNI and its plantation partners. Results from the BMP implementation are compared to those achieved under standard plantation practices in reference blocks. At the outset of the research, reference and BMP blocks had similar conditions and performance. There are a total of 15 blocks in Sabah and 10 blocks in Sumatra, with blocks averaging 25 ha.

In Sabah, with field planting of rep 5 completed, four reps entered the mature stage and harvest has started. Replicate 1 started the fourth year of harvesting; Replicate 2 –third year, Replicate 3 - second year, and Replicate 4 - first year in November 2017. Replicate 5 is still in the immature phase.

At the second site in South Sumatra, the first year of harvesting is ongoing in Replicates 1 to 4. Replicate 5 is in the second Immature year of maintenance. Data analysis from the nursery stage in both sites is ongoing, and further publications are planned for 2018. Results are already being used in IPNI training courses for the plantation partners and the wider industry.

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 is including all growth stages of the oil palm and proposes monitoring over a period of at least eight years. *IPNI-2010-SEAP-4*

### **Oil Palm Training Program**

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

IPNI Southeast Asia Program has been developing the learning platform for 4R Nutrient Stewardship in Oil Palm. We developed this course to explain the concept of 4R Nutrient Stewardship, and to outline the principles that define the four “rights” in the context of a successful oil palm operation. It is intended to adapt and integrate those fundamental principles into a comprehensive method of nutrient management that meets the criteria of sustainability within an oil palm production system.

Currently the course contains two modules with sub topics. Module 1 includes two sections: 1) 4R Principles and Methods in Oil Palm-What is 4R; Soil, Plant and Fertilizer Sampling; Plant Growth Measurements; Zero Fertilizer Plots; and Field Audits), and 2) Applied 4R Nutrition in Oil Palm (Right Source, Rate, Time, Place, and Key Performance Indicators in Nursery, Replant, Immature, and Mature oil palm). Module 2 includes the Concepts, Processes and Protocols for High Fresh Fruit Bunch (FFB) Yields of oil palm (Yield Gaps and their Measurements; Performance Benchmarking Plantation Intelligence; Estate Scale Experimentation in Commercial Operations; and Best Management Practice (BMP) Process and Protocols).

In 2017, for the first time, a course jointly organized by IPNI and IJM Plantations Berhad was offered at IJM’s Estates in Sabah, Malaysia. IJM is a leading Malaysian plantation company, and its top-class facilities, experienced staff and supportive senior management made this course a success. The course was conducted over three and a half days, at full capacity with 34 participants from the oil palm industry and supporting sectors representing various oil palm producing countries. The participants came from Malaysia, Sri Lanka, and India. A second course was given later in the year at the plantation of Wilmar International in Kalimantan, Indonesia, with another 25 participants. *IPNI-2016-SEAP-03*

### **Nutrient Expert Development and Assessment**

Project Leader: Mirasol Pampolino, International Plant Nutrition Institute (IPNI), Southeast Asia Program, Manila, Philippines. Email: mpampolino@ipni.net

The objectives of this project, initiated in 2011, are: 1) to develop, test, and refine the Nutrient Expert® (NE) fertilizer decision support tool for new crops and new geographies, maize in sub-Saharan Africa; rice in China and India; soybean in China and India; wheat in North Africa; and maize with different variety types in the Philippines); 2) to conduct field trials and build agronomic databases for non-cereal crops (i.e., cassava, cotton); and 3) to initiate development of ICT-based tools to help in the dissemination of the field-validated versions of NE.

Development, field validation and refinement of NE for new crops and geographies in Asia and Africa continued in 2017. Field validation consists of at least two years of testing NE recommendations against local recommendations and farmer’s fertilizer practices (FFP). A tool is considered field validated after recommendations from it has been demonstrated to be effective in improving farmers’ yields and profits or maintained farmers’ high yields, and also improved their fertilizer use efficiency. Development and enhancement of the mature versions for multi-platform use, such as with computers and mobile Android devices, continued in 2017.

In 2017, six beta versions for new crops or geographies were developed: Potato - China, Rice - Bangladesh, Maize - Ghana, Maize - Togo, Maize - Burkina Faso, and Cassava - Philippines. Field validation and

refinement continued for three beta versions: Soybean - India, Hybrid Maize - Ethiopia, and Hybrid Maize - Tanzania. The field validation of two NE tools were completed: NE Maize Nigeria and NE Wheat North Africa (Morocco). The NE Data Analytics was further developed and improved to enable automatic data capture, storage, and export, and a feature enabling NE recommendations to be sent in bulk to farmers through text messaging from an Android device was constructed. We conducted one site visit and three consultation meetings with local experts, and delivered nine NE presentations to different partners and users. We published four NE articles in refereed journals and one press release. Building regional capacity for NE development through training continued.

This project has produced 13 field-validated mature versions, and nine beta versions are under field validation, covering a total of six crops, 18 countries, and eight languages. The mature NE versions are now being used by regional programs in Asia and Africa to roll out 4R-compliant fertilizer recommendations in their regions. They are available for download at [software.ipni.net](http://software.ipni.net). *IPNI-2010-GBL-52*

### ***Transferring Oil Palm Plantation Best Management Practices (BMP) from Southeast Asia to West Africa***

Project Leader: Shamie Zingore, International Plant Nutrition Institute, Nairobi, Kenya. Email: [zingore@ipni.net](mailto:zingore@ipni.net)

Project Cooperator: Thomas Oberthür

Best Management Practices (BMP) in oil palm plantations were introduced in Ghana, West Africa in 2013. The study aimed at identifying and implementing improved agronomic management practices that meet site-specific needs and opportunities for enhanced productivity, profitability, and environmental sustainability of oil palm production by providing assistance in training, agronomic and economic data analysis, and planning for wide-scale implementation of BMPs at a commercial scale.

Parallel sets of comparable oil palm blocks, representative of a plantation, were selected at three commercial plantations. Site-specific BMPs were then introduced in one block, while standard estate practices were maintained in the other block, thus considered as a control or reference block (REF). In 2017, field conditions in the BMP blocks were at a steady state, but fruit bunch yields at all plantation sites declined compared to 2016. This was most likely due to the drought that occurred two years earlier. Average yields at the BMP blocks decreased to 17.2 t/ha fruit bunches and 14.8 t/ha at REF blocks, a yield difference of 2.4 t/ha, or 16% between the two treatments. While field upkeep was good in most blocks, fertilizer recommendations for 2017 were not implemented by the estates except for the Norpalm plantations.

Results of the fertilizer trial did not show clear yield responses, but identified nitrogen and potassium to be the most limiting nutrients in Ghanaian oil palm systems. In the irrigation trial, the treatment effects began to show after 36 months because of the time-lag between removal of agronomic constraints and their effect on yield. The irrigation+fertilizer (I1F1) treatment produced an extra yield of about 5 t/ha over the control plot that had no irrigation or fertilizer, and >4 t/ha for the fertilizer alone or irrigation alone treatments. In 2018, the differences are expected to be more pronounced, with yields of >35 t/ha at the I1F1 treatment.

Training activities have enhanced the capacity of the plantations to adapt components of BMPs at plantation scale. Results of the trials are expected to further increase capacity on water and 4R nutrient management, particularly for marginal production areas and hilly landscapes in Ghana. *IPNI-2010-GBL-53* ❖

# Sub-Saharan Africa Program

Dr. Shamie Zingore, Director

## Ethiopia

### ***Out-scaling 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification in Ethiopia***

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

Crop productivity in smallholder farming systems in Ethiopia is low, with national average yields of less than 3 t/ha for cereals. As available arable land is becoming increasingly scarce, increases in production will be driven largely by intensification of inputs rather than expansion of land area.

