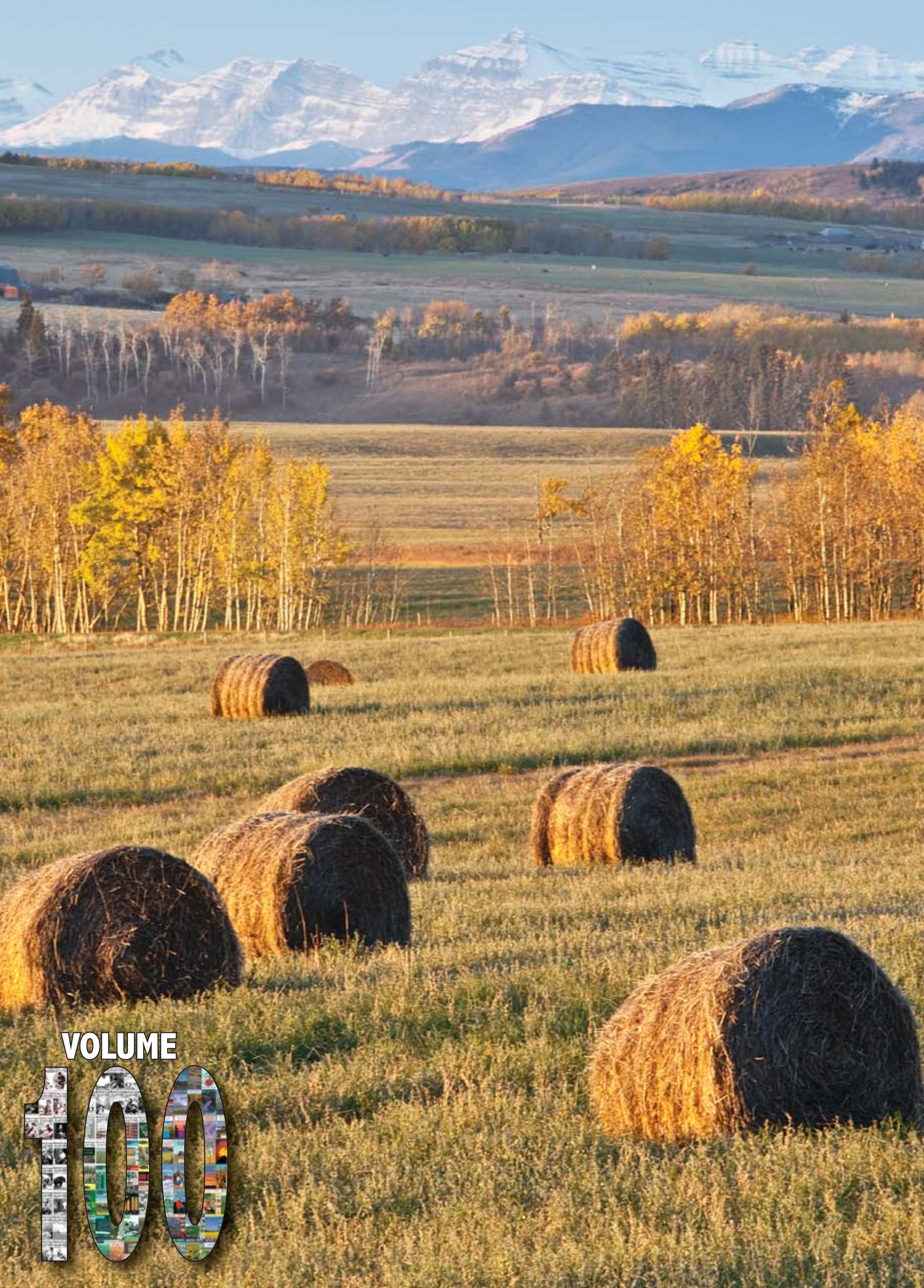
BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

2016 Number 4

Taking a Long Look at Crop Rotations in the Northern Great Plains



In This Issue...

Adapting Oil Palm BMPs in Ghana

Controlled-Release Urea and Banana

Plant Nutrition and Disease Resistance

Also:

Our IPNI Scholars for 2016!

...and much more

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BETTER CROPS WITH PLANT FOOD

Vol. C (100) 2016, No. 4

Our cover: Autumn field scene in central Alberta, Canada.
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Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* can be found at: >**www.ipni.net/bettercrops**<

IPNI thanks the Government of Saskatchewan for their support of this publication through its resource tax funding.

IPNI Scholar Award Recipients - 2016

The International Plant Nutrition Institute (IPNI) has selected the winners of the annual Scholar Award Program. A total of 36 graduate students, representing 14 countries, were chosen in 2016. Each winner receives the equivalent of US$2,000.

AFRICA

Amira Hachana

Bayou Bunkura Allito

Muneta Grace Manzeke

Ms. Amira Hachana, National Institute of Agronomy, Tunis, Tunisia. **Ph.D. Program:** Diagnostic of the Biodiversity of Rhizosphere Microflora and its Interaction with *Rhizobium Leguminosarum* Nodulating Pea in Different Bioclimatic Areas of Tunisia.

Mr. Bayou Bunkura Allito, Kwame Nkrumah University of Science and Technology, Kumasi, Ashanti, Ghana, Africa. **Ph.D. Program:** *Rhizobium* Strain and Host-variety Interaction Effect on N_2 Fixation and Yield of Faba Bean in Southern Ethiopia.

Ms. Muneta Grace Manzeke, University of Zimbabwe, Harare, Zimbabwe. **Ph.D. Program:** Geospatial Variation of Bioavailable Micronutrients in Tropical Soils and its Effects on Crop Productivity and Human Nutrition.

CHINA

Gu Chiming

Li Ting

Liang Guopeng

Khalid Mehmood

Zhang Qian

Dr. Gu Chiming, Wuhan Botanical Garden of Chinese Academy of Science, Moshan, Wuchang, Wuhan, China. **Ph.D. Program:** Study on Non-Point Pollution Condition and Control Measures in Danjiangkou Reservoir, Hubei, China.

Ms. Li Ting, Institute of Soil Science, Chinese Academic of Sciences, Nanjing, China. **Ph.D. Program:** Composition and Bioavailability of Soil Available Potassium of Typical Farmland in China.

Mr. Liang Guopeng, Chinese Academy of Agricultural Sciences, Beijing, China. **M.Sc. Program:** Seasonal Patterns of Soil Respiration and Soil Biochemical Properties under Nitrogen Addition.

Mr. Khalid Mehmood, University of Chinese Academy of Sciences, Beijing, China. **Ph.D. Program:** Amelioration of Acid Soils Using Low Energy Consuming Biochars Combined with Inorganic Fertilizers for Improved Crop Growth.

Ms. Zhang Qian, Chinese Academy of Agricultural Sciences, Beijing, China. **Ph.D. Program:** Effect of Organic Amendments and its Microbiological Mechanism under Rice-Wheat Rotation.

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

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

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

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

EASTERN EUROPE/MIDDLE EAST


Andrey Paratunov


Alena Ozheredova


Anastasia Chobanu


Muhammad Asif

Mr. Andrey Paratunov, Volgograd State Agrarian University, Volgograd, Russia. **M.Sc. Program:** Tomato Fertigation in a Dry Steppe Zone of Volga-Don Interfluve.

Ms. Alena Ozheredova, Stavropol State Agrarian University, Stavropol, Russia. **Ph.D. Program:** The Effect of Fertilizers and Technologies on Winter Wheat Production in Central Ciscaucasia.

Ms. Anastasia Chobanu, Belgorod Agrarian University, Belgorod, Russia. **M.Sc. Program:** The Effect of Fertilizers on Biological Indicators of Soil Fertility.

Mr. Muhammad Asif, Sabanci University, Tuzla/Istanbul, Turkey. **Ph.D. Program:** Impact of Climate Change on Wheat Nutrition and Physiology.

NORTH AMERICA


Carolyn Wilson


Sara Berg


John Breker


Jarom Davidson


Kelsey Hoegenauer


Sarah Mueller


Jared Spackman


Elizabeth Trybula

Ms. Carolyn Wilson, Dalhousie University, Halifax, Nova Scotia, Canada. **M.Sc. Program:** Effect of Diverse Compost Products on Soil Quality and Potato Productivity.

Ms. Sara Berg, South Dakota State University, Brookings, South Dakota, USA. **M.Sc. Program:** Evaluation of Tillage and Cover Crop Impacts on Corn Nitrogen Requirements in Southeastern South Dakota.

Mr. John Breker, North Dakota State University, Fargo, North Dakota, USA. **M.Sc. Program:** Recalibration of Potassium Soil Test for Corn in North Dakota.

Mr. Jarom Davidson, University of Arkansas, Fayetteville, Arkansas, USA. **M.Sc. Program:** Validation of N-STaR Nitrogen Rate Recommendations and Evaluation of N-STaR Soil Sampling Procedures for Clay Soils in Arkansas.

Ms. Kelsey Hoegenauer, University of Arkansas, Fayetteville, Arkansas, USA. **Ph.D. Program:** Using Cover Crops to Recycle Nutrients in an Arkansas No-Till System.

Ms. Sarah Mueller, Purdue University, West Lafayette, Indiana, USA. **Ph.D. Program:** Supplemental Late-vegetative Nitrogen Application for High-yield Corn: Agronomic, Economic and Environmental Implications with Modern versus Older Hybrids.

Mr. Jared Spackman, University of Minnesota, Minneapolis, Minnesota, USA. **M.Sc. Program:** Nitrogen Fertilizer Source, Timing and Rate Impacts on Maize Nitrogen Use Efficiency and Mineralization Potential of Minnesota Soils.

Ms. Elizabeth Trybula, Purdue University, West Lafayette, Indiana, USA. **Ph.D. Program:** Crop Water Productivity Response to Potassium Rate Application in Humid and Semi-Arid Conditions.

OCEANIA

Mr. Getachew Agegnehu Jenberu, James Cook University, Cairns, Queensland, Australia. **Ph.D. Program:** Biochar, Compost and Biochar-compost: Crop Performance, Soil Quality and Greenhouse Gas Emissions in Tropical Agricultural Soils.


Getachew Agegnehu Jenberu

SOUTH AMERICA


Walter Carciochi


Clara Milano


Martín Torres Duggan


Eduardo Cancellier


Shivelly Los Galettos


Lauren Menandro


Saulo Augusto Quassi de Castro

Mr. Walter Carciochi, University of Mar del Plata, Balcarce, Buenos Aires, Argentina. **Ph.D. Program:** Evaluation of Diagnosis Methods of Sulfur Availability in Maize.

Ms. Clara Milano, National Southern University, Bahia Blanca, Buenos Aires, Argentina. **M.Sc. Program:** Biological Nitrogen Fixation of Native Legume Grasses Introduced to the Degraded Grasslands of Southwestern Buenos Aires Province, Argentina.

Mr. Martín Torres Duggan, University of Buenos Aires, Buenos Aires, Argentina. **Ph.D. Program:** Forage Productivity Improvement under Manure, Rock Phosphate, and Zeolites Applications.

Mr. Eduardo Cancellier, Federal University of Lavras, Lavras, Minas Gerais, Brazil. **Ph.D. Program:** Development of Bio-based Coatings for Production of Controlled-Release Fertilizers and Availability of Controlled-Release Phosphorus.

Ms. Shivelly Los Galettos, State University of Ponta Grossa, Ponta Grossa, Parana, Brazil. **Ph.D. Program:** Efficiency of Phosphate Fertilization as Influenced by the Application of Phosphogypsum in No-till System.

Ms. Lauren Menandro, Agronomic Institute of Campinas, Campinas, São Paulo, Brazil. **M.Sc. Program:** Characterization, Agronomic and Industrial Recovery of Sugarcane Shoots and Old Leaves.

Mr. Saulo Augusto Quassi de Castro, University of São Paulo, Piracicaba, São Paulo, Brazil. **M.Sc. Program:** Contribution of Nitrogen Fertilizer in Sugarcane Due to Crop Rotation, Straw Removal and Nitrogen Rates.

SOUTH ASIA


Ridham Kakar


Kiran K.R


Rumesh Ranjan


Pragyan Paramita Rout


Vijayakumar Shanmugam


Arunbabu Talla


Abdul Rehman

Ms. Ridham Kakar, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. **Ph.D. Program:** Integrated Nutrient Management under Ginger-cauliflower Cropping Sequence in North-West Himalayas.

Mr. Kiran K.R., Indian Agricultural Research Institute, New Delhi, India. **Ph.D. Program:** Mobilization of Soil Iron to Minimize Iron Deficiency Chlorosis of Soybean under Ambient and Elevated CO_2 and Temperature Conditions.

Mr. Rumesh Ranjan, Indian Agricultural Research Institute, New Delhi, India. **Ph.D. Program:** Genetic Analysis and Identification of QTL's Influencing Nitrogen Use Efficiency in Wheat.

Ms. Pragyan Paramita Rout, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. **Ph.D. Program:** Development and Standardization of Sensors for Soil Moisture Monitoring and Precision Nutrient Management for Growing Flower Crops under Fertigation and Matric Suction Irrigation.

Mr. Vijayakumar Shanmugam, Indian Agricultural Research Institute, New Delhi, India. **Ph.D. Program:** Potassium Management in Aerobic Rice–Wheat Cropping System.

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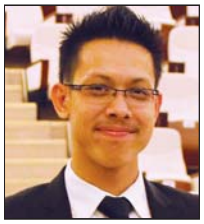
Mr. Abdul Rehman, University of Agriculture, Faisalabad, Pakistan. **Ph.D. Program:** Exploring the Role of Zinc Nutrition in Yield Improvement, Grain Biofortification and Resistance against Abiotic Stresses in Wheat.