In the past decade, the Ethiopian government has taken steps to support agricultural growth through targeted investments to ensure access to fertilizers and soil testing. The project seeks to backstop these investments by developing approaches and tools for the effective transfer of 4R Nutrient Stewardship knowledge to extension systems and smallholder farmers. This project is being implemented in collaboration with the Agricultural Transformation Agency (ATA) and the International Maize and Wheat Improvement Center (CIMMYT) to demonstrate the impact of various 4R strategies on crop productivity and profit. The project is also adapting various 4R knowledge products for use by extension systems, farmer groups, and fertilizer dealers in Ethiopia.

Analysis of data from on-farm nutrient omission trials in the 2017 cropping season in Hawassa and Adami Tullu indicated the magnitude of nutrient limitations with average yield responses of 3, 1, 0.5, and 1 t/ha, respectively for nitrogen (N), phosphorus (P), potassium (K) and micronutrients. Yields of up to 7 t/ha were observed with the balanced application of NPK plus micronutrients, an increase of 5 t/ha above average yields in Ethiopia. This illustrated the potential to sustainably increase yields with balanced nutrient management. However, spatial variability in response to balanced application of nutrients indicated the need for more site-specific nutrient recommendation. Subsequently, nutrient response yield data was used to develop site-specific nutrient recommendations using the Nutrient Expert® tool, and validation trials were established in the 2017 cropping season.

Capacity building of extension officers in the project areas has continued through their regular involvement in the establishment and management of 4R demonstration sites, and through targeted training workshops. Further, the project has continued to partner with local stakeholders to translate 4R knowledge products into the local Amharic language.

To initiate discourse on challenges facing the fertilizer sector in Ethiopia, the project, in collaboration with local stakeholders, organized a two-day workshop on “The status of fertilizer use and fertilizer recommendation”, in Addis Ababa in July 2017. The project brought together key public and private stakeholders in the agriculture and fertilizer sectors, and resulted in a report summarizing the technical and policy issues facing the fertilizer industry in Ethiopia, and the options for improving fertilizer use and use efficiency in the country. *IPNI-2014-ETH-1*

## Kenya

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

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

Project Cooperators: Nesbert Mangale, Julius Nyabiche, Joseph Chacha, and George Odour

There is an urgent need for the sustainable intensification of crop productivity in smallholder farming systems, given the current low productivity levels which frequently fall short of meeting the food needs. The 4R Nutrient Stewardship principles provide a framework that help farmers have sustainable increases in their crop yields and profits. Results from a project over the past four years illustrate that this is feasible. In the past five years, IPNI has employed field and ICT-based approaches to disseminate 4R Nutrient Stewardship knowledge and practices in a pilot site in western Kenya, targeted at supporting crop production intensification among smallholder farmers. The project used on-farm demonstration sites to demonstrate the impact of various 4R techniques, including site- and crop-specific fertilizer recommendations, on crop productivity and profits. The

project also developed various 4R knowledge products for farmers, extension agents and fertilizer dealers, while using various media and ICT platforms to communicate 4R information to farmers.

Analysis of yield data from nutrient omission sites demonstrated that improved crop yields can only be sustained through balanced nutrition. Mean maize grain yield in the nitrogen, phosphorus, and potassium (NPK) treatment was always >4 t/ha, and was consistently higher than all other treatments in all cropping seasons. Omission of any one of the macronutrients resulted in a steady decline in yields over time, whereas under full macronutrient application, yields remained relatively stable. Balanced nutrition with NPK was also observed to result in lower variability in yields compared to the other treatments.

The success of the dissemination strategy developed by the project offers a simplified step by step platform that can be used in successfully disseminating 4R nutrient management knowledge in other parts of the region, with the key objective of helping smallholder farmers sustainably increase yields and profits in their farms. However, for farmers to fully benefit from the 4R components, there is need for further interventions at the policy level aimed at improving the current extension agent: farmer ratio, reducing the farm gate prices of fertilizers to enable farmers afford fertilizers at the right quantities, and improved access to markets to allow farmers enjoy benefits of increased production, among other interventions. *IPNI-2013-SSAP-2*

## Multi-Country

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

Project Leader: Shamie Zingore, International Plant Nutrition Institute, Nairobi, Kenya. Email: [zingore@ipni.net](mailto:zingore@ipni.net)

Project Cooperator: Rebbie Hararwa

Despite the potential of Integrated Soil Fertility Management (ISFM) technologies to improve crop productivity in sub-Saharan Africa (SSA), adoption by farmers has been very limited. The underlying challenges include poor integration of existing knowledge and lack of effective knowledge products for farmers, extension agents and policy makers. Recognizing IPNI's leadership role in plant nutrition research, development and partnership development, the Alliance for a Green Revolution in Africa (AGRA) awarded a significant grant to IPNI to establish and backstop a soil health consortia of eight countries (Kenya, Uganda, Tanzania, Rwanda, Malawi, Mozambique, Ethiopia, and Zambia). The objectives of the project were: 1) harmonization of ISFM information at the country and regional level; 2) development of a regional database for agronomic information; and 3) develop communication products to support farmers and policy makers to make informed decisions on investment in ISFM technologies.

Soil health consortia have been established in the eight countries bringing together extension workers, researchers, fertilizer and seed input suppliers, and plant and soil laboratories. Currently, the consortia has a membership of over 200 institutions and 2,000 individuals. The consortia are integrated at the regional level to allow the flow of information on the best agricultural practices and agricultural innovations across the countries. More than 10,000 published and raw datasets have been collected and collated, and one-stop repositories for agricultural and ISFM information established for each country. The materials held in these repositories include information on soil fertility management, best management practices for different crops and geographies, soil maps, policy documents, guides for agricultural extension agents, and training modules. The consortia has also developed a range of communication products which include policy briefs, extension guidelines, manuals and books of abstracts that have been distributed to over 100,000 stakeholders. Between 2014 and 2017, the consortia reached over 6 million people with different packages of agricultural information.

In 2017, the project was refocused to support the fertilizer industry. IPNI established the Fertilizer Industry Research and Development Forum in partnership with AFAP, AGRA, and Columbia University to organize high level fertilizer and nutrient management knowledge sharing workshops. The forum supported the networking and capacity development of local, regional and international fertilizer companies in Africa. It also provided an opportunity for IPNI to promote widespread use of the principles of 4R Nutrient Stewardship and the Nutrient Expert® decision support tools through the fertilizer industry.

*IPNI-2013-SSAP-1*

## **Enhancing the Capacity for Dissemination of Site-specific Maize Production Intensification Technologies under Variable Farm, Climatic and Soil Fertility Conditions in Kenya and Zimbabwe**

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

Project Cooperators: Alfred Micheni, Isaiah Nyagumbo, Regis Chikowo, and Monica Mucheru-Muna

Maize is the most important food crop in Kenya and many other countries in Africa. However, its productivity has remained low mainly due to climatic conditions and soil constraints. Conservation agriculture (CA) based on reduced tillage, surface retention of crop residues, and crop rotation can help in the amelioration of these constraints. An experiment was initiated in 2014 to evaluate the long-term effects of balanced nutrient management in maize production systems under CA and conventional tillage (CT).

A fertilized maize crop was planted during the long rainy season and then was rotated with an un-fertilized bean crop during the short rainy season. The bean crop is expected to benefit from the residual fertilizer from the maize planted in the previous season. The fertilizer treatments were nitrogen and potassium (NK), nitrogen and phosphorus (NP), PK, NPK, and NPK+calcium (Ca)+magnesium (Mg) +zinc (Zn) +boron (B) +sulfur (S). The project is implemented in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), Kenya Agricultural and Livestock Research Organization (KALRO), and the University of Nairobi.

Key findings from the long-term balanced nutrient trials over the past year indicate that CA increased maize grain yields relative to CT by 36%. Additionally, balanced nutrition (NPK+Ca/Mg/Zn/B/S) had the highest grain yield across both CA and CT. The results highlight the importance of balanced nutrient management and CA for sustainable maize production intensification in Kenya. Similarly, CA increased the unfertilized bean yields relative to CT by 38%.

In terms of capacity building, an M.Sc. student from the University of Nairobi conducting research on the project was able to complete his thesis titled “Nutrient management options for enhancing productivity of maize and bean under conservation and conventional tillage systems.” *IPNI-2014-SSAP-03*

## **Taking Maize Agronomy to Scale in Africa (TAMASA)**

Project Leader: Peter Craufurd, International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya.

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Project Cooperator: Bernard Vanlauwe

The overall objective of the “Taking Maize Agronomy to Scale in Africa” (TAMASA) project is to work with extension service providers (i.e., input suppliers, government and private research and extension services, agro-dealers, and others) to co-develop systems and applications/tools that enhance capacity to effectively develop and disseminate site-specific nutrient and agronomic recommendations. The project is implemented in collaboration with CIMMYT, IITA, and national research institutions in three pilot study countries in Ethiopia, Nigeria, and Tanzania. IPNI has been leading the development of the site-specific nutrient management (SSNM) recommendations, focusing on the Nutrient Expert® (NE) fertilizer decision support tool. Nutrient Expert uses SSNM to develop strategies to manage fertilizer macronutrients, nitrogen (N), phosphorus (P), and potassium (K), and secondary and micronutrients taking into account nutrients from both indigenous and mineral sources.

Over 700 on-farm multi-location nutrient omission trials (NOTs) were conducted in a wide range of maize production areas in Ethiopia, Nigeria, and Tanzania between 2015 and 2017 to generate yield, yield response, and nutrient uptake datasets for calibration of NE. The nutrient omission trials, located at multiple sites, were designed as a diagnostic tool to identify which of the macronutrients (N, P, or K) are limiting maize growth, and to determine other possible constraints related to soil secondary and micronutrients. Consequently, Nutrient Expert for maize (NEM) was co-developed for Ethiopia, Tanzania, and Nigeria. Approximately 420 on-farm validation trials were conducted in Ethiopia, Nigeria, and Tanzania, in which recommendations generated using NE were compared with soil-test based nutrient recommendations, the current regional fertilizer recommendations, and a control plot with no fertilizer applied.

Data collected from NOTs showed that maize response to different nutrients varied from farm to farm, and this was most pronounced in Nigeria and southern highlands of Tanzania. The validation trial results showed that use of NE improved yields (up to about 5 t/ha on average), agronomic fertilizer use efficiency, and profits

over farmer management practices and current recommendations. Nutrient Expert was used by extension agents to generate over 1,886 fertilizer recommendations for individual farmers in 2017 in Ethiopia, Nigeria, and Tanzania. Similarly, NE was used by OCP agronomists to generate 4,841 recommendations for individual farmers in spillover countries in Nigeria, Ghana, and Togo under the OCP School Lab Program. Overall, the use of NE was highly effective as a simple and cost-effective tool for improving fertilizer recommendations in smallholder farming systems characterized by highly variable soil fertility conditions. *IPNI-2015-SSAP-04*

### **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](mailto:rchikowo@agric.uz.ac.zw)

Site-specific nutrient management is important in smallholder farming areas of sub-Saharan Africa to enhance efficient use of scarce nutrient resources, considering that significant variability in soil fertility exists within and between farms. Over the six years of this study, multi-locational on-farm nutrient omission trials have been conducted in pilot sites in eastern and northeastern Zimbabwe to establish maize yield response to the application of nitrogen, phosphorus, and potassium (NPK), selected micronutrients (zinc, boron), manure, and lime under variable soil fertility conditions. The experiments also sought to establish nutrient-determined maize yield gaps in major maize-growing areas in Zimbabwe, and assess balanced fertilizer management strategies to optimize maize production under rain-fed conditions.

In 2017, the project focused on assessing the effects of: 1) conventional tillage (CT); 2) basins-based conservation agriculture (CA) (B-CA); and 3) furrow-based CA (F-CA) on sandy soils with contrasting soil organic carbon (SOC). Farms had SOC ranging from 0.18 to 0.89% and clay content from 6 to 15%. Nutrient omission trials using N, P, K, cattle manure (M) and their combinations were set up on twenty farms, each with two fields per farm selected. Infertile fields had SOC <0.4%, were more acidic, had lower amounts of exchangeable bases (magnesium, calcium, K), available P, and total N. Grain yields increased from 0.3 t/ha for unfertilized control to 4.1 t/ha for the NPKS+M treatment. Yield response to N was consistently larger than P or K, irrespective of soil fertility status. Response to N increased with the increase in soil fertility, suggesting higher N use efficiency for soils with higher SOC. Except for NPKSM, no significant yield differences were observed under the residual and additive plots for treatments, when N was added each year. At productivity levels of <4 t/ha, there was no yield gain in applying both P and K for consecutive years, suggesting that nutrient investments by resource-constrained farmers for Year 2 could target only N application. Maize grain yields were significantly higher under B-CA compared to F-CA and CT, suggesting a positive effect due to moisture conservation and concentration of nutrients. The consistently large yields with the NPKSM treatment highlight the importance of integrated nutrient management combining mineral and organic sources of nutrients in agro-ecologies receiving unreliable rainfall. Nitrogen and P remain the most limiting nutrients, and complementary organic nutrient management approaches should be employed to increase soil carbon and sustain soil productivity. *IPNI-2011-ZWE-1* ❖

# North Africa Program

Dr. Mohammed El Gharous, Consulting Director

Dr. Hakim Boulal, Deputy Director

## Algeria

### **Improving Nutrient Management Knowledge in Rain-fed Wheat Cropping Systems of Algeria**

Project Leader: Omar Zaghouane, Algeria Institut National des Grandes Cultures, Alger, Algeria.

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Project Cooperators: Jugurtha Khaled and Hakim Boulal

This project was initiated in 2014 with the objective to develop a Nutrient Expert® (NE) fertilizer decision support tool for Algerian farmers and extension specialists to implement appropriate nutrient management practices for wheat production in rain-fed areas. In the 2016-2017 cropping season, eight nutrient omission trials were established in the region of Tiaret, located in the north west of Algeria. Each on-farm experimental plot was planted with bread wheat (BW) and durum wheat (DW) under seven nutrient treatments (kg/ha): 1) optimum treatment (OPT: 140 kg N + 60 Kg P<sub>2</sub>O<sub>5</sub> + 36 kg K<sub>2</sub>O for DW and 120 kg N + 48 kg P<sub>2</sub>O<sub>5</sub> + 34 kg K<sub>2</sub>O for BW); 2) omitting nitrogen (N) from OPT; 3) omitting phosphorus (P) from OPT; 4) omitting potassium (K) from OPT; 5) control (without fertilizers); 6) site-specific nutrient management (SSNM) (according to NE recommendations); and 7) farmer fertilizer practice (FFP).