Chuck Chuan Ng

SOUTHEAST ASIA

Mr. Chuck Chuan Ng, University of Malaya, Kuala Lumpur, Malaysia. **Ph.D. Program:** Soil-plant Interaction of Trace Elemental Metals in Vetiver Grass.

Frontiers of Potassium Science Conference | kfrontiers.org

Organizers have designed this unique international conference being held in Rome, Italy on January 25-27, 2017, as a forum to exchange information on how to improve potassium plant nutrition and soil management to better the health of soils, plants, animals, and humans. The 4R Nutrient Stewardship framework is integrated into the conference structure to keep the discussions anchored to the information needs of farmers and those who provide nutrient management guidance.

Please visit http://KFrontiers.org to obtain all program and registration details, and to sign up for all pre- and post-conference updates.

Speakers (Selected list)

Marta Alfaro, Instituto de Investigaciones Agropecuárias (INIA), Chile.
Michael Bell, University of Queensland, Australia.
Sylvie Brouder, Purdue University, USA.
Ismail Cakmak, Sabanci University, Turkey.
Heitor Cantarella, Agronomic Institute of Campinas, Brazil.
Paul Fixen, International Plant Nutrition Institute, USA.
David Franzen, North Dakota State University, USA.
Keith Goulding, Rothamsted Research, UK.
Philippe Hinsinger, UMR Eco&Soils, INRA-Montpellier SupAgro, France.
John Kovar, USDA ARS, USA.
Kaushik Majumdar, International Plant Nutrition Institute, India.
Robert Mikkelsen, International Plant Nutrition Institute, USA.
Scott Murrell, International Plant Nutrition Institute, USA.
Steven Oosthuyse, HortResearch SA, SQM, South Africa.
Mike Rahm, The Mosaic Company, USA.
Michel Ransom, Kansas State University, USA.
Zed Rengel, The University of Western Australia, Australia.
Vinod Kumar Singh, Indian Agricultural Research Institute, India.
Michael Stone, Purdue University, USA.
Jeff Volenec, Purdue University, USA.
Connie Weaver, Purdue University, USA.
Philip White, James Hutton Institute, Scotland.

Example Discussion Topics

Potassium in Sustainable Intensification of Cropping Systems
How do potassium inputs and outputs compare for different cropping systems and geopolitical boundaries?

4R Source: Improving Decisions About the Source of Potassium to Apply
How does the source of potassium fertilizer affect its proper placement in the soil?

4R Rate: Improving the Accuracy of Potassium Rate Recommendations
Why and to what extent do various crops differ in their recovery efficiency of potassium?

4R Time: Improving Decisions About When to Apply Potassium
What are the genetic effects on potassium accumulation rates, partitioning, and plant metabolism?

4R Place: Improving Potassium Placement Decisions
What plant characteristics (rhizosphere biology and chemistry, root architecture, etc.) most influence potassium placement decisions?

Connecting Frontier Science to Frontier Practice
How do we increase the impact of scientific findings on soil and crop management of potassium in the field?

Testing the Benefits of Balanced Nutrient Use and Crop Diversification on Soil Productivity and Health

By Miles Dyck, Dick Puurveen, and Tom Jensen

A long-term crop rotation study in the Northern Great Plains of Canada helps our understanding of the interactions between crop rotation and nutrient management.

The majority of nutrient management field research is conducted over a short time frame of up to a few years at most. However, when it is possible to continue a set of experimental treatments for many decades, this so called "long-term research" can be very helpful in providing observable results that short-term research cannot offer.

One such long-term research site is 60 miles (100 km) southwest of Edmonton, Alberta, near the Village of Breton located in the Boreal Forest region. These "Breton Classical Plots" were established in 1930 by Dr. Frank Wyatt and Dr. John Newton of the Department of Soils, University of Alberta. Soil in this region is commonly referred to as "Gray Wooded", but soil classification systems refer to the soil as Gray Luvisolic (Canada), Boralf (U.S. Soil Taxonomy), and Albic Luvisol (FAO Soil Classification).

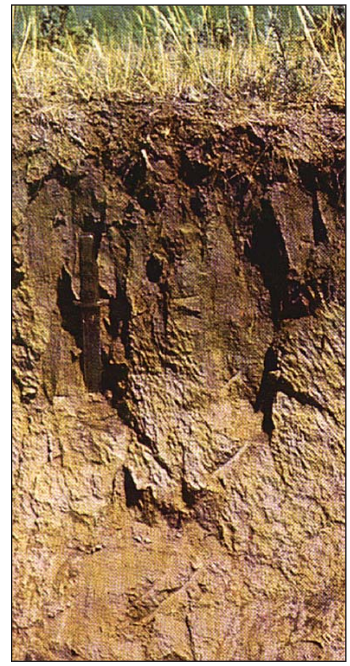
This soil type formed under mixed wood forest and its associated understory vegetation, and is much different than adjacent grassland soils of the Northern Great Plains. As early farm settlers converted the prime, naturally fertile grassland soils to cropped agriculture in the early 1900s, the later arriving settlers began clearing and farming these Gray soils.

The soil's original gray color that is left after clearing and cultivation is the result of the release of organic acids into the soil from forest leaf litter, which leach the top soil horizon of humus and fine clay particles to create a coarser-textured, gray-colored surface horizon 2 to 6 in (5 to 15 cm) thick. Additionally, the accumulated forest litter of plant leaves, deadfall, etc. is not well mixed into the surface soil horizons due to a lack of activity by organisms like earthworms and soil arthropods, and the characteristic tree and shrub roots are coarse and sparsely distributed within the soil (Dyck et al., 2012).

These low organic matter soils are not inherently fertile for arable crop production compared to grassland soils that have humus-enriched surface horizons from the fibrous roots of the abundant grass species. As a result, early settlers had challenges growing adequate crop and forage yields for their mixed farming operations on these soils.

The Breton Classical Plots were initiated to compare two different crop rotations, and select nutrient additions, in order to inform farmers how to improve crop production on these soils. In the beginning, a short rotation with only wheat was compared to a longer rotation including both grain crops and a mixed forage for hay. Minor adjustments have been made over the decades, but since 1941 the site's two rotations have been a Wheat-Fallow (WF) rotation, and a Wheat-Oat-Barley-Hay-Hay (WOBHH) rotation. The hay crop is a brome grass/alfalfa mixture. The forage species are under-seeded into a barley crop during the third year of the five-year rotation and hayed for two years before being terminated in the last year. Wheat is grown the following year. The plots are designed so that all of the crop phases of each rotation are present in the plots each year.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium.



Gray Luvisol soil on the left compared to a Dark Brown Chernozem grassland soil on right. Note the light colored leached top mineral horizon below the forest litter layer in the Gray Luvisol soil, in contrast to the humus-enriched grassland topsoil.

The crop rotation plots are split into the various nutrient addition treatments, one including N, P, K, and S, and as importantly a separate omission treatment for each of the four macronutrients. The nutrient treatments outlined in **Table 1** have been in place since 1980.

Table 1. Nutrient management split plots of the Breton Plots. (Dyck, 2015).

Nutrient treatment	Description
Control	No nutrients applied
Manure	Cattle feedlot manure, sourced locally, rate based on the N content of the manure.
N, P, K, and S	Balanced macronutrients
NSK (-P)	P omission treatment
NPK (-S)	S omission treatment
PKS (-N)	N omission treatment
NPS (-K)	K omission treatment

Table 2. Nutrient source and application rates (lb/A) according to rotation, phase, and fertility treatment.

		Rotation-Phase					
Nutrient	Source	WF-Wheat	WF-Fallow	WOBHH-Wheat	WOBHH-Oats	WOBHH-Barley silage[1]	WOBHH-Forage hay
N	Manure[2]	80[3]	0	78[4]	78[3]	0	0
N	Urea	80	0	45	67	45	0
P_2O_5	Triple super phosphate	46	0	46	46	46	46
K_2O	Potassium chloride	53	0	53	53	53	53
S	Elemental S	18	0	18	18	18	18

[1]Barley silage is under seeded to forage.
[2] Actual application rate of manure is determined by laboratory analysis and based on total N content. Rates of P, K, and S applied with the manure vary slightly due to annual differences in feedlot manure as affected by local availability of grain and hay sources, feed rations and bedding material.
[3] Manure for Wheat-Oats-Barley-Hay-Hay-Oats (WOBHH-Oats) and Wheat Fallow-Wheat (WF-Wheat) is applied in the spring prior to planting.
[4] Manure for the WOBHH-Wheat is applied in the previous fall prior to the plough down of second growth hay of that year.

Soil Organic Matter Trends

The ability to observe long-term changes in soil properties within the Breton plots, as affected by crop rotation and nutrient management, is most useful to nutrient management decision making. Back in 1930, these Gray soils had a soil organic matter (SOM) content of 2.4% after the leaf litter layer was mixed with the leached mineral surface soil layer and underlying B horizon (**Figure 1**). Today, check plots receiving no fertilizer or manure under the WF rotation have seen a 24% loss in SOM down to 1.8%. Long term fertilization with NPKS has lessened this loss to a current 2.2% SOM. Application of manure has increased SOM content up to 3.6%.

In contrast to the WF rotation, the continuously cropped WOBHH rotation has shown improved SOM status under all treatments. Even the check (without nutrient input) has 3.2% SOM, and the NPKS fertilizer treatment up to 3.8%. The manure treatment has greatly increased its SOM content to 4.7%. The positive performance of the manure treatment is based upon the large addition of organic material providing much more than just the N, P, K, and S. However, the gains found in check, with two out of five years in forage production, associated fibrous grass root growth, and symbiotic N fixation inputs from alfalfa, are perhaps more surprising. Another possible benefit from deep-rooted perennial grasses and alfalfa comes from their ability to transport other nutrients (i.e., S, Ca, Mg) to soil surface zones, placing them nearer to growing cereal crop roots.

Wheat Yield Trends

Analysis of wheat yield trends over the last nine years (2007 to 2015) makes clear the current implications of adopting practices over the long-term. Both the WF and WOBHH rotations are yielding lowest in the check treatments where zero nutrient addition is combined with continual removal of nutrients through crop harvest (**Figure 2**).

The highest yielding treatment, also common to both rotations, was the NPKS treatment. However, a divergence is observed between the two rotations, which is related to the impact of omitting K. Wheat yield in the NPS plots has fell relative to the NPKS plots in the WOBHH rotation, but this gap is not seen in the WF rotation. This difference is linked to the greater removal of K under the WOBHH rotation due to the harvest of hay. Over the long-term, this has lowered K availability to a larger degree compared to the WF rotation where only grain is removed from the plots.

The omission of N from the WF rotation results in very low yields that are similar to those obtained in the check. Thus, the addition of N is critical to the productivity of these Gray soils farmed under a WF system. In contrast, the WOBHH benefits from inclusion of an alfalfa forage legume crop within the two-year hay phase. As a result, wheat yields under N omission are far greater than those obtained in check plots.

Given adequate K input, the brome grass/alfalfa mixture in this five-year rotation improves Gray soil productivity and soil health. The inclusion of mixed forages in a crop rotation also lends itself to the mixed farming operations commonly

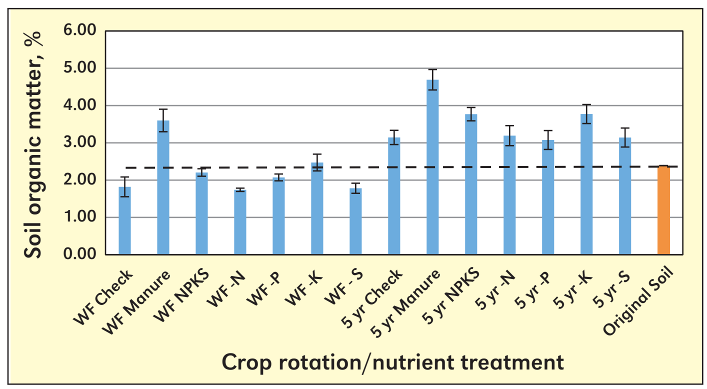


Figure 1. Soil organic matter percentage as affected by crop rotation and nutrient treatment, 2013 soil sample analysis results. Error bars represent the standard error.

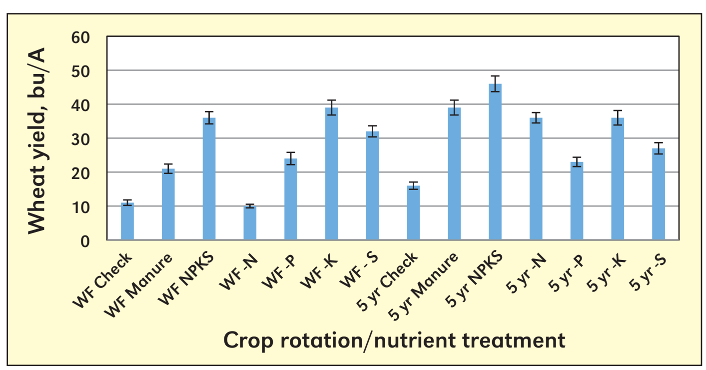


Figure 2. The effect of crop rotation and nutrient treatment on average wheat crop yields in each rotation, over a nine-year period (2007 through 2015). Error bars represent the standard error.

Breton Plots, University of Alberta.

practiced in the area. Integrating crop and livestock, growing mixed forage crops, and returning livestock manure to fields on a regular basis will increase soil productivity compared to only growing small grains or oil seed crops.

The Breton Classical Plots are an extremely valuable legacy of crop rotation and nutrient treatment research, allowing observation of the long-term effects that cannot be measured in the short term. The research results emphasize the positive influence a balanced application of N, P, K, and S can have on a soil, whether applied as fertilizers or livestock manure. There is much discussion presently about what constitutes soil productivity and soil health, and what should be measured to assess the quality of a soil. The SOM and yield potential differences between the combinations of crop rotation and nutrient application are clearly observed at the Breton Plots, and help answer what practices maintain or improve soil capability for agricultural production. BC

Dr. Dyck (E-mail: mdyck@ualberta.ca) and Mr. Puurveen (E-mail: puurveen@ualberta.ca), Renewable Resources Department, University of Alberta, Edmonton, Alberta, Canada. Dr. Jensen is a Director of the IPNI North America Program (E-mail: tjensen@ipni.net).