The sowing date was between the period of December 11-16, 2016. The sources of fertilizer used in the experiment were triple super phosphate (TSP) for P, potassium sulfate for K, and urea for N. The cumulated rainfall in the 2016-2017 cropping season was 344 mm, with 41% of the total rain registered in the month of January. Also, spring was very dry, with only 50.2 mm rainfall in four days. Experimental results showed that the average grain yields of DW and BW in the OPT treatment were 2.6 t/ha and 2.7 t/ha, respectively. The control treatment reduced the grain yield by 11% and 18% for BW and DW respectively over OPT. The omission of N, P, and K had no significant effect on grain yield of DW. In BW, the omission of P and K had no significant effect on the grain yield, however omitting N reduced the grain yield by 14% over OPT. For both species of wheat, the average grain yield of FFP treatment was 22% less than the OPT. Fertilizers recommendations based on SSNM increased the average grain yield of wheat by 22% compared to FFP. The project will continue for at least one more cropping season. *IPNI-2014-DZA-1*

## Morocco

### **Best Management Practice of Nutrient of Olive Orchards in Rain-fed and Irrigated Areas of Morocco**

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Project Cooperator: El Antari Bouizgaren

This experiment began in 2014 with the objective to assess the effect of improved methods for nutrient recommendations in olive orchards in Morocco. Two on-farm experimental sites were selected in the irrigated and rain-fed areas of Marrakech and Essaouira Provinces. The planting density were 204 trees/ha under irrigated and 25 trees/ha under rain-fed conditions. At each site, four treatments were used: 1) no additional fertilization (control); 2) farmer fertilizer practice (FFP); 3) fertilization based on nutrient removal (NR); and 4) fertilization based on foliar analysis (FA). Two olive varieties, Haouzia and Menara, were studied in both sites. The applied nutrients in the different treatments at the irrigated site in 2017 were 0.50 kg nitrogen (N)/tree for FFP, 0.50 kg N + 0.18 kg P<sub>2</sub>O<sub>5</sub> + 0.41 kg K<sub>2</sub>O/tree for FA and 0.52 kg N + 0.25 kg P<sub>2</sub>O<sub>5</sub> + 0.88 kg K<sub>2</sub>O/tree for NR. In the rain-fed site, nutrients applied in different treatments were: FFP (no additional fertilizers were applied by farmer), 0.27 kg N + 0.25 kg P<sub>2</sub>O<sub>5</sub> + 0.60 K<sub>2</sub>O kg/tree for FA treatment, and 0.35 kg N + 0.23 kg P<sub>2</sub>O<sub>5</sub> + 0.55 kg K<sub>2</sub>O/tree for NR.

No significant yield difference was found between the two varieties in the irrigated area, however a significant effect of fertilization treatment was measured. The FA and NR treatments produced similar average yields (59 kg/tree) that was significantly higher compared to the FFP (9 kg/tree) and the control (12

kg/tree) yields. In the rain-fed areas, the highest average olive yields (43 kg per tree) were obtained when the fertilization program was based on FA and NR methods with no significant difference between the treatments. Olive yield under both FA and NR treatments was significantly higher than FFP (11 kg/tree) and the control (13 kg/tree) treatments. There was no significant difference in olive oil content between the fertilizer treatments in both the rainfed and irrigated areas. *IPNI-2013-MAR-1*

### **Development and Dissemination of 4R Nutrient Stewardship Knowledge to Support Crop Production Intensification**

Project Leader: Hakim Boulal, International Plant Nutrition Institute, Settlat, Morocco. Email: hboulal@ipni.net

Project Cooperators: Mohamed El Gharous and Zaid Guirrou

The objective of this project is to develop a Nutrient Expert® (NE) tool for Moroccan farmers and extension specialists to implement appropriate nutrient management practices for wheat production. In the 2016-2017 cropping season, nutrient omission trials were established in four regions of Morocco: Abda-Hmar (semi-arid region), Chaouia (intermediate-semi-arid region), Fez (rain-fed favorable area), and Tadla (irrigated area). At each region, 10 on-farm trials were planted with bread wheat (BW) and durum wheat (DW) under eight nutrient treatments: 1) optimum treatment [OPT: 84-36-45 kg N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O/ha in Abda-Hmar, 90-56-45 kg/ha in Settlat (Chaouia), 99-65-50 kg/ha in Berrechid (Chaouia), 127-68-63 kg/ha in Fez, and 160-90-100 kg/ha in Tadla; 2) omitting nitrogen (N) from OPT; 3) omitting phosphorus (P) from OPT; 4) omitting potassium (K) from OPT; 5) control (without fertilizers); 6) site-specific nutrient management (SSNM) (according to NE recommendations); 7) Soil test (fertilization according to soil analysis); and 8) farmer fertilizer practice (FFP).

From the time of sowing to physiological maturity, the cumulative rainfall ranged from 193 mm in Hmar to 331 mm in Fez. Results of the study showed that the rain-fed areas of the Hmar region were less favorable for wheat production with an average grain yield of 0.8 t/ha and 1.3 t/ha, respectively for BW and DW. However in the Fez region, grain yields of wheat were the highest with an average of 3.4 t/ha with no significant differences between BW and DW. Among the three rain-fed regions, the highest response to macronutrient application was observed in the favorable region of Fez where omitted N, P, and K decreased the grain yield of BW by 17%, 14%, and 24% respectively, and the grain yield of DW by 38%, 32%, and 30%. In all the rain-fed regions, SSNM significantly increased the grain yield of wheat compared to FFP. In the irrigated area of Tadla, no significant difference was observed between the grain yield of DW and BW. For both species, the maximum grain yield was obtained with OPT treatment with 8.9 t/ha (BW) and 9.3 t/ha (DW). For both species, on average the omission of N, K, and P reduced the grain yield of wheat by 33%, 27%, and 20%, respectively. Similar increase of grain yields of BW and DW were obtained by the SSNM treatment compared to FFP, with an average of 1.5 t/ha. *IPNI-2014-MAR-2*

### **Towards Management of Fertilization to Control Wheat Crown Rot Caused by *Fusarium culmorum***

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Project Cooperators: Miss Siham Bahaa-eddine, Hakim Boulal, and Mohamed El Gharous

Wheat crown rot, caused by *Fusarium culmorum*, is becoming an increasing constraint to Moroccan wheat production for inducing grain yield losses that vary between 12 and 17%. This project was initiated in 2014 with the objective to develop a fertilizer management package to control this disease in durum wheat. The management strategy is based on the use of different combinations of nitrogen (N) fertilizer, ammonium nitrate (AN) or urea, in combination with phosphorus (P) and potassium (K). Field experiments were established in November 2016 at three locations: two under rain-fed conditions (Sidi El Aidi and Jemaat Shaim) and one under supplemental irrigation (Khemis Zemamra). The experimental design was a strip plot with four blocks, where treatments included two levels of inoculation (*Fusarium*-inoculated or non-inoculated seeds). The inoculation treatment was crossed with six fertilizer treatments: 1) diammonium phosphate (DAP); 2) DAP + potassium sulfate (KS); 3) DAP + AN; 4) DAP + urea; 5) DAP + KS + AN; and 6) DAP + KS + urea.

Disease severity index (DSI) results for Jemaat Shaim found significantly lower values for treatments receiving DAP+KS, DAP+KS+AN, or DAP+KS+urea, with the average value being 0.24. The average DSI was 0.42 for DAP alone, DAP+AN, and DAP+Urea. The trend was similar for the number of whiteheads at Khemis Zemamra. A significant effect of fertilization was observed on the grain yield at Sidi El Aidi. The lowest yield was 0.74 t/ha for DAP+KS+AN and the highest yield was 1.2 and 1.3 t/ha for DAP+AN and DAP+KS, respectively. In contrast, K fertilization at planting reduced the thousand kernel weight (TKW) at

Sidi El Aidi where disease severity had a significant impact, especially for DAP+KS and DAP+KS+AN that registered a TKW of 28 and 20 g, respectively. The grain quality, measured as vitreousness, was found to be dependent on N and K application.