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Dyck, M.F., J.A. Robertson, and D. Puurveen. 2012. The University of Alberta Breton plots. www.prairiesoilsandcrops 5:96-104.

Dyck, M.F. 2015. 2015FO21R - Coordinated N and S fertilizer management to increase crop N uptake and reduce environmental N losses. Research Report ACIDF.

Using Plant Physiology to Diagnose Nitrogen Deficiency in Wheat

By Andreas Neuhaus, Marianne Hoogmoed, and Victor Sadras

A nitrogen nutrition index (NNI) is presented as a robust interpretation method to guide profitable and sustainable in-season N applications in dry climates with unfertile soils.

Risk management and improved confidence in diagnosing early N deficiency is the focus of this research.

Trial site in South Australia with different wheat varieties growing under a range of N treatments. Part of the trial is irrigated, while the other is rainfed to determine the effects of water deficit on the N dilution curve.

Nitrogen is a major yield and profit driver for cereal production in the Mediterranean climates of Western Australia (WA) and South Australia (SA). The yield components of plants/m^2, spikelets/plant, grain number/spikelet, and grain weight in relation to N are fairly well understood. However, N fertilizer inputs can be difficult to match to the seasonal conditions, especially when only based on pre-season soil tests. Using a plant-tissue test that is more directly related to yield components such as biomass and achievable yield (and maybe protein) responses, rather than just adequate nutrient tissue concentrations at different growth stages, may overcome some of the limitations associated with a pre-season soil test and predicted mineralized N. Such a plant test may help to guide N fertilizer applications to improve crop yields and profitability with more certainty.

Abbreviations and notes: N = nitrogen.

Nitrogen supply from mineralization of organic matter is often irregular in WA and SA because of fluctuations in soil moisture and temperature. Low and unreliable rainfall in these climates restrict N supply and target yields. It makes sense to adopt a flexible and robust strategy that can account for changes in soil and seasonal conditions and thereby reduces the risk of mis-matching N supply and demand with fertilizer N applications rates and timings. Past research has worked towards a N nutrition index (NNI) obtained from whole shoots in well-watered, high-yielding conditions. Can the same concept be transferred to water-limited and lower-yielding growing areas in WA and SA? This question is being investigated in a project led by Dr. Sadras. He recently reviewed the NNI and linked the concept to plant water relations (Sadras and Lemaire, 2014). This NNI concept, if adjusted to water-limited climates, may have the potential to provide a useful tool for growers/advisers to guide in-season N recommendations in order to close the yield gap between actual and target yields, similar to the interpretation model developed by the fertilizer company CSBP Ltd. (Southern, 1985) for macro- and micronutrients in WA.

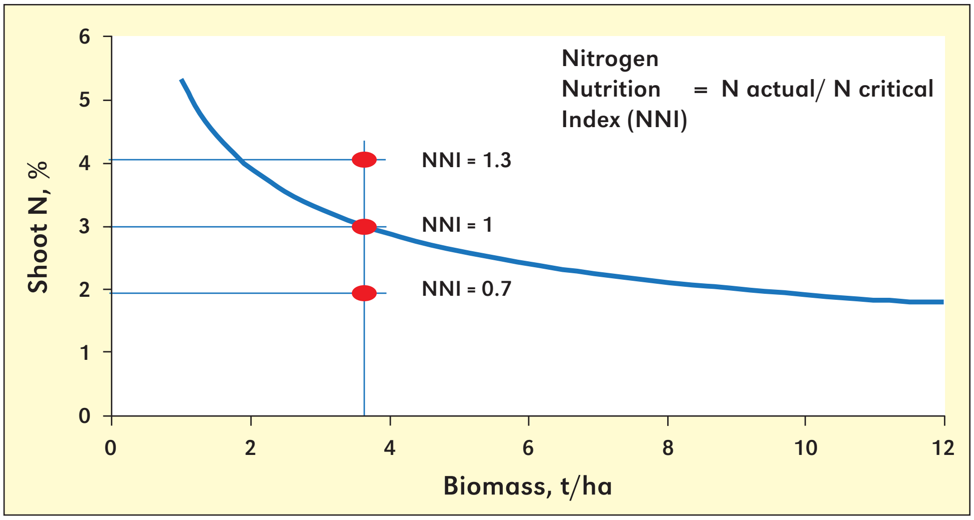

Figure 1. Example of a critical N dilution curve for the crop vegetative period in well-watered conditions. Red points represent three plant tissue tests for shoot N concentration and the corresponding biomass to illustrate when N would be deficient in the plant (NNI < 1, N concentration is below the minimum N concentration that is required for maximum growth), sufficient (NNI = 1, N concentration is matching the minimum N concentration for maximum growth) or in high, luxurious supply (NNI > 1, N concentration is above the minimum N concentration that is required for maximum growth).

Determination of NNI

A critical N concentration represents the minimum N concentration that is required to achieve maximum biomass. Crop growth is a sensitive indicator that integrates all major constraints, including water and N supply. Crop growth is also directly related to N uptake and slows down under N deficiency. Maximum growth would lead to maximum yield in well-watered conditions, but doubts can be raised for cropping areas with a hot, dry finish that reduces harvest index (Heerwaarden et al., 1998). Canopy management in these water-limited climates may favor below maximum growth, which can be controlled with N deficit. Thus this benchmark of maximum growth needs to be tested and validated before developed further for WA and SA conditions.

Over the course of a season the critical N concentration naturally decreases as the crop grows and the leaf to stem ratio declines. This is because stem or structural tissue has a lower N concentration than the photosynthetic leaf tissue. Furthermore, competition for light increases and more N is translocated within the plant from older, shaded leaves to younger, more photosynthetically active leaves. The end result of these processes over the course of the growing season is a critical "N dilution curve" that can be obtained from trial data by drawing a line through all critical N concentrations plotted against crop biomass (**Figure 1**). NNI is a calculated ratio using the measured N concentration in relation to the established N dilution curve.

The NNI is a robust concept in that plant sampling can occur throughout the vegetative period when fertilizer decisions are made. Whole shoot sampling is relatively easy and quick and is ideal for interpreting mobile nutrients that get remobilized within the plant, such as N.

This plant physiological concept needs to be calibrated using local trial data, thereby integrating variety and climate specific conditions that are reflected in the whole shoot N analysis at the time of sampling. The expectation is that dilution curves will "shift" downwards under water deficit, and with varieties storing high concentration of water soluble carbohydrates (Hoogmoed and Sadras, 2016).

More importantly, NNI can be used as an intermediate variable to correlate to yield and protein. More relevant information can be made available for N decision making on farms, assuming the N uptake would not be limited by other nutrient deficiencies, or the growth stage, and that weather conditions are favorable. The NNI to yield correlation will also show if crop yield peaks at NNI < 1, which would indicate the benefits of some degree of N deficit in WA and SA.

This NNI will be explored in greater detail in field trials conducted currently in SA and WA. The aim of these trials is to validate the plant physiological framework and to investigate the interaction of N nutrition and water deficit in rainfed broad-acre agriculture. BC

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Adapting Oil Palm Best Management Practices to Ghana: Opportunities for Production Intensification

By T. Rhebergen, T. Fairhurst, S. Zingore, M. Fisher, T. Oberthür, and A. Whitbread

An increasing global demand for palm oil, and limited availability of agricultural land in Southeast Asia, has driven a rapid expansion of new oil palm plantings in West Africa.

Sub-optimal climate conditions and generally low yields in West Africa, combined with highly fragmented land holdings limit the potential for expansion of large-scale plantings.

Research conducted in Ghana indicates that production increases can alternatively be sought by applying best management practices to land already planted with oil palm.

The large demand for palm oil has resulted in a rapid expansion of global oil palm cultivation. Most of the current expansion is taking place in Sub-Saharan Africa and Latin America as land available for new oil palm planting is limited in Southeast Asia. As a result, oil palm production in many West African (WA) countries has increased in the past decade. However, compared with the major producing countries in Southeast Asia and Latin America, average bunch yields in WA are very low (**Table 1**).

Table 1. Area planted, fruit bunch production and yields in the main producer countries in oil palm production regions worldwide in 2013 (FAO, 2015).

Region	Country	Production, '000 t fruit bunches	Mature area, '000 ha	Bunch yield, t/ha
S.E. Asia	Indonesia	120,000	7,080	16.9
	Malaysia	100,000	4,550	22.0
	Papua New Guinea	2,100	150	14.0
	Thailand	12,812	626	20.5
Total		234,912	12,406	18.9
Lat. America	Colombia	4,991	250	20.0
	Ecuador	2,317	219	10.6
	Guatemala	1,480	65	22.8
Total		8,788	534	16.5
W. Africa	Cameroon	2,450	135	18.1
	Ghana	2,100	360	5.8
	Liberia	176	17	10.4
	Nigeria	5,000	2,000	2.5
	Sierra Leone	210	28	7.5
Total		9,936	2,540	3.9

Smaller yields in WA are partly the result of sub-optimal climate conditions and poor management practices. Water stress is the main yield-determining factor outside management control in WA. In order to guide government policy makers and investors, it is essential to know where the most suitable conditions for the expansion of oil palm production in WA exists. Using Ghana as a case study, we describe a framework for evaluating areas that are both suitable and available for oil palm production based upon land suitability evaluation (LSE) methods and GIS techniques. We conclude by providing recommendations for the sustainable development of the oil palm sector in Ghana.

Land Suitability Evaluation (LSE) and Data Analysis

We conducted the LSE in three-steps. First, we defined climatically suitable areas for oil palm based upon climate and soil data obtained from WorldClim (www.worldclim.org), the ISRIC/WDC (https://soilgrids.org), and the FAO (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/) soil databases, respectively. Four climatic zones (CZs) with varying suitability for oil palm were delineated in Ghana, based upon water deficits calculated using the method of Surre (1968). These CZs were grouped according to mean annual water deficit (mm/year), which integrates relevant climate (i.e., rainfall amount and distribution) and soil properties (i.e., water holding capacity) in a single parameter that delineates areas similar in terms of oil palm productivity (Olivin, 1968; van der Vossen, 1969). We defined four CZs:

1. **Optimal:** areas with a mean annual water deficit <150 mm;
2. **Favorable:** areas with a mean annual water deficit <250 mm;
3. **Suitable:** areas with a mean annual water deficit <400 mm; and
4. **Unsuitable:** areas with a mean annual water deficit >400 mm.

Areas that were climatically suitable were overlaid with biophysical and topographic constraints categorized as either 'suitable' or 'not suitable' (**Table 2**). Solar radiation, temperature, and slope were included because, after water deficit (WD), they are the most important factors that affect the growth and performance of oil palm (Paramananthan, 2003).

Table 2. Suitability for oil palm production based on climate and topography parameters (Paramananthan, 2003).

Limitation	Units	Suitable	Unsuitable
Climate			
Solar radiation	MJ/m^2	7 to 21	<7 or >21
Temperature	°C	18 to 37	<18 or >37
Topography			
Slope	°	<20	>20

In the final step, we excluded the most current land-use information, including protected areas defined by IUCN (Dudley, 2008), and urban settlements (Balk et al., 2006; CIESIN et al., 2011). Data on protected areas and urban settlements were obtained from the World Database on Protected Areas (http://protectedplanet.net) (IUCN and UNEP-WCMC, 2014) and the Socioeconomic Data and Applications Center (SEDAC) (http://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-extents/data-download) (CIESIN et al., 2011).

Areas Suitable and Available for Oil Palm Production in Ghana

Suitable areas for oil palm production (WD <400 mm/year) are found in the wetter southern parts of Ghana, and are estimated at 73,500 km^2 or 31% of the total land area. Unsuitable areas for oil palm production (WD >400 mm/year) are 165,000 km^2 and occur in the northern regions characterized by a hot and dry climate. Optimal areas for oil palm (WD <150 mm/year) are estimated at 5,800 km^2 and occur in the south of the Western Region and a smaller area west of Koforidua in the Eastern Region (**Figure 1**). Suitable areas for oil palm production were reduced by 9% to 67,200 km^2 after excluding biophysical/topographical constraints, and urban settlements and protected areas. The reduction was greatest in the optimal production zone (-30%), where large areas of forest reserve and urban settlements occur. Few large, contiguous tracts of land remain available for oil palm within this zone (**Figure 1**).

The Effect of Climate Change on Oil Palm Production in Ghana

Compared to a previous suitability assessment (van der Vossen, 1969), our methodology shows a larger suitable area (+20%) for oil palm production in Ghana. The difference is likely the result of different methods used to determine suitability, but also because of a changing climate. Meteorological observations show that the climate in the oil palm belt has changed between 1960 and 2000. In particular, temperatures increased and there was less, but more variable rainfall. These climate trends are projected to continue to 2050 (EPA and Ministry of Environment, 2011), suggesting a more favorable water balance and growing

Field evaluations are carried out to pinpoint deficiencies in management practices that contribute to yield gaps. Site-specific best management practices are then developed and proposed as remedial action.