A pooled data analysis, based on a qualitative regression analysis of grain yield with grain yield components, fertilization treatments and wheat crown rot disease components revealed that the important factors to consider were number of grains per ear, number of ears/m<sup>2</sup>, disease severity, TKW, and number of whiteheads in order of importance. In this linear relationship, disease severity and number of whiteheads impacted grain yield negatively. *IPNI-2014-MAR-3*

## Senegal

### **Assessment and Validation of Nutrient Expert® for Fertilization Recommendations of Maize in Senegal**

Project Leader: Moussa Ndienor, Senegal Institute of Agricultural Research (ISRA), Email: ndienor1@yahoo.fr

This project was initiated in 2017 to develop a Nutrient Expert® (NE) tool for farmers and extension agents to implement appropriate nutrient management practices for maize production. In the 2017 rainy season, four nutrient omission trials (one on-station and three on-farm) were established in the southern groundnut basin of Senegal (Kaolack region, Nioro Department). At each site, a split-plot experimental design was used, with two varieties (Suwan and Obatama) in the main plot and eight nutrients treatments in the sub-plots. The nutrient treatments were: 1) optimum treatment (OPT: 122 kg N + 30 kg P<sub>2</sub>O<sub>5</sub> + 30 kg K<sub>2</sub>O/ha); 2) omitting nitrogen (N) from OPT (-N); 3) omitting phosphorus (P) from OPT (-P); 4) omitting potassium (K) from OPT (-K); 5) fertilization based on soil analysis (SA: 68 kg N + 32 kg P<sub>2</sub>O<sub>5</sub>/ha); 6) fertilization based on the target yield (Ya: 126 kg N + 86 kg P<sub>2</sub>O<sub>5</sub> + 85 kg K<sub>2</sub>O/ha); 7) control (without fertilizer application); and 8) farmer fertilizer practice (FFP: 99 kg N + 30 kg P<sub>2</sub>O<sub>5</sub> + 30 kg K<sub>2</sub>O/ha). The treatments were replicated four times at the research station, whereas each on-farm field site represented one replication.

The results at the experimental station and the on-farm sites showed that the highest grain yields of both the maize varieties were achieved with fertilization based on the target yield. The Obatama variety showed significantly higher response to fertilizer treatments than the Suwan variety. The comparison of various fertilizer treatments showed that grain yield of maize decreased significantly without fertilization, and N and P were the most limiting nutrients for maize at the experimental station and in the on-farm trials. The project will continue for three cropping seasons for the validation of Nutrient Expert tool. *IPNI-2017-SEN-01*

## Tunisia

### **Optimizing the Fertilization of Olive Orchards in Tunisia**

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Project Cooperators: Ajmi Larbi and Mahdi Fendri

This project was initiated with the objective to increase the revenues of Tunisian olive farmers through the adoption of best fertilizer management practices, and consisted of three research activities. The objective of the first activity was the assessment of the nutrient status of olive orchards in rain-fed and irrigated areas. The study continued in 2017 ('on' year) in the rain-fed area of northwest Tunisia. The olive orchards were fertilized by an application of 2 to 4 kg ammonium nitrate (AN)/tree in February. Foliar analysis for nitrogen (N), phosphorus (P), and potassium (K) showed that nutrient contents decreased significantly, and were lower than those observed during the 'off' year (2016). In consequence, application of N, P, and K remain indispensable to overcome constraints of the conventional fertilization.

The objective of the second activity was the development of the Deviation from Optimum Percentage (DOP) approach as alternative to the critical concentration diagnosis. A survey of 20 farmers was carried out to assess farmers' fertilization practices. Furthermore, a foliar diagnosis [N, P, K, calcium (Ca), and magnesium (Mg)] was carried out in the same farms to make a diagnosis on the fertilization efficiency practiced by the farmers using the critical concentration and DOP index. Results of the survey showed that most of the farmers (61%) apply only N in the fertilization program, and in spite of the presence of the drip irrigation system in all surveyed orchards, only 39% of farmers apply fertilizers through the drip irrigation system. According to the results of foliar analysis, we found 45, 50, and 80% of N, P, and K deficiency cases, respectively. The DOP analysis showed that most of the orchards (60%) have a severe nutritional imbalance

while only 16% have an equilibrated nutritional balance.

The objective of the third activity was the assessment of the effect of foliar fertilization on olive trees under saline conditions in an irrigated area of northern Tunisia. The electrical conductivity of the irrigation water was 4.6 mS/cm. Foliar fertilization consisted of different sources of N, P, K, Ca, and boron (B) using two types of water: tap and saline water. Results of three experimentation years showed that foliar fertilization increased cumulated olive yield by 22% and 8% with tap water and saline mixture, respectively. An improvement of the nutritional status was also observed during all of the years, except for sodium, which increased above the threshold level when saline water was used for foliar fertilization. *IPNI-2014-TUN-1*

### **Optimizing Nutrient Management of Wheat in Tunisia**

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Project Cooperators: Oussama Kheriji, Tarek Jarrahi, Rachid Zouani and Radhouen Nciri

This project was initiated in 2014 in Tunisia with the objective to develop a Nutrient Expert® (NE) fertilizer decision support tool for Tunisian farmers and extension specialists to implement appropriate nutrient management practices for wheat production in the rain-fed areas. In the 2016-2017 cropping season, nine nutrient omission trials (three per region) were established in three regions of Tunisia: the semi-arid unfavorable region of Siliana, the semiarid favorable region of Manouba, and the subhumid region of Beja. Each experimental plot was planted with bread wheat (BW) and durum wheat (DW) under seven nutrient treatments: 1) optimum treatment (OPT); 2) omitting nitrogen (N) from OPT; 3) omitting phosphorus (P) from OPT; 4) omitting potassium (K) from OPT; 5) site-specific nutrient management (SSNM) based on the recommendations of the NE tool; 6) control (without fertilizer application); and 7) farmer fertilizer practice (FFP). The rates of fertilizer applied per hectare in the OPT treatment from semi-arid to the favorable rain-fed areas were 107-117 kg N/ha + 45 kg P<sub>2</sub>O<sub>5</sub> + 25 kg K<sub>2</sub>O. The ranges of fertilizer applied in the SSNM treatment from semi-arid to favorable rain-fed areas were 80-96 kg N, 42-56 kg P<sub>2</sub>O<sub>5</sub>, and 24-41 kg K<sub>2</sub>O.

For both species of wheat and all the regions, the highest wheat yields were obtained in the SSNM treatment: 4.3 t/ha (DW) and 4.7 t/ha (BW) in the sub-humid favorable rain-fed (Beja) region; 4.4 t/ha (DW) and 4.1 t/ha (BW) in the semi-arid favourable area (Manouba); and 1.3 t/ha (DW) and 2 t/ha (BW) in the semiarid unfavorable area (Siliana). Contrasting results were observed in terms of nutrient effects on the grain yield in the different regions. In water-limited Siliana, there was no significant effect of N, P, and K on grain yield for both DW and BW. In Manouba, omitting N, P, or K reduced the grain yield of DW by 50, 27, and 28% respectively, however no significant effect was observed on the grain yield of BW. In Siliana, omitting N, P, and K had no significant effect on the grain yield for both species of wheat. Compared to FFP treatment, the SSNM treatment significantly increased the grain yield of BW in all the rain-fed areas. In the case of DW, SSNM significantly increased the grain yield by more than 43% over FFP only in the Manouba region. *IPNI-2014-TUN-2* ❖

# Middle East Program

Dr. Munir Rusan, Consulting Director

## Egypt

### ***Balanced Fertilization of Major Crops in Egypt***

Project Leaders: Adel Abdelkhalik, Evergrow for Specialty Fertilizer Company, Cairo, Egypt.

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There are two objectives for this project: 1) determine the effect of different sources of potassium (K) and balanced fertilization on the yield of the major crops of the common cropping systems in Egypt; and 2) promote and extend to farmers the most efficient fertilization and irrigation techniques. For this project, field experiments were conducted on maize with the following treatments investigated: 1) no K fertilizer; 2) 114 kg K<sub>2</sub>O/ha as potassium sulfate; 3) 114 kg K<sub>2</sub>O/ha as potassium nitrate; and 4) 114 kg K<sub>2</sub>O/ha as potassium chloride. Potassium fertilizers were added at three doses: 46, 56, and 66 days after planting.

It was found that all sources of K stimulated vegetative growth, increased yield and its components as compared with the untreated treatment (control). The highest biological maize yield (19 t/ha) was obtained by potassium nitrate, followed by potassium chloride (18.5 t/ha) and then by potassium sulfate (16.4 t/ha). Grain yields were 8.6, 6.9, and 8.2 for potassium nitrate, potassium chloride, and potassium sulfate, respectively. The lowest grain yield (6.5 t/ha) was obtained by the control treatment where no K was added. For the potato crop, 93 kg K<sub>2</sub>O/ha were applied. Tuber yields were 46.3, 44.9, 42.0, and 36.9 t/ha for the potassium nitrate, potassium sulfate, potassium chloride, and control treatments, respectively. *IPNI-2012-EGY-1*

### ***Balanced Fertilization of Egypt's Major Crops through Fertigation***

Project Leaders: Mahmoud Elkholy, Director of East Delta Agricultural Services Project (EDASP), Port Said, Egypt.

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The objectives of this project were to: 1) evaluate the benefits of balanced fertilization on the yield of major crops of the common cropping systems in Egypt; and 2) promote and extend to farmers the most efficient fertilization and irrigation techniques. For this, field experiments were conducted in Port Said Governorate on sugar beet as a winter crop in the 2016/2017 season, which was planted after the rice crop Giza 178 in one location. In another location in the same Governorate, the same experiment was conducted on wheat as a winter crop planted after the rice crop in 2016/2017 season. The following treatments were investigated: 1) farmer fertilization practice (FFP); 2) nitrogen and phosphorus (NP); 3) nitrogen, phosphorus, and potassium (NPK); 4) NPK+boron (B); 5) NPK+zinc (Zn); and 6) NPK+B+Zn.

The sugar beet root yield and percent sucrose increased with balanced fertilization and the highest result was from treatment 6 with a yield of 46.4 t/ha and 20.2% sucrose. The lowest yield (38.9 t/ha) and lowest sucrose % (18.2) resulted from FFP. Similarly, in the second site, the wheat grain yield was the highest (7.8 t/ha) for the balanced fertilization with micronutrients and was the lowest (5.7 t/ha) for FFP. In the third site where mango and pear trees were grown, the fruit weights per tree were the highest for the balanced fertilization which reached 79.4 kg/tree for pear and 33.5 kg/tree for mango. The lowest fruit yield (49.4 and 13.8 kg/tree, respectively) resulted from FFP. *IPNI-2013-EGY-2*

## Jordan

### ***Balanced Fertilization of Major Crops of Rain-fed Areas in Jordan***

Project Leaders: Mohammad Asaad, National Center for Agricultural Research and Extension, Soil Fertility

Researcher: Munir Rusan, Department of Natural Resources and Environment, Jordan University of Science and Technology, Irbid, Jordan. Email: mrusan@ipni.net or mrusan@just.edu.jo

The objectives of this project were to: 1) determine the effect of balanced fertilization on the yield of major

crops of the rain-fed area in Jordan; and 2) to increase awareness and transfer knowledge of the fertilizer best management practices. Several trials were conducted throughout Jordan in the southern (Karak governorate), central (Amman-Madaba governorate) and northern regions (Irbid governorate). These locations represent the different agroecological zones of Jordan. For this study in 2016, several field experiments were conducted on wheat in all locations. In the northern region there were an additional two field demonstrations on onion and olives investigated. The following treatments were investigated: (T1) farmer fertilization practice (FFP) which represents the recommended rate by the Ministry of Agriculture, where diammonium phosphate (DAP) and urea fertilizers were applied before seeding at rates of 100 and 55 kg/ha, respectively; (T2) nitrogen, phosphorus, and potassium (NPK) representing balanced fertilization, where DAP, urea and sulfate of potash (SOP) fertilizers were applied before seeding and at tillering (50% and 50%) with rates of 100 kg/ha, 55 and 60 kg/ha, respectively; and (T3) NPK+ representing the balanced fertilization for higher yield where fertilizers were added as in T2, but with a rate of 25% higher. The target yield for treatments T1 and T2 was 2 t/ha, meanwhile, the target yield for the treatment T3 was 2.5 t/ha. The area allocated for each treatment was 0.5 ha.

In the southern Jordan, the wheat grain yields for T1, T2, and T3 treatments were 1.82, 2.36, and 1.72 t/ha at the first farm and 1.54, 1.46, and 1.48 t/ha at the second farm, respectively. In central Jordan, the wheat grain yields for the T1, T2, and T3, at the first farm were 1.52, 1.40, and 1.79 t/ha, and 1.44, 1.07, and 1.42 t/ha at the second farm. In northern Jordan, where wheat was planted on farm one and onion on the second, the wheat grain yields for the T1, T2, and T3 were 1.28, 1.54 and 1.58 t/ha, respectively. The dry onion yields were 16.6, 49.9, and 41.7 t/ha for the Texas variety and 21.1, 31.7, and 37.9 t/ha for the local Giza variety for the T1, T2, and T3, respectively. For the olive plantation, the highest fruit yield obtained was by the balanced NPK application (78.2 kg/tree), while the lowest fruit yield resulted from FFP (43.5 kg/tree). *IPNI-2015-JOR-1*

### **Fertigation of Major Crops of Irrigated Areas in Jordan**

Project Leaders: Shehadeh Murad Munir Rusan, Department of Natural Resources and Environment, Jordan University of Science and Technology, Irbid, Jordan. Email: [mrusan@just.edu.jo](mailto:mrusan@just.edu.jo)

Unlike rain-fed areas in Jordan, fertilizer use in the irrigated areas are frequently either overfertilized or unbalanced. The major irrigated vegetable crops in Jordan are tomato, cucumber, and pepper, while the major fruit trees are citrus, grape, banana, and a recent interest in date palm. The main cropping systems are under protected agriculture where drip fertigation occurs. With fertigation, rate, time, and place of nutrient application is highly controlled. However, there are different techniques that inject the fertilizers into the pressurized irrigation system. The major ones are by-pass injection system, Venturi injection system and hydraulic pumping system. Different systems have different performance and efficiency that mainly affects the placement of fertilizers and the time of applications. Therefore, the objective of this study was to compare the performance of the different fertilizer injection systems on plant growth and to increase awareness and transfer the knowledge of fertigation.

For this study, in 2016 one field demonstration was planted with tomato in three plastic houses in the farmer's field. The area of each plastic house was 312 m<sup>2</sup>. The following treatments were investigated: 1) Fertigation with by-pass injection system with every irrigation (continuous); 2) Fertigation with by-pass injection system with every fourth irrigation; 3) Fertigation with hydraulic pump injection system with every irrigation (continuous); and 4) Fertigation with an automatic computerized base controlling the pH and EC of the fertigation solution. In the first month there was no irrigation until the planting of the seedlings, following that irrigation was applied every two to three days. The amount of irrigation water applied was 2948 m<sup>3</sup>/ha.