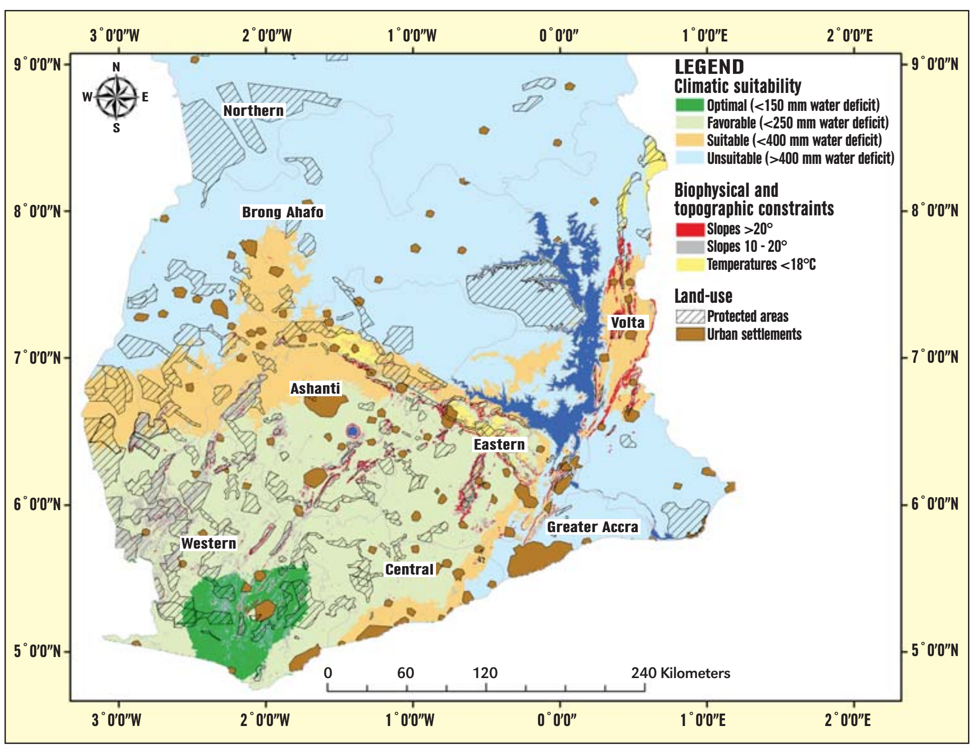

Figure 1. Map of southern Ghana showing suitable and available areas with potential for expansion in oil palm production, after excluding biophysical and topographical constraints and urban settlements and protected areas.

Abbreviations and notes: IPNI Project GBL-53

Table 3. Impact of yield intensification assuming moderate to full impact of best management practice (BMP) implementation across Ghana.							
	-------------- Current status --------------			Potential yield increase with BMP, %	---------- Yield intensification with BMP ---------		
Area, ha	Bunch production, M t	Yield, t/ha	Economic value*, US$/yr		Bunch production, M t	Yield, t/ha	Economic value*, US$/yr
330,000	1.9	5.8	402 M	25	2.4	7.3	502 M
				50	2.9	8.7	603 M
				75	3.3	10.2	703 M
				100	3.8	11.6	804 M

* Assuming an Oil Extraction Rate (OER) of 21% and a Crude Palm Oil (CPO) price of US$1,000/t.

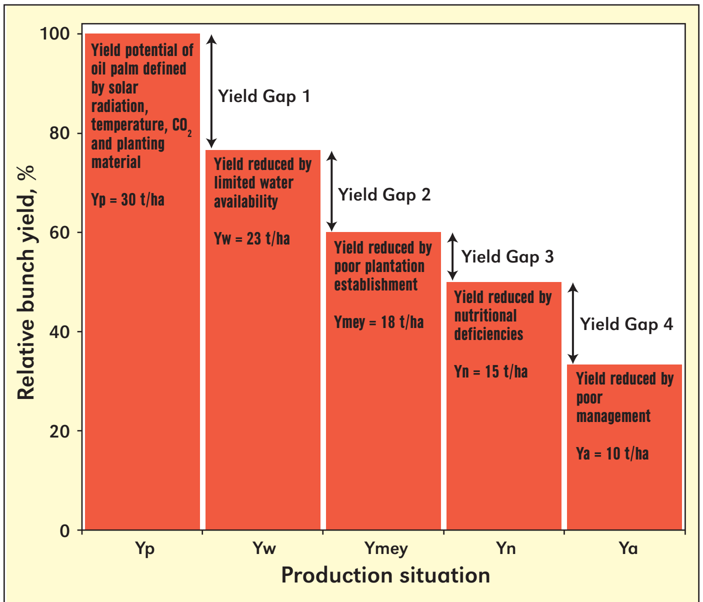

Figure 2. Yield gap model with various production situations and its associated yield gaps. When analyzing yield gaps in Ghana, water limited yield (Yw) is the most relevant benchmark because of the countries' rainfed conditions and sub-optimal climate.

conditions for oil palm in Ghana in the future. Alternatively, temperature increases will most likely increase evapotranspiration and aggravate soil-moisture conditions during periods of drought. This could lead to higher water deficits, and adversely affect oil palm production.

Key Constraints to the Production of Oil Palm in Ghana

The suboptimal amount and distribution of rainfall (water deficit) is the main constraint limiting oil palm production in WA. An almost linear inverse relationship between bunch yield and water deficit has been found in several studies in WA and Ghana (Danso et al., 2008; Olivin, 1968). Each 100 mm increase in water deficit reduces bunch yields by 10 to 15% (Corley and Tinker, 2003; Olivin, 1968), and 40 to 50% if the palms were subjected to severe water stress in the preceding year as well (Caliman et al., 1998). Soils with a high water storage capacity are desirable to cope with WA's climate, and represent a significant resource for oil palm development in Ghana. These results emphasize the need to explore the frequency and intensity of water deficits, and the occurrence of drought as prerequisites to planning future expansion of the area of oil palm (Caliman, 1992).

Restrictions to Area Expansion in Ghana

The annual shortage in crude palm oil (CPO) will increase from 35,000 t to 127,000 t by 2024 (MASDAR, 2011) if current production levels are maintained. To meet the projected oil demand in Ghana, suitability mapping identifies opportunities for area expansion into the most suitable lands for higher yields. Whilst area expansion is possible, fragmentation of suitable and available land largely hinders the establishment of large-scale plantations. This is exacerbated by other land-use types that were not part of the assessment, such as land under cocoa and rubber production, annual cropping, mining, high conservation value (HCV) areas, and fallow land that is part of slash and burn agriculture. Moreover, land acquisition is further complicated by complex land tenure arrangements that prevail in southern Ghana that make it difficult for investors to acquire land for the development of large-scale plantations (Ahiable, personal communication).

Opportunities to Increase Oil Palm Production in Ghana with Best Management Practices

Alternatively, production in Ghana can be increased by improving productivity (Rhebergen et al., 2014). To identify entry points in improving yields, yield gap analysis (YGA) is a useful tool. YGA partitions yield gaps between different causes, such as environment and management, thus providing a systematic process to assess opportunities in increasing yields (**Figure 2**).

Under satisfactory climatic conditions in Ghana, the maximum average attainable bunch yield is estimated at 25 t/ha (Rhebergen et al., 2014). With a country average bunch yield of 5.8 t/ha, current yield gaps are mostly the result of inadequate crop agronomic management, poor crop recovery, and soil fertility constraints that have not yet been sufficiently addressed. Opportunities for increasing production can therefore be sought by improving current management practices. Yield intensification on land already planted to oil palm may be an important policy for sustainable oil palm development in Ghana and WA. Adapting BMPs to local conditions can identity the management practices that are responsible for yield gaps (Donough et al., 2010). Improving agronomic management of existing palm stands shows considerable scope for yield intensification in Ghana, which can alleviate pressure for further land clearing for new plantations and greatly increase profitability for investors and farmers alike (**Table 3**).

Conclusions

The suitability assessment shows that highly fragmented suitable areas for oil palm production in Ghana are limiting the expansion of large-scale plantings. Therefore, a feasible strategy for expansion of smallholder production is needed, provided there are enough and efficient milling facilities to process the fruit. Alternatively, research conducted in Southeast Asia and Ghana indicate that production increases can be sought by applying BMPs to land already planted with oil palm. Closing yield gaps in Ghana could make a significant contribution to the national CPO supply and could lead to an increased profitability for investors and farmers alike. Moreover, increasing productivity in already existing palm stands reduces the need to clear land for new plantations. BC

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Nutrient Use Efficiency in Oil Palm Nurseries

By Hendra Sugianto, Christopher Donough, Rahmadsyah, Chin-Huat Lim, and Thomas Oberthür

Soil tests are useful in selecting suitable topsoil for use as growth medium in oil palm nurseries to avoid differences in plant growth between sites.

Nutrient use efficiency (NUE) in oil palm nurseries can be improved with appropriate application rates and timing.

Further improvements in NUE in oil palm nurseries could come with more efficient irrigation and use of slow-release nutrient sources.

High quality seedlings are an important prerequisite for high yielding, mature oil palms. Oil palm seedlings are typically groomed for one year in the nursery before being planted into the field. Nurseries usually practice a two-stage system, in which a pre-nursery stage of 12 to 14 weeks is followed by the main nursery stage that lasts between 38 to 40 weeks.

Standardized fertilizer programs are used in both nursery stages. However, the nutrient supply capacity of the topsoil growth medium is not routinely determined, potentially causing suboptimal and inefficient application of nutrients. The International Plant Nutrition Institute (IPNI) analyzed samples of plants and topsoil growth medium, in a collaborative project with Wilmar Group in South Sumatra, Indonesia, to understand nutrient use efficiency (NUE) in two-stage oil palm nurseries.

The South Sumatra Project

The South Sumatra project was implemented at three separate sites. Pre-germinated hybrid oil palm seeds were sown in weekly batches at the pre-nursery. Ten batches of each were assessed in 2012 and 2013 at sites 1 and 2, involving a total of 63,500 plants. In 2014 at site 3, four batches were assessed totaling 9,200 plants. In each batch, one part was subjected to Best Management Practices (BMP) following the methods of Rankine and Fairhurst (1999), while the rest were managed using the Standard Estate Practices (SEP) of the partner plantation. BMP and SEP treatments continued in the main nursery, involving 26,108 plants at sites 1 and 2 and 4,750 plants at site 3. The main difference between BMP and SEP in the two nursery stages was the fertilizer program summarized in **Table 1**.

Table 1. Nutrients supplied in the oil palm nursery of the South Sumatra project.

	Pre-nursery application, g/plant		Main nursery application, g/plant	
Nutrient	BMP[1]	SEP[2]	BMP	SEP
N	0.9	2.2	24.4	30.1
P	0.6	1.2	24.7	26.2
K	0.3	0.8	31.5	35.4
Mg	0.1	0.4	4.5	3.0

[1]Best Management Practice; [2]Standard Estate Practice

Nutrient losses in each nursery system were estimated by comparing the total amount of nutrients retained in the growth medium and plants at the end of each nursery stage, with the total amount of nutrients in the growth medium at the start of each nursery stage and nutrients supplied by fertilizers during each stage. Initial values were determined for the growth medium by sampling the topsoil-filled, unplanted and unfertilized bags. Bags were sampled again at the end of pre- and main nurseries stages to obtain the final nutrient content.

Each sampled plant was measured (as described by Donough et al. 2014), then carefully removed from its bag and separated from the growth medium. All samples of air-dried soil and oven-dried plant portions were combined according

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium. IPNI Project SEAP-04

Seedlings are planted in polythene bags (polybags) filled with a suitable medium, usually topsoil. On the left, the pre-nursery bags (15 cm x 23 cm) are arranged in beds (10 bags wide and 100 bags long) and the main nursery (right) uses larger bags (38 cm x 45 cm) arranged in an equilateral triangular pattern (90 cm spacing). Seedlings are irrigated in the nursery, using a fine spray provided by perforated polythene tubes.

to site, giving a total of 24 samples for each nursery. This was comprised of six samples of dried plant tops (two treatments BMP and SEP, three sites per treatment), six samples of dried plant roots, and six samples each of initial and ending growth media.

Nutrient Losses

The nutrient balance was much better under BMP in the pre-nursery stage (**Table 2**). In the main nursery, the BMP nutrient balance was still superior but the absolute difference smaller. The Mg balance in the main nursery was better with SEP. The values for P appear low as only plant-available P, but not total soil P, was determined.

Table 2. Nutrient balance in the oil palm nursery of the South Sumatra project.

Nutrients	Pre-nursery nutrients retained[1], % BMP[3]	Pre-nursery nutrients retained[1], % SEP[4]	Main nursery nutrients retained[2],% BMP	Main nursery nutrients retained[2],% SEP
N	76	52	70	65
P	9	7	12	10
K	76	18	47	43
Mg	39	24	70	91

[1]Nutrients in soil plus plant tissue at end of the pre-nursery period as a % of nutrients added in fertilizers plus initial soil contents; [2]Nutrients in soil plus plant tissue at end of the main nursery period as a % of nutrients added in fertilizers plus initial soil and plant tissue contents; [3]Best Management Practice; [4]Standard Estate Practice.

There were significant differences in the nutrient balances between sites. **Table 3** illustrates these differences for the K balances, which are attributable to site differences in the properties of the topsoil growth medium, including the clay, organic C, and soil N content, and the cation exchange capacity (data not shown). This clearly indicates the usefulness of soil tests in the selection of suitable topsoil growth medium.

Table 3. Potassium balance in oil palm nurseries at three sites of the South Sumatra project.

Site[1]	Retained K (%) in pre-nurseries[2] BMP[4]	Retained K (%) in pre-nurseries[2] SEP[5]	Retained K (%) in main nurseries[3] BMP	Retained K (%) in main nurseries[3] SEP
1	94	9	37	20
2	71	34	62	48
3	66	12	86	77

[1]Three different oil palm nurseries involved in the project; [2]K in soil plus plant tissue at end of the pre-nursery period as a % of K added in fertilizer plus initial soil content; [3]K in soil plus plant tissue at end of the main nursery period as a % of K added in fertilizer plus initial soil and plant tissue contents; [4]Best Management Practice; [5]Standard Estate Practice.

Plant Growth and Nutrient Use Efficiency

Plant growth under BMP and SEP was not significantly different (**Table 4**). This indicates sufficient nutrients were supplied by either treatment. In the pre-nursery, BMP plants were very similar in size to SEP plants despite receiving far less nutrients (**Table 1**). This indicates that nutrient supply was excessive with SEP, with the lower nutrient balance in the SEP pre-nursery (**Table 2**) suggesting that much of this oversupply is lost. Early applications in the SEP pre-nursery fertilizer program could be eliminated without any adverse effect on pre-nursery plant growth. This is shown by similar plant growth achieved with late applications in the BMP pre-nursery fertilizer program.

Table 4. Plant growth measures in the oil palm nursery stage of the South Sumatra project.

Growth Indicators	Pre-nursery stage[1] BMP[3]	Pre-nursery stage[1] SEP[4]	Main nursery stage[2] BMP	Main nursery stage[2] SEP
Stem diameter[5] (cm)	1.0	0.9	6.2	5.9
Plant height[6] (cm)	24	25	90	85
Fronds per plant[7]	4.7	4.7	14	14
Petiole cross-section[8] (cm^2)	-	-	1.2	1.1
Plant dry weight[9] (g)	2.5	2.9	636	534

[1]Growth measured once at end of PN period; [2]Data shown for measurements after 28 weeks in MN; [3]Best Management Practice; [4]Standard Estate Practice; [5]Stem diameter at soil level; [6]Height from soil surface to tip of longest frond; [7]Fully expanded green fronds only; [8]Product of width and depth of petiole at proximal end of frond, measured on the 3rd fully expanded frond, measured only in MN; [9]PN sampled at end of PN period, MN sampled at 36 weeks at 2 sites and 28 weeks at 1 site.

In the main nursery, BMP plants were marginally larger (**Table 4**) even though they received slightly less nutrients except for Mg. Donough et al. (2014), reporting early results from Sites 1 and 2 only, attributed this to the higher proportion of readily available P supplied in the BMP main nursery fertilizer program.

In the pre-nursery stage, partial factor productivity [PFP = plant dry weight (g) per g nutrient applied] was better with BMP, especially for K (**Figure 1a**). Internal efficiency [IE = plant dry weight (g) per g nutrient uptake] was only marginally different between the two treatments (**Figure 1b**). Again, this is an indication of excessive and untimely supply of nutrients through SEP. BMP nutrients were applied near the end of the pre-nursery period. SEP nutrients, on the other hand, were applied regularly after sowing. This suggests losses of nutrients that were applied during the early stage of the pre-nursery. In the main nursery, differences between treatments were small for both PFP and IE (**Figure 2a** and **2b**), indicating similar nutrient use efficiency in BMP and SEP fertilizer programs.

Conclusions

The loss of nutrients from the oil palm nursery system, especially in the pre-nursery stage, can be high if generous fertilizer rates are applied and not appropriately timed. Further improvement in nutrient retention in the pre-nursery stage should be possible with the adoption of irrigation methods that supply water more efficiently and are possibly grouped with slow-release nutrient sources.

The difference between current practices and BMP are smaller in the main nursery stage. Yet, as in the pre-nursery, improvements in irrigation and use of slow-release nutrient sources will further help reducing nutrient loss and improve nutrient use efficiency in the main nursery.

Use of standardized fertilizer programs at various locations may lead to differences in plant growth between locations. Soil tests should be used to guide selection of suitable topsoil growth medium for planting in oil palm nurseries. BC

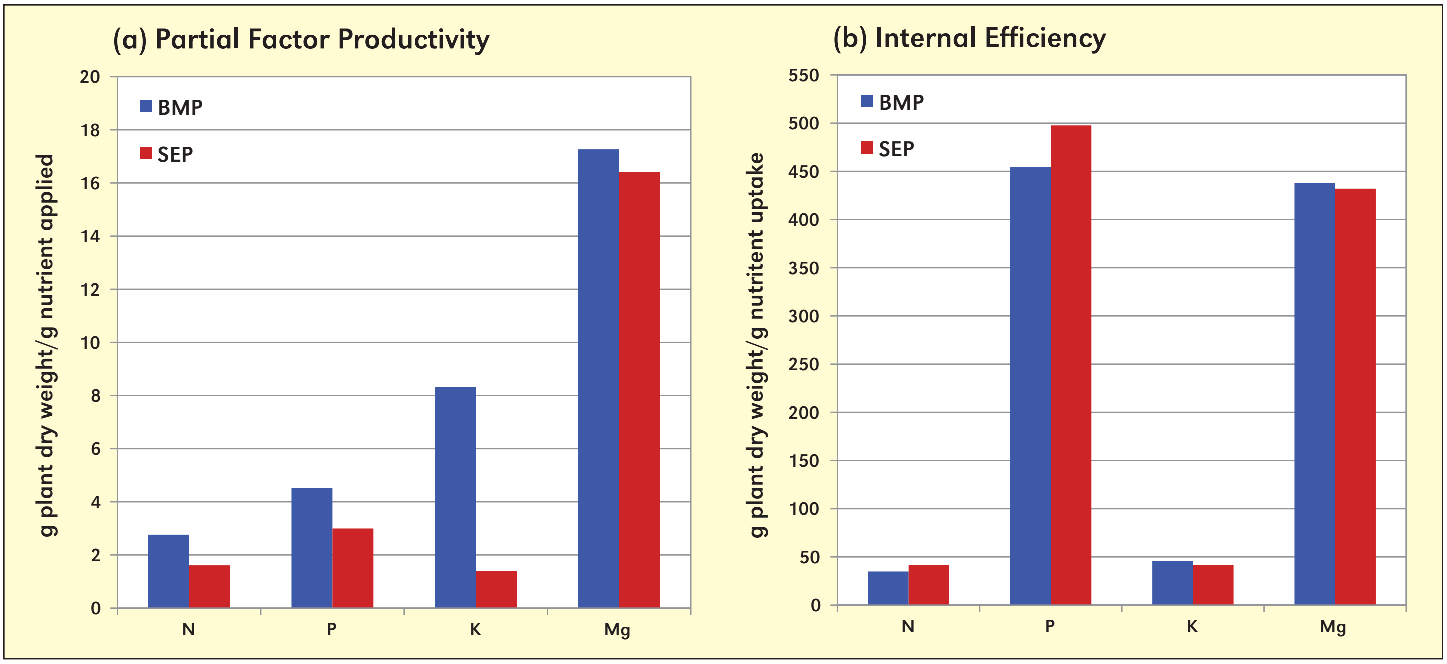

Figure 1. Partial factor productivity and internal efficiency for nutrients applied under best management (BMP) and standard estate (SEP) practices in the pre-nursery of the South Sumatra project.

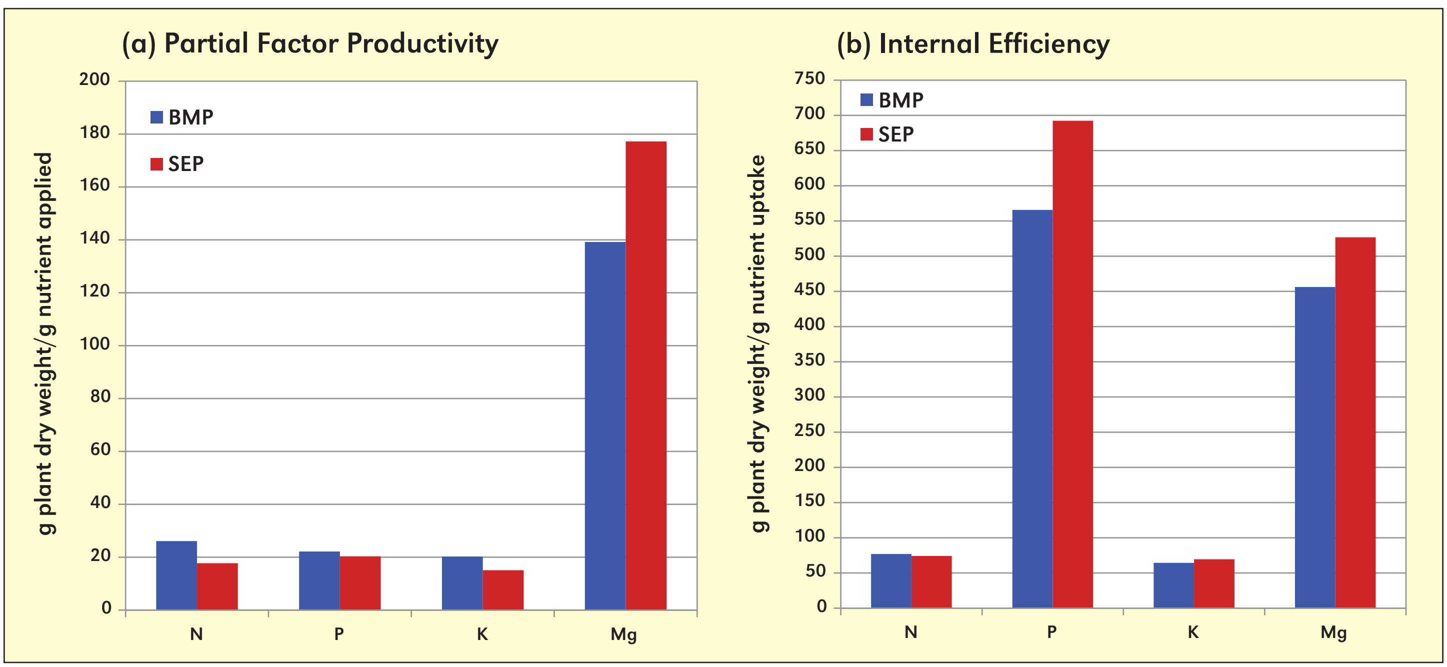

Figure 2. Partial factor productivity and internal efficiency for nutrients applied under best management (BMP) and standard estate (SEP) practices in the main nursery of the South Sumatra project.

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Data used were generated from a collaborative project between IPNI Southeast Asia Program (SEAP) and Wilmar International Limited (WIL). All fieldwork and data collection were carried out by staff of WIL in three oil palm nurseries located within South Sumatra, Indonesia. IPNI staff and consultants helped design and analyze results. All direct costs of fieldwork and implementation were borne by WIL. Canpotex provided funds to cover the cost of IPNI consultants and laboratory analyses. All laboratory analyses were done by Asian Agri Laboratory in North Sumatra, Indonesia.

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Controlled-Release Urea in Banana Production in Southern China

By Hongwei Tan, Liuqiang Zhou, Yan Zeng, Huiping Ou, Jinsheng Huang, Xiaojun Zhu, and Shihua Tu

Researchers tested complete or partial substitution of controlled-release urea for regular urea in order to identify new options capable of offering high fruit yield along with improved efficiencies in crop management and N use.

Banana is widely grown in southern China where the crop covers 400,000 ha and annual fruit production has reached 12 million t (MOA, 2013).

Banana requires much larger quantities of nutrients (especially N and K) than other common field crops due to the crop's obviously large biomass. In order to improve N use efficiency during the rainy, summer season, growers often have to divide their N fertilizer into six to eight applications to minimize ammonium volatilization, nitrate leaching, and denitrification. Since manual fertilizer application are still common in China's plantations, these split applications have created difficult, time consuming, and costly work in the hot, humid, and sometimes wet fields.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium. IPNI Project CHN-GX15

Controlled-release urea (CRU) is considered to be an N source capable of delivering enhanced efficiency in crop production. Use of CRU has reduced the number of split applications of N fertilizer while still improving crop yield and crop N uptake (Haderlein et al., 2001; Geng et al., 2015). These characteristics make CRU an ideal N source for banana.

The objectives of this study were to examine the optimal rates and timing of CRU manufactured by Agrium Inc. (Calgary, Alberta, Canada) and to evaluate its influence on banana yield and quality. Researchers wanted to offer science-based information for proper CRU use. This three-year (2013 to 2015) field experiment compared different rates, timings, and blends of CRU and regular urea (RU) (**Table 1**). The full rate of N

Table 1. Controlled-release urea (CRU) and regular urea (RU) rates and application timings tested with banana, Guangxi, China.

Treatment	N rate, kg/ha Total	CRU	RU	Timing of application Basal	Side-dressings
No N (CK)	0	0	0	0	0
RU (5)[1]	673	0	673	1	5
CRU (1)	673	673	0	1	1
CRU (2)	673	673	0	1	2
CRU+RU (80:20) (1)	673	538	135	1	1
CRU+RU (80:20) (2)	673	538	135	1	2
CRU @ 80% N rate (1)	538	538	0	1	1
CRU @ 70% N rate (1)	471	471	0	1	1
CRU+RU (60:40) @ 80% N rate (1)	538	323	215	1	1

[1]Figures in the brackets refer to the number of side-dressings.
Rates for P and K were 176 kg P_2O_5/ha (as fused Ca-Mg phosphate) and 878 kg K_2O/ha (as potassium chloride), which were split three times between basal, flower bud initiation, and the fruit swelling stages.

Table 2. Effects of different controlled-release urea (CRU) and regular urea (RU) combinations on banana yields in 2013 to 2015, Guangxi, China.

Treatment	---- 2013 ---- Yield, t/ha	±% vs. RU	---- 2014 ---- Yield, t/ha	±% vs. RU	---- 2015 ---- Yield, t/ha	±% vs. RU
No N (CK)	16.2 c[2]	-48	24.5 c	-36	18.9 d	-61
RU (5)[1]	31.0 ab	-	38.4 b	-	48.1 b	-
CRU (1)	33.2 a	7.0	40.9 a	6.6	50.5 ab	5.0
CRU (2)	34.0 a	9.8	41.0 a	6.8	52.1 a	8.2
CRU+RU (80:20) (1)	30.6 b	-1.4	39.1 ab	1.9	48.7 b	1.2
CRU+RU (80:20) (2)	30.8 b	-0.7	39.4 ab	2.8	50.6 ab	5.1
CRU @ 80% N rate (1)	31.3 ab	0.9	38.7 b	1.0	47.7 b	-0.8
CRU @ 70% N rate (1)	30.8 b	-0.9	38.2 b	-0.5	45.5 c	-5.4
CRU+RU (60:40) @ 80% N rate (1)	30.3 b	-2.3	39.3 ab	2.4	48.5 b	0.8

[1]Figures in the brackets refer to the number of side-dressings.
[2]Values in each column followed by different letters are statistically different at p=0.05.

applied as RU was split six times between a basal application, three seedling side-dressings, flower bud differentiation, and fruit swelling. The CRU was applied basally and the remainder was either side-dressed solely at the seedling stage, or was split between the seedling and fruit swelling stages. Prior to the flower bud shooting stage, all fertilizers were broadcast and incorporated into the soil around the drip line of the banana canopy. The banana seedlings were transplanted in the first year and the suckers (daughter plants) sprouted from the previous plant corms that were used as the second and third crops.

Yield Responses

Banana yields varied considerably from year to year, but trends showed an increase with time. Importantly, CRU increased banana yield while reducing the number of split applications of N (**Table 2**). The two full rate CRU treatments consistently produced the highest yields. Dividing CRU into two side-dressings improved yield marginally compared to the single side-dressing, but with no economic advantage (**Table 3**). In the first two years, CRU applied at 80% of the full N rate produced higher yields than the full rate of RU, but this trend ended during year 3. CRU applied at 70% of the full N rate consistently produced lower yields and this yield gap increased with time. Blended CRU+RU (80:20) produced slightly lower yields than RU in year 1, but this reversed in the last two years, especially for the treatment with two side-dressings. Similar results were observed for the reduced rate (80%) CRU+RU blend, which also implies a feasible practice at this location.

Banana yields were not significantly related to agronomic traits such as plant height, stem girth, or flower bud shooting date, but they were related to finger number per plant and finger weight (data not shown). The study found that adequate finger number per plant, and bigger fingers, were key to obtaining high yields. This observation agrees with other research that reports on CRU's benefits on yield components such as increased kernel/ear and 100-kernel weight for maize (Wang et al. 2011), increased boll number per plant and boll weight for cotton (Hu et al., 2011), and increased effective tillers, filled grain per panicle, and 1000-grain weight in rice (Yang et al., 2013).

Economic Returns and Agronomic Efficiency

For net returns, all CRU options generated more income than the RU treatment (**Table 3**). Among the CRU options, the two full N rate treatments proved most profitable.

Besides the potential for CRU to improve yield and profits with reduced labor, based on the large N input that is associated with banana crop production, the anticipated environmental gains related to CRU are large. Researchers report that CRU can reduce

Table 3. Economic returns as affected by combinations of controlled-release urea (CRU) and regular urea (RU), Guangxi, China.

Treatment	2013	2014	2015
	---- Net income[2], US$/ha ----		
No N (CK)	5,690	10,020	5,520
RU (5)[1]	11,400	15,240	15,600
CRU (1)	13,100	17,120	17,200
CRU (2)	13,300	16,940	17,590
CRU+RU (80:20) (1)	11,880	16,290	16,530
CRU+RU (80:20) (2)	11,760	16,060	17,050
CRU @ 80% N rate (1)	12,320	16,210	16,220
CRU @ 70% N rate (1)	12,120	16,000	15,410
CRU+RU (60:40) @ 80% N rate (1)	11,920	16,570	16,630

[1]Figures in the brackets refer to the number of side-dressings.
[2]Net income refers to the values after deducting the total cost including fertilizers (CRU prices have exceeded regular urea by US$154 to US$200/t), pesticides, labor, irrigation, and harvest.

N losses via ammonium volatilization by 51 to 71% in winter wheat (Lu and Song, 2011) and by 51 to 91% in summer maize (Zhao et al., 2009). In rice, N loss reductions of 24 to 27% through runoff were measured in paddy fields by Ji et al. (2007), and Xie et al. (2016) found 28 to 55% less N_2O emissions in maize.

In this study, agronomic efficiency (AE) from CRU, used alone, at a reduced rate, or in combination with RU, was higher than with RU alone (**Table 4**). The CRU options providing reduced N rates had the highest AE values for three consecutive years, which were followed by the two CRU treatments providing the full N rate.

Table 4. Agronomic efficiency (AE) of nitrogen as affected by combinations of controlled-release urea (CRU) and regular urea (RU), Guangxi, China.

Treatment	AE[2] in 2013		AE in 2014		AE in 2015	
	kg/kg	±% vs RU	kg/kg	±% vs RU	kg/kg	±% vs RU
RU (5)[1]	22.0	-	21.1	-	43.4	-
CRU (1)	25.3	15	24.9	18	47.0	8
CRU (2)	26.5	20	25.0	18	49.3	14
CRU+RU (80:20) (1)	21.4	-3	22.2	5	44.2	2
CRU+RU (80:20) (2)	21.7	-1	22.7	8	47.0	8
CRU @ 80% N rate (2)	28.1	28	27.1	28	53.5	23
CRU @ 70% N rate (1)	30.9	40	29.7	41	56.5	30
CRU+RU (60:40) @ 80% N rate (1)	26.2	19	28.1	33	55.0	27

[1]Figures in the brackets refer to the number of side-dressings.
[2]Agronomic efficiency = kg grain yield increase/kg applied N.

Summary

Controlled-release urea significantly reduced the number of fertilizer N applications from a 6-split strategy with regular urea to a less demanding and less costly 2 to 3 splits with CRU. Banana yields with CRU were generally 5 to 10% higher compared to RU. The higher yields were attributed to improved finger number per plant and finger weight. The full CRU-N rates proved best, followed by CRU applied at a reduced (80%) N rate. However, reduced N rate options could only maintain two to three years of high yield production given the site's soil fertility status. Agronomic efficiency of N was the highest for both reduced rate (70% and 80%) CRU options, followed by either CRU treatment applied at the full N rate. CRU alone achieved the best returns, but CRU applied in blends with urea, or in reduced rates, were all feasible practices. BC

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Diagnosis of the Nutritional Status of Rainfed Olive Orchards

By Ajmi Larbi, Mahdi Fendri, Hakim Boulal, Mohamed El Gharous, and Monji Msallem

Foliar analysis is used to confirm the nutritional constraints in rainfed olive yields in Tunisia that are caused by inadequate and improper nutrient management.

Tunisia is one of the most important olive-growing countries of the southern Mediterranean region. Despite the crop's importance, the main constraints facing Tunisian olive production are low productivity, aging trees, and inadequate nutrient management. The nutritional deficit in these orchards has resulted in crop losses, low fruit quality, and in severe cases, the death of trees. Generally, fertilization is done without any previous knowledge of the nutritional status of the trees or the soil nutrient balance. Excessively negative, or positive, nutrient balances are hampering the sustainability of olive crop productivity and orchard soil fertility in Tunisia.

Nutrient application should meet, and not exceed, the seasonal demands of the orchard. It is important to understand the nutritional status of olive trees and their real nutrient demand to get fertilizer application right. In rainfed orchards, farmers often limit their application of fertilizers because of the risks of low rainfall, the high cost of fertilizers, and a general lack of knowledge concerning the importance of adequate fertilization.

Table 1. Description of on-farm experimental olive sites in northern Tunisia.

Farm	Area, ha	Tree age, yr.	Planting density, tree/ha	Yield, kg/tree 2014	Yield, kg/tree 2015	Nutrient input[1], kg/tree
1	20	62	100	7.0	35	3
2	4	40	100	6.0	28	3-4
3	0.5	55	100	10.5	39	30

[1] Common farm practice of applying 3 to 4 kg ammonium nitrate/tree in February. Farm 3 received 30 kg cattle manure/tree.
Cumulative rainfalls were 545 mm in 2014 and 533 mm in 2015. Olive tree density was 100 trees/ha (10 x 10 m spacing) planted with Chétoui and Jarboui varieties.

Table 2. Soil analysis of the three on-farm olive orchards sites in Teboursouk, Tunisia.

Farm	Depth, cm	Organic matter, %	Total $CaCO_3$, %	pH	Available K, ppm	Available Ca, ppm	Available P, ppm
1	0-30	1.7	48	8.5	231	9,670	46
	30-60	1.7	46	8.5	208	9,250	38
2	0-30	1.0	56	8.7	295	8,970	87
	30-60	0.9	53	8.5	262	8,130	75
3	0-30	0.9	47	8.1	290	8,650	85
	30-60	0.9	47	8.3	271	9,340	87

On-farm experiments were conducted during 2014 and 2015 in three rainfed orchards located in the north-western province of Teboursouk. The olive orchards were 40 to 60 years old, which represents the average for the region. The average fruit yield was low (1,000 kg/ha) in 2014 and was considered an "off" year. In 2015, an "on" year, yield exceeded 2,800 kg/ha. Besides wanting to highlight the NPK balance and the role that best nutrient management practices can play, researchers also wanted to determine if nutrient management can help to reduce the yield swings that result from olive's typical alternating (on/off) fruit-bearing years.

For foliar diagnosis, leaf samples were collected from each experimental site in July for both years. In each farm, two bulk leaf samples were collected, each leaf sample comprised of 150 healthy, fully expanded mature leaves collected from the middle portion of non-bearing current season shoots. Leaves were analyzed for N, P, and K. The olive orchards were fertilized by one broadcast application of 3 to 4 kg AN/tree in February (common farm practice) in both years of experimentation, except for farm 3 where 30 kg cattle manure/tree was applied (**Table 1**).

The soil was clay loam texture, characterized by 46 to 57% total $CaCO_3$, 0.9 to 1.7% organic matter, and pH (water) of 8.1 to 8.7. Soil available K (ammonium acetate extractable) varied between 230 and 294 ppm, available Ca between 8,650 and 9,670 ppm, and available P (Olsen) varied between 46 and 85 ppm (**Table 2**). There was no significant difference between surface (0 to 30 cm) and sub-surface (30 to 60 cm) sampling for all the analyzed parameters.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; AN = ammonium nitrate; $CaCO_3$ = calcium carbonate. IPNI Project TUN-1

The olive tree tolerates a wide range of soil pH, but a neutral to slightly alkaline (7 to 8.5) pH is most suitable. Organic matter and $CaCO_3$ content of the soils were adequate for proper growth of trees. Olive trees need at least 1% soil organic matter (Soyergin et al., 2002) and can tolerate a wide range of lime content in the soil up to very high values of 76% (FAO, 2006).

The available P contents in the soil of the three farms showed moderate variation. The minimum value was 38 ppm, above the critical level of 8 ppm proposed by Gargouri and Mhiri (2002). The soil available K was moderate considering the soil texture (clay loam soil). Based on the soil analysis, soils of the on-farm experimental sites were suited for olive tree cultivation.

Foliar Analysis

Foliar analysis showed that 50% and 67% of olive orchards were deficient in N in the 2014 "off" year and 2015 "on" year, respectively. A generally inadequate approach to N fertilization was considered the root cause of this N deficiency. The common practice of using a single application of ammonium

Table 3. Foliar N, P, and K analysis of olive tree varieties growing at three olive farms in Teboursouk, Tunisia.

			---- Farm 1 ----		---- Farm 2 ----		---- Farm 3 ----		---- Average ----	
		Threshold values[2], %	Chétoui	Jerboui	Chétoui	Jerboui	Chétoui	Jerboui	Chétoui	Jerboui
Nutrient	Year		%							
N	2014[1]	1.5 to 2	1.67 a[3]	1.41 a	1.45 b	1.59 a	1.70 a	1.37 a	1.61 a	1.46 a
	2015		1.37 b	1.40 a	1.77 a	1.37 b	1.59 b	1.42 a	1.58 b	1.40 b
P	2014	0.1 to 0.3	0.10 a	0.13 a	0.11 a	0.13 a	0.11 a	0.13 a	0.11 a	0.13 a
	2015		0.11 a	0.09 b	0.08 b	0.09 b	0.08 b	0.09 b	0.09 b	0.09 b
K	2014	0.8 to 1	0.91 a	0.76 a	0.92 a	0.99 a	1.04 a	0.77 a	0.96 a	0.84 a
	2015		0.66 b	0.58 b	0.49 b	0.61 b	0.38 b	0.54 b	0.51 b	0.58 b

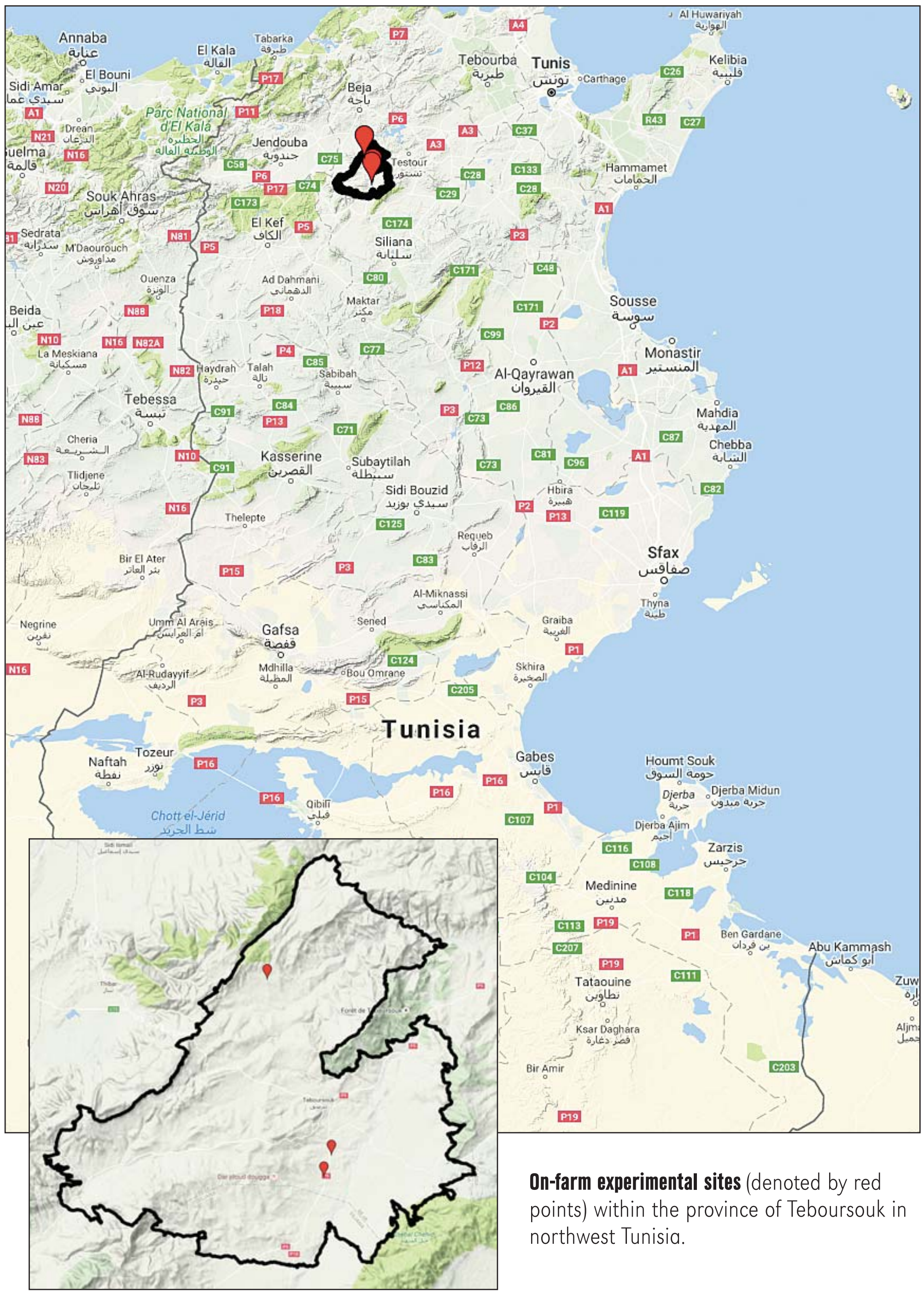
[1]2014 = "off" fruit-bearing year while 2015 = "on" fruit-bearing year.
[2]Pastor et al. (2005)
[3]For each nutrient, values followed by different letters in the same column differ significantly at $p < 0.05$.

nitrate each year leaves the fertilizer highly susceptible to loss, largely through leaching away from the root zone. The higher yield (over 30 kg/tree) observed in 2015 increased the extent of N deficiency, due to higher N uptake by the trees and the absence of any split application of N (**Table 3**).

For P, no deficiency was observed in 2014. However, leaf P concentrations decreased during 2015 below the published critical value of 0.1%. The low P concentration in 2015 can be attributed to high yielding trees, a corresponding high extraction of P by fruits, and also to the calcareous nature of these orchard soils that regularly precipitate P (Hidalgo et al., 2011). The conventional soil application of P is usually not very efficient (Ferreira et al., 1986) and foliar application remains the best alternative to correct P deficiency.

Similar to P, leaf K concentration also decreased in 2015. Although this is mainly due to the high fruit yield in 2015, the fall in leaf K concentration can be explained by redistribution of K from the leaves to the fruit during the period between July until December/January (harvest period). Furthermore, the high content of $CaCO_3$ and the soil texture (22 to 30% of clay) with high adsorptive power can affect soil K availability for olive trees (Hidalgo et al., 2011).

According to the threshold values in **Table 3**, three cases of N deficiency, zero cases of P deficiency, and two cases of K deficiency were found from the six samples taken during 2014. However, 2015 found



On-farm experimental sites (denoted by red points) within the province of Teboursouk in northwest Tunisia.

Symptoms of N (top), P (middle) and K (bottom) deficiency in rainfed olive orchards, Teboursouk, Tunisia.

Table 4. Nitrogen, P, and K leaf concentration range (% dry matter, var. Chétoui) in three olive farms, January 2016, Teboursouk, Tunisia.

Nutrient, %	July 2015	Jan 2016
N	1.37 to 1.77	1.26 to 1.31
P	0.08 to 0.11	0.04 to 0.06
K	0.38 to 0.66	0.34 to 0.38

four cases of N deficiency, five cases of P deficiency, and six cases of K deficiency.

In January 2016, a foliar diagnosis was done for subplots planted to the Chétoui variety (**Table 4**). Results showed moderate N deficiency and severe P and K deficiency as the range of leaf nutrient concentrations decreased from the July 2015 values. These foliar analyses confirmed the nutrient deficiencies observed.

Summary

In rainfed areas of Tunisia, low fertilizer use by olive farmers, mainly during the high fruit-bearing year, contributes to severe N, P, and K deficiency. The use of foliar P and K fertilization remains essential to overcome constraints related to P precipitation in highly calcareous soil or poor fertilizer solubilization under rain water scarcity. BC

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The Interaction Between Plant Nutrition and Disease: Focus on Verticillium

By Brad Geary and Doug Jacobson

A review of the influence plant nutrition can have on plant disease susceptibility using the soil-borne fungal disease *Verticillium* as a case study example.

Most of us know that human health and disease prevention is directly tied to nutrition. Scurvy, for example, is a disease resulting from a lack of vitamin C that causes gum disease and other ailments. Humans can eliminate scurvy by consuming vitamin C in their diets. Plants are also dependent on nutrition for growth and disease reduction. Unlike humans, plants primarily obtain their nutrients from a small area of soil surrounding their roots. Proper nutrition clearly improves plant health, but not all plant diseases are cured by nutrition. However optimal plant nutrition can help reduce the US$5 billion lost annually to crop diseases in the world. Balanced plant nutrition is an effective and affordable way to minimize or prevent plant disease.

All plants are dependent on mineral nutrients for their growth and overall health and quality. Fourteen mineral nutrients are considered essential, with N, P, and K being considered primary, due to the quantity found within the plant and the large amount needed for proper plant growth. A number of other nutrients (e.g., Ca, Mg, Mn, Fe, B, etc.) also influence plant growth and disease interactions. The relationships and mechanisms by which plant nutrients and diseases interact are varied and complex. A particular disease might inhibit the plant's ability to absorb an essential nutrient, while the absorption of a particular nutrient might allow the plant to escape the effects of a particular disease.

Proper plant nutrition is essential to resisting disease. If an otherwise healthy plant is deficient in any of the nutrients required for proper growth, its susceptibility to disease increases. Proper plant nutrition can inhibit the pathogen's ability to infect the plant. One of the advantages to reducing disease with nutrients is that—to a certain degree—growers can control the supply of nutrients available and their timing to the plant. This topic is complex and readers are urged to consult the references at the end of this article for more information on specific crops and nutrients.

Due to their importance and quantity needed, N, P, and K are often the first nutrients to be depleted in the soil and are regularly supplemented through fertilizer applications. These three nutrients play a key role in plant development and health. Nutrient-deficient plants are less likely to tolerate stress and are more susceptible to disease; likewise, plants grown with an excessive supply of these elements may be subject to increased disease and to lower plant quality and development (Univ. California, 1992).

Nitrogen is essential for the production of amino acids, proteins, enzymes, hormones, phytoalexins (antibiotics), and other cellular components, as well serving an essential role in photosynthesis and growth. Phosphorus within a plant is primarily used for energy transfer and protein metabolism. Potassium, unlike N and P, does not become part of any plant material, but remains unattached as a regulator of plant growth through activation of at least 60 different enzymes in meristematic tissues, among other essential roles.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; B = boron; Fe = iron; Mn = manganese. IPNI Project USA-UT8

Plant Nutrition and Verticillium

Verticillium is a destructive soil-borne fungal disease influenced by mineral nutrition. The fungus enters plant roots and begins to clog the vascular system, resulting in the characteristic wilt associated with the disease. There are very few chemical treatments available to eliminate *Verticillium*, so agronomic and field cultural practices are very important. Soil fertility and mineral nutrition affect *Verticillium* virulence by reducing the inoculum density of spores in the soil and by influencing the host plant's resistance to the pathogen.

Jack Kelly Clark Univ. of California

Vascular discoloration in cotton stem resulting from Verticillium infection.

Howard F. Schwartz, Colorado State Univ.

Brad Geary, Brigham Young Univ.

Cliff Snyder/IPNI Photo

Symptoms of Verticillium wilt infection in sunflower (top), potato (middle) and cotton (bottom) plants.

Verticillium wilt affects over 300 host plants in many plant families. Verticillium wilt on lettuce is a serious problem that has resulted in complete crop failure in some areas. Peppers, tomatoes, and potatoes are well known examples of vegetables that can be severely damaged by *Verticillium*. Unfortunately, populations of *Verticillium* remain in the soil for several years, limiting when lettuce, or other crops, can be planted again. Control options are limited to fumigation or switching to crops that are not *Verticillium* hosts. Recent research has shown that Verticillium damage can be greatly reduced with the proper balance of mineral nutrients within the susceptible plants.

A number of studies have found that N management can decrease Verticillium wilt severity in many crops, including lettuce, cotton, eggplant, olive, and potato. Plants primarily take up N as ammonium (NH_4^+) and nitrate (NO_3^-). Verticillium wilt generally decreases when N is supplied as NH_4^+, rather than in the NO_3^- form, which has shown an increase in disease severity of Verticillium wilt in eggplants (Elmer, 2000). Although the exact mechanisms by which NH_4^+ decreases Verticillium wilt is unknown, it is postulated that the acidification of the rhizosphere due to the extrusion of H^+ ions to balance the charge created by NH_4^+ uptake has a detrimental effect on the pathogen. Evidence supporting H^+ ions influence on *Verticillium* comes from a study where lettuce was grown under low pH conditions, high H^+ ions, and Verticillium wilt was not as severe (Subbarao, 2012).

An adequate Mn supply has been shown to decrease the severity of Verticillium wilt and other plant diseases. Plant tissues low in Mn are more susceptible to fungal diseases such as *Verticillium*, while tissues with adequate Mn concentrations successfully resist many fungal infections. Manganese availability works in tandem with the form of N present and soil acidity to decrease *Verticillium* severity. Higher Mn uptake is generally found in low pH soils, where more of the N may also be N present in the NH_4^+ form due to slower nitrification.

Phosphorus deficiency in soils severely limits plant yield, but research on P and *Verticillium* indicates that it does not have as great an influence as other nutrients. In preliminary studies, an increase in P fertilization of cotton, independent of other nutrients, resulted in an increase in *Verticillium* severity. Clearly, reducing P inputs may a cause P deficiency in plants, limit plant growth, and allow disease to take advantage of a weakened plant, but excessive soil P concentrations may encourage diseases like *Verticillium*. It is important to analyze soil and plant tissues to maintain optimal P concentrations and maintain good plant health.

Potassium uptake is typically greater than for any other nutrient. It is now commonly accepted that ensuring an adequate K supply generally decreases many plant diseases. This is true for *Verticillium*, where increased K fertilization corresponds to a decrease in wilt severity. For example, when cotton is heavily infested with *Verticillium*, an associated deficiency of K is commonly found. Pistachio and potato also show decreases in *Verticillium* severity with increased rates of K fertilization. This relationship between K and plant disease should be used to encourage proper plant nutrition and not excessive K fertilization rates.

Despite the complex relationships between plant nutrition and plant disease, proper nutrition is an essential component to disease resistance. Clearly there are no guaranteed solutions concerning disease mitigation through plant nutrition, but proper nutrition is one certain way that growers can combat plant disease. Keep in mind that too much of any nutrient can be detrimental to plant growth and that balanced nutrition is essential for optimal crop growth and development. BC

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IPNI Appoints Potassium Program Director

The International Plant Nutrition Institute (IPNI) has appointed Dr. T. Scott Murrell as Director of its new Potassium Program.

For the past 20 years, Dr. Murrell has worked for IPNI (2007 to present) and its predecessor the Potash & Phosphate Institute (PPI; 1996 to 2007) as IPNI Director of the North America Program and PPI Regional Director of the Northcentral U.S. Program, respectively. Most recently, Dr. Murrell's focus within the IPNI North American Program has been on the improvement of nutrient management within corn-soybean cropping systems, data management for soil testing and crop nutrient uptake, and soil potassium assessment. Dr. Murrell will continue his work with data management as that is an integral component of potassium plant nutrition and management.

"All IPNI scientists' activities include agronomic programs that address potassium, nitrogen, phosphorus, and other plant nutrients as part of the Institute's regional and global tactical plans," explained IPNI President Dr. Terry L. Roberts. "Our addition of a Potassium Program Director completes our team of Directors that will have primary and global focus on each of the major nutrients." BC

Dr. T. Scott Murrell, Director of the IPNI Potassium Program.

Crop Nutrient Deficiency Photo Contest Entries Due December 6, 2016

Photo by Hari Gowthem G.

Calcium deficiency in wheat.

There is still time to beat the deadline for submitting entries to the annual IPNI photo contest for plant nutrient deficiencies.

Our list of prizes is as follows:

- US$250 First Prize for best overall photo
- US$150 First Prize Awards and US$100 Second Prize Awards within each of the four plant nutrient categories (Nitrogen, Phosphorus, Potassium, and Other Nutrients).
- In addition, the grand prize winners and first place winners will receive the most recent copy of our USB image collection. For details on the collection, please see http://ipni.info/NUTRIENTIMAGECOLLECTION

Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest.

Winners will be notified and announced in early 2017. Look for results posted on ipni.net. BC

Increasing Beef Production with Improved Soil Nutrient Use: Brazil's Challenge

By Eros Francisco

Pasture for grazing is the major land use in Brazil, but the country's livestock systems are generally very inefficient.
Brazil has great potential to increase its beef production, but farmers will need to follow results from agronomic research and adopt recommended technologies.
Liming, fertilizer use, and other techniques are useful best management practices to change this current reality.


E. Francisco/IPNI Photos

Livestock farming systems examples in Brazil with low (left) and high (right) technology adoption.

Brazil's livestock-related agriculture currently occupies 25% of the country's total area of 851 million (M) ha. Agriculture for livestock is the largest land use type compared to other uses including: federal lands (18%), conservation units (15%), forests and natural vegetation (13%), Indian reservations (13%), other purposes (15%), and cities and infrastructure (0.2%). About one quarter of the area occupied by livestock agriculture is used to grow crops; however, the remaining land (about 180 M ha) grows forage grasses mainly for grazing (IBGE, 2015).

Forage production systems in Brazil are very diverse with 45% growing native vegetation and 55% cultivated forages. 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.). Despite this, these pastures support the world's largest (212 M head) commercial cattle herd (IBGE, 2015), which makes Brazil the second largest beef producer and exporter in the world.

Most of Brazil's tropical soils are weathered with low nutrient availability (especially P), medium to high acidity (H^+ and Al^{3+}), and low organic matter content. Therefore, and because of the amount of land devoted to grain production, the country is the world's fourth largest fertilizer consumer with about 32 M t of fertilizer products used in 2015. But according to the National Fertilizer Association (ANDA, 2015), only 1.5% of that amount is designated to pasture land, while soybeans, maize, sugarcane, coffee, and cotton consume 91% of the total.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum; H^+ = hydrogen ion; BMP = best management practice; US$1 = R$3.2 (Brazilian Real).

Brazil's average stocking rate is about 1 head per ha. In terms of actual land use, this is a very inefficient livestock system that can be improved by BMPs including soil amelioration (correcting acidity and increasing nutrient availability) and better grazing methods.

Why don't livestock farmers apply fertilizer to their fields? Cunha (2013) lists the following four reasons: 1) tropical grasses have a low nutrient requirement, 2) famers rarely associate low biomass production with low soil fertility and don't usually perceive a return from fertilizer, 3) livestock systems have poor grazing efficiency, and 4) technical assistance is scarce.

Recommendations

Multiple species of *Brachiaria* grass dominate the great majority of forages used in Brazilian pastures. Some of these grasses are commonly known to be tolerant to soil acidity and to have a relatively low nutrient requirement. Despite such characteristics, *Brachiaria* grasses do respond positively to liming and fertilizer application, as demonstrated by several studies.

Figure 1 shows dry matter yield of *Brachiaria decumbens*

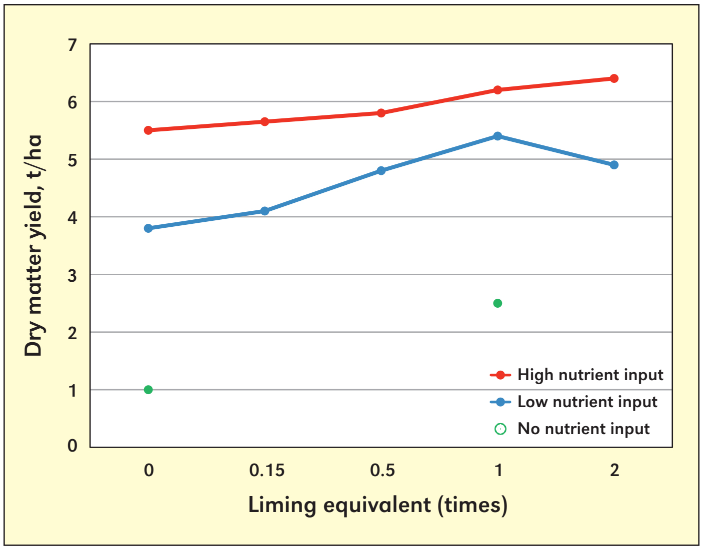

Figure 1. Dry matter yield of *Brachiaria decumbens* in response to liming and nutrient application. Adapted by Barcelos et al. (2011).

Table 1. Dry matter yield of *Brachiaria brizantha* cv. Marandu in response to phosphogypsum application.

	Dry matter yield, t/ha	
Phosphogypsum rate, kg/ha	Year 1	Year 2
0	3.4	5.8
200	4.2	8.7
1,500	4.5	9.7

Source: Souza et al. (2011).

Table 2. Phosphorus and potassium recommendations for the establishment and maintenance of pastures in the Cerrado, based on soil analysis and nutrient demand of plants or level of technology adoption.

Level of nutrient demand or technology adoption	- - - Soil P[1] - - -				- - - Soil K - - -		
	Very low	Low	Medium	Optimum	Low	Medium	Optimum
	- - - P_2O_5, kg/ha[2] - - -				- - - K_2O, kg/ha - - -		
	Establishment[3]						
Low (<1 AU[5]/ha)	40-120	30-90	20-60	0	20	0	0
Medium (1-3 AU/ha)	70-180	55-135	35-90	0	40	20	0
High (3-7 AU/ha)	80-240	50-150	40-120	0	60	30	0
	Maintenance[4]						
Low (<1 AU/ha)	-	15-40	0	0	40	0	0
Medium (1-3 AU/ha)	-	20-50	15-30	0	100	40	0
High (3-7 AU/ha)	-	30-60	15-40	0	200	100	0

[1]Interpretation of P-Mehlich availability depends on soil clay content.
[2]Rates of P_2O_5 varies according to soil clay content in direct relation.
[3]Soluble sources of P are recommended in furrow or broadcast plus incorporation. Potassium application can be broadcasted.
[4]Single broadcast application in the beginning of rainy season for P and K (<40 kg K_2O/ha). Split broadcast applications with 30 day intervals for K_2O rates >40 kg K_2O/ha.
[5]Animal unit: 454 kg cow.
Source: Vilela et al. (2004) and Cantarutti et al. (1999).

Table 3. Dry matter yield of *Brachiaria decumbens* in response to N and P rates.

	- - - N rate, kg/ha - - -			
P_2O_5 rate, kg/ha	0	75	150	300
0	3.4	-	-	-
60	3.4	8.1	10	12
120	3.6	8.3	12	15

Source: Lupatini et al. (2010).

in response to liming and levels of nutrient application. Liming reduces Al^{3+} toxicity, provides Ca^{2+} and Mg^{2+}, and increases nutrient use efficiency for subsequent fertilizer applications. According to Vilela et al. (2004), liming recommendations for pastures in the Cerrado region, based on soil base saturation (BS), vary according to species tolerance to soil acidity or low soil fertility: 35% BS for highly tolerant grasses (i.e., *Brachiaria decumbens*, *Brachiaria humidicola*, and *Andropogon* gayanus), 45% BS for moderately tolerant grasses (i.e., *Brachiaria brizantha cv.* Marandu, *Panicum maximum cv.* Vencedor, and *Setaria anceps*), and 55% BS for less tolerant grasses (i.e., *Panicum maximum cv.* Tanzânia, *Panicum maximum cv.* Mombaça, *Pennisetum purpureum*, *Cynodon* spp). The authors also recommend that when the level of Mg is below 0.5 $cmol_c$/kg, a dolomitic type of lime should be used.

Another practice that may be adopted to mitigate subsoil acidity is phosphogypsum application. Phosphogypsum is commonly recommended at 50 kg/ha for each percent clay in the soil. Phosphogypsum will reduce the level of Al^{3+} saturation in the subsoil and provide plant with S in the form of sulfate (SO_4^{2-}). **Table 1** presents two years of results with *Brachiaria brizantha cv.* Marandu in response to phosphogypsum application.

Recommendations for P and K fertilizer rates in Brazil's pastures are based on the nutrient requirement of the grass plus a soil analysis (**Table 2**). In soils low in P, the response to P application may exceed the effect of other nutrients. In some Cerrado soils, P fixation is extreme and creates strong competition between the soil and plant. As a result, liming is a BMP to increase soil P availability and promote its efficient use by plants. As pastures are perennial crops, P application and incorporation is recommended prior to seeding. Phosphorus application is necessary to achieve high dry matter yields in intensified livestock systems (**Table 3**).

Tropical grasses take up high amounts of K, which is

E. Francisco/IPNI Photos

Examples of integration of livestock, cropping, and forestry to achieve better use of pasture lands. (Top to Bottom: *Brachiaria* grass planted with maize, forage grass planted after soybean, forage grass planted with trees).

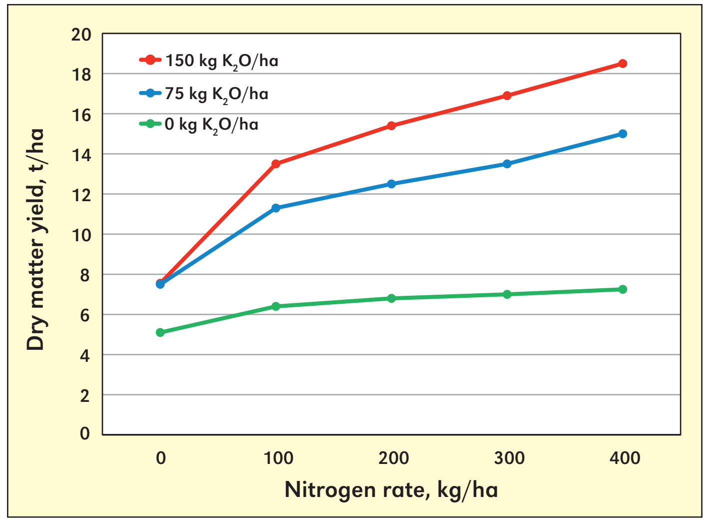

Figure 2. Cumulative dry matter yield of *Brachiaria decumbes* in response to N and K rates. Source: Carvalho et al. (1991).

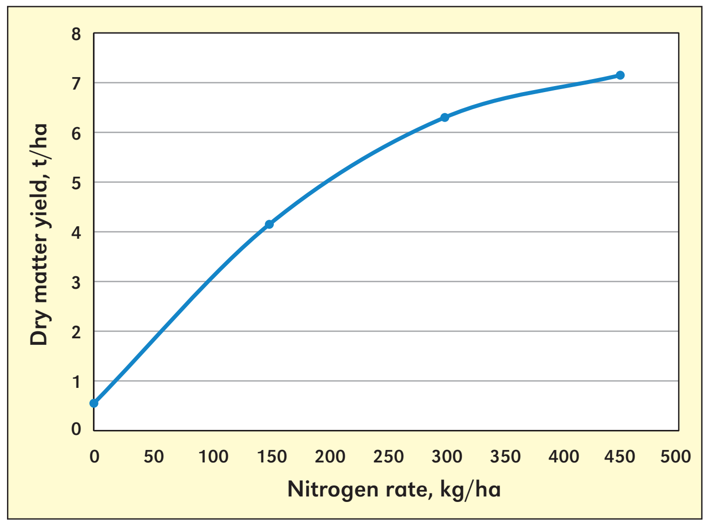

Figure 3. Dry matter yield of *Panicum maximum* in response to N rates. Source: Sarmento (2005).

an important nutrient to control evapotranspiration and sustain the high photosynthetic performance of C4 plant types. In soils low in K, plants struggle to accumulate biomass and the response to any N application is compromised (**Figure 2**).

Nitrogen is a key nutrient to promote biomass production and C4 plants grown in tropical environments are very responsive to N (**Figure 3**).

Rates recommended for N fertilizer will vary widely depending on soil conditions, plant demand, technology adoption by the farm, and irrigation. Vilela et al. (2004) recommended 50 kg N/ha, along with 30 kg S/ha for the establishment of pastures in the Cerrado. Cantarutti et al. (1999) recommended the same amount of N and S for livestock systems using moderate technology, but 100 to 150 kg N/ha in farms using higher technology. For the maintenance of pastures in the Cerrado, Vilela et al. (2004) recommended 100 to 150 kg N/ha for medium-tech farms and 200 kg N/ha in higher-tech farms. These higher N rates are recommended to be split into three applications of at least 50 kg N/ha during the beginning, middle, and end of the rainy season. The authors encourage the use of ammonium nitrate or ammonium sulfate to avoid

Table 4. Nitrogen requirement considering the impact of faming management on N use efficiency (NUE) and grazing efficiency (GE).

Farming management	NUE, kg DM[1]/kg N	GE, %	N requirement, kg N/AU[2]
Very bad	<30	<40	170
Bad	30-35	40-45	130
Medium	35-40	45-50	100
Good	40-45	50-55	85
Very good	45-50	55-60	70
Excellent	>50	>60	60

[1]Dry matter yield.
[2]Animal unit: 454 kg cow.
Source: Martha Junior et al. (2004).

potential N losses due to volatilization. Urea may be used if soil and weather conditions are monitored to ensure adequate soil moisture, mild temperatures, and an application just prior to a rain when possible. For highly intensive livestock systems, N rates may also be adjusted according to other parameters (i.e., grazing efficiency, level of farm management) as is suggested in **Table 4**.

Benefits

Despite the low efficiency of most of the livestock farming systems in Brazil due to very low stocking rates, some farmers are showing impressive beef yields with the adoption of new techniques and technology (e.g., correctly managing grazing harvest, investing in improved animal genetics, and applying fertilizers to increase soil fertility to sustain high biomass production). **Table 5** shows a successful farm in the state of Mato Grosso do Sul that achieved high beef productivity by significantly increasing stocking rates compared to the state's average, and other low-tech farms.

Regions