The highest fruit tomato yields of 6.2 and 6.1 t/ha were obtained with continuous fertigation through the by-pass system or the hydraulic pump system. The lowest fruit tomato yield was obtained with fertigation every fourth irrigation using the by-pass system (5.4 t/ha), followed by fertigation every fourth irrigation using the hydraulic pump system (5.9 t/ha). *IPNI-2015-JOR-2* ❖

# Russia Program

**Dr. Svetlana Ivanova, Vice President Eastern Europe & Central Asia and Director**  
**Dr. Vladimir Nosov, Director**

## ***Improvement of Recommendations for Potassium Fertilizer Use and Adjustment of Currently used Soil Potassium Test Interpretation Classes in Intensive Cropping Systems***

Project Leader: Vladimir Romanenkov, Pryanishnikov Research Institute for Agricultural Chemistry of the Russian Academy of Agricultural Sciences, Laboratory of Geographical Network of Fertilizer Experiments, Moscow, Russia.  
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Project Cooperators: Siskevich Yuriy, Korchagin Victor, Nazarenko Olga, and Lukin Sergey

This 5-year project located in Lipetsk, Voronezh, Belgorod, and Rostov oblasts has a special focus on the efficiency of the direct and residual effects of potassium chloride (KCl) for three consecutive crops in rotation. The project includes short-term field experiments conducted on large industrial farms located in Central Russia (Lipetskaya, Voronezhskaya, Belgorodskaya oblast) and South of Russia (Rostovskaya oblast) on Chernozem soils.

The single application of KCl was applied to the first crop in rotation (sugar beet, grain maize, rapeseed, or soybean). For the next two crops in rotation, the residual effect of KCl has been monitored and studied. The effect of four KCl rates (from 30 to 280 kg K<sub>2</sub>O/ha) was studied on the background of optimal nitrogen (N) and phosphorus (P) rates and absolute control (without fertilizers).

The project aims were to: 1) determine optimal application rates of KCl based on crop response to K application, crop quality, K balance, and economic parameters; and 2) assess the suitability of the existing soil K testing methods with a view to predict soil K supply. In soil samples collected at the beginning of the experiment (2012) and over the next five seasons (2013-2017), exchangeable (in 1 M NH<sub>4</sub>OAc), mobile (in 0.5 N HAc or in 1% (NH<sub>4</sub>)<sub>2</sub>CO<sub>3</sub>), and easily exchangeable (in 0.01 M CaCl<sub>2</sub>) K forms were determined.

Summarized results for 2012 to 2017 showed that on chernozems K supply depends on the exchangeable K pool. In the Central Russia region (Lipetsk, Voronezh, Belgorod) for sugar beet and grain maize grown on chernozems, exchangeable K (in 1 M NH<sub>4</sub>OAc) in the soil test is the most sensitive to predict crop response to application of K fertilizers.

Results for 2012 to 2017 also showed that on chernozems with increased and medium soil K levels, maximum yield increase due to K was for sugar beet (7.5 to 9.2 t/ha), followed by grain maize (1.3 t/ha), spring rapeseed (0.2 t/ha), and soybean (0.1 t/ha). The average contribution of K to the yield increase was maximum for grain maize (18%), followed by sugar beet (14 to 15%), spring rape (13%) and soybean (6%). After one year of K fertilizer application for the first crop in rotation, residual K resulted in substantial yield increase for the subsequent second crop in rotation –cereals, grain maize, and soybean. Moreover, residual K improved crop quality and profitability of crop production. However, after the second year after K fertilizer application, residual effect on yield and quality of the third subsequent crop in rotation was not significant.

*IPNI-2012-RUS-1*

## ***Fertigation of Field Vegetable Crops***

Project Leader: Yuriy Pleskachev, Volgograd State Agrarian University, Volgograd, Russia. Email: pleskachiov@yandex.ru

Project Cooperator: M.S. Poltoradnev

A research field experiment with tomato was conducted in 2017 at Gornaya Polyana Research Farm, Volgograd State Agrarian University, Volgograd. The light Chestnut soil (Haplic Kastanozem Chromic) had a clay texture, low salinity, low organic matter (OM) content (1.8%), alkaline pH (7.9), and very high concentrations of available phosphorus (P) and potassium (K) extracted with ammonium carbonate solution (49 ppm P<sub>2</sub>O<sub>5</sub> and 521 ppm K<sub>2</sub>O) in the 0 to 20 cm soil layer. Calcium was a predominant exchangeable cation in the soil. The initial soil sampling was done before tomato transplanting, after a complex nitrogen (N), P, and K fertilizer application in the spring that consisted of 21 kg/ha of each N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O. The following fertigation treatments were applied to tomato (20 kg N/ha x 6 fertigation events = 120 kg N/ha): 1)

Ammonium nitrate (AN) (Grower Practice); 2) AN + Foliar fertilizers; 3) Calcium nitrate; 4) Calcium nitrate + foliar fertilizers; 5) Calcium nitrate (#1 through 4 fertigation events) and Calcium Nitrate + Potassium Chloride (KCl) (5 and 6 fertigations); 6) Calcium nitrate (#1 through 4 fertigations) and Calcium Nitrate + Potassium Chloride (5 and 6 fertigations) + foliar fertilizers.

From tomato flowering to fruit set, treatments 5 and 6 received 12.7 kg chloride (Cl)/ha and 16.9 kg  $K_2O$ /ha during both fifth and sixth fertigations. Foliar fertilizers were sprayed as 0.6% solution at 300 l/ha including the following two products: 1) Folicare 18-18-18 at intensive vegetative growth; and 2) Folicare 10-5-40 at flowering to fruit set.

Fertigation with AN, calcium nitrate, and calcium nitrate + potassium chloride (Treatments 1, 3, and 5) gave the following marketable yields of tomato: 61, 64, and 79 t/ha, respectively. The spraying of foliar fertilizers increased the marketable yield of fruits by only 1% when AN or calcium nitrate were used for fertigation. Foliar fertilization, however, resulted in a 15% yield increase when a combination of calcium nitrate and KCl were used for fertigation. The maximum yield of 91 t/ha was thus obtained in the sixth treatment. Both of the increases in fruit number per plant and fruit weight contributed to such a considerable yield improvement. This also represents a much better water use efficiency by tomato plants. The highest content of total soluble solids in tomato fruits was also obtained in treatment 6. Fruits harvested from this treatment, moreover, had a longer shelf life. *IPNI-2015-RUS-4*

### **Optimization of Spring Rapeseed Nutrition**

Project Leader: Shamil Aliev, Tatar Research Institute for Agricultural Chemistry and Soil Science, Kazan, The Republic of Tatarstan, Russia. Email: niixp2@mail.ru

Project Cooperator: M.S. Poltoradnev

All components of 4R Nutrient Management are considered in this project. Field studies in the Republic of Bashkortostan in 2017 were conducted at Kalinin Agricultural Enterprise, LLC (Sterlitamak District). The soils here are leached Chernozems (Voronich Chernozems Pachic) with a high organic matter content (7.2%) and a medium concentration (9 ppm) of available sulfur (S), routinely extracted with 1M potassium chloride (KCl) solution. Four fertilizer treatments containing nitrogen (N), phosphorus (P), potassium (K), and S were studied in 2017: 1) Grower Practice of 89-20-14 kg N-P-S/ha, including ammonium nitrate (AN) prior to planting and 20-20-14 kg N-P-S/ha at planting; 2) 89-33-16 kg N-P-K/ha, including AN and monoammonium phosphate (MAP) prior to planting, and 16-16-16 kg N-P-K/ha at planting; 3) 84-33-16-4 kg N-P-K-S/ha, including AN and MAP prior to planting, and 13-19-19-5 kg N-P-K-S/ha at planting; and 4) Recommended Practice of 88-36-16-18 kg N-P-K-S/ha, including AN and 20-20-14 kg N-P-S/ha prior to planting, and 13-19-19-5 kg N-P-K-S/ha at planting.

The 2017 season was characterized by near-optimal weather conditions. Grower fertilizer practice resulted in 2.7 t seed/ha (moisture content = 12%). At the same time, the recommended practice based on soil fertility and attainable yield level gained a yield improvement to 3.1 t/ha or 12%. The additional profit due to 4R nutrient management was equal to US\$74/ha. Moreover, oil concentration in seeds increased from 31 to 38%, respectively. Compared to a zero-S treatment, S fertilizer application at rates of 4 and 18 kg S/ha increased yield by 5 and 13%, respectively. *IPNI-2015-RUS-5*

### **Optimization of Winter Wheat Nutrition**

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Project Cooperators: M.S. Poltoradnev

The 2016-2017 season was the second experimental season under this project. Field experiments with winter wheat were again conducted at two locations having different soil types: Southern Chernozem (Haplic Chernozem Pachic) and Light Chestnut soil (Haplic Kastanozem Chromic). Both soils had a heavy texture, high pH, moderate organic matter (OM) content (3.8% and 1.8%, respectively), high nitrate-nitrogen (N) levels (31 to 87 ppm), medium concentrations of available phosphorus (P) (18 to 19 ppm  $P_2O_5$ ), and medium and 'increased' concentrations of available potassium (K) (255 to 370 ppm  $K_2O$ ) in the 0 to 20 cm soil layer. Available forms of P and K were extracted with ammonium carbonate solution.

The 2016-17 season had close to normal weather conditions. The best nutrient management practices in

both locations included three sprays with potassium nitrate (PN): 1) 5% solution at tillering (2.4 kg N/ha and 8.1 kg K<sub>2</sub>O/ha); 2) 3% solution at stem elongation (1.4 kg N/ha and 4.9 kg K<sub>2</sub>O/ha); and 3) 3% solution at heading (1.4 kg N/ha and 4.9 kg K<sub>2</sub>O/ha).

Both yield and quality of wheat grain were considerably improved compared to typical grower management practices for N, including ammonium nitrate (AN) topdressing in early spring at 34 kg N/ha. Grain yield was increased to 3.7 and 4.9 t/ha (Moisture content = 14%) or by 16 and 25% on the Chestnut soil and Chernozem, respectively. Grain protein concentration increased by 1% and gluten content improved by 2 to 3%. Grain quality thus matched the III class. A late-season application of urea at heading–flowering of 30 kg N/ha, in addition to AN topdressing in early spring, resulted in lower grain quality compared to foliar sprays with PN, especially without starter K fertilizer application on Southern Chernozem (4 N 16 P) were given at planting as monoammonium phosphate in 2016). Based on the two seasons of data available at this time, foliar fertilization with potassium nitrate seems to be a promising approach when growing winter wheat in Lower Volga. Nitrogen application is very minimal with these management practices. *IPNI-2015-RUS-6*

### **Intensification of Forage Production in the Vologda Region**

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This three-year project started in 2016 in Vologda, the key region for milk production in Northwestern Russia. It has a special focus on the intensification of northern forage production for dairy farms. The intensification consists of more intensive cutting, combined with applications of nitrogen (N), phosphorus (P) and potassium (K) in optimized rates and time to meet needs of management for higher content of crude protein and soluble sugars. In addition, the most important forage quality parameters are monitored such as Neutral Detergent Fiber (NDF), NDF Digestibility, ensiling qualities, and nitrates. The project goals are as follows: 1) Determine real nutrient removal coefficients for highly productive forages; 2) Determine the optimal number and time of cuttings; and 3) Optimization of rates and time of fertilizer applications to meet both high productivity and forage quality as well as low production cost. The project includes on-field trials conducted on an Umbric Albeluvisols soil (WRB, 2006) with low content of organic matter (OM) (>2%) and elevated plant-available P (101 to 150 ppm) and K (121 to 170 ppm). Trials were conducted on a leading regional dairy farm which has 2,600 ha of crop area under forages and 4,110 cows. The project design included two treatments: 1) Farmer practice (FP); and 2) Optimized fertilization (OF). In both treatments the same highly productive forage mixture seeds were planted in 2016.

In 2017, plots received two fertilizer rates. The first was FP which included 68 kg N/ha at the beginning of vegetation growth in spring, and 68 kg N/ha after first cut. The second rate was OF which included 80 kg N/ha in the beginning of vegetation in spring, and 80, 50, and 50 kg N/ha after first, second, and third cuts. In spite of unfavorable weather conditions, low temperatures and excess rains, higher N rates split into four applications, with more intensive cutting, resulted in a significant increase in both productivity and quality of forages in the OF treatment. The yield of green mass for the OF treatment was 67 t/ha (four cuts), while for FP only 47 t/ha (three cuts). Corresponding yield of dry matter was 10 and 8.3 t/ha. The quality of forages was improved in the OF treatment as well. Average yield of green mass for this farm in 2017 was only 19 t/ha for two cuts for the season. For the OF treatment, forage productivity was more than tripled over average productivity for this farm. In spite of increased production cost/ha due to higher N rates and increased number of cuts in OF treatment, the economics of forage and silage production have been substantially improved. Production cost per kg of forage grass and silage was lower than targeted by the farm. *IPNI-2016-RUS-8*

### **Improving N and S Fertilizer Management System under Crop Rotation**

Project Leader: Vladimir Nosov, International Plant Nutrition Institute, Krasnodar, Russia. Email: vnosov@ipni.net

Project Cooperators: G.V. Chuvarleeva and V.M. Kildyushkin

Field experiments with winter barley during the 2016-2017 season were conducted at four agricultural enterprises of AgroGard agroholding, Kuban Branch, located in different districts of Krasnodar Krai. Soils at these locations are Typical and Common Chernozems (Voronik Chernozems Pachic) with moderate organic matter (3.3 to 4.3%) and low concentrations of available sulfur (S) (2 to 4 ppm) routinely extracted with 1M

potassium chloride (KCl) solution. A cool spring delayed winter barley growth and development, but the rest of the season was quite favorable. Grower practice for phosphorus (P) and potassium (K) fertilizers was considered to be optimum based on soil fertility and attainable yields of winter barley. Fertilizer treatments (kg/ha) for this crop were: 1) Grower practice for nitrogen (N): 80 to 88 N, 68 P and 26 K, including 10-26-26 prior to planting, monoammonium phosphate (MAP) at planting, ammonium nitrate (AN) spring topdressing; 2) Recommended N: 80 to 85 N, 68 P, 26 K, including 10-26-26 prior to planting, MAP at planting, AN spring topdressing; 3) Recommended N: 80 to 85 N, 68 P, 26 K, including 10-26-26 prior to planting, MAP at planting, urea spring topdressing; 4) Recommended N+S1: 83 to 88 N, 68 P, 26 K, 8 S, including 13-19-19-6 prior to planting, MAP at planting, Ammonium Nitrate spring topdressing; and 5) Recommended N+S2: 83 to 91 N, 68 P, 26 K, 16 S, including 16-20-0-12 + KCl prior to planting, MAP at planting, AN spring topdressing.

Grower fertilizer practice produced yields of 6.6 to 7.1 t/ha (Moisture content = 14%) for winter barley grain. The right source, rate, and time for both N and S in Treatment 5 increased grain yield by 0.3 to 0.4 t/ha, or 5 to 6% in three field experiments compared to grower practice. Protein concentration in barley grain was increased by 0.2 to 0.8% in these three locations. A grower nutrient management practice was considered to be optimal in one location. Spring topdressing with AN had the same effect as urea on grain yield and quality of winter barley in two locations. Ammonium nitrate was, however, the much preferable source of N at the other two locations. From the study, it seems that cool spring temperatures could negatively affect the rate of urea hydrolysis in heavy textured Chernozem soils. High soil pH could also have led to ammonia volatilization resulting from surface application of urea. *IPNI-2016-RUS-9* ♦





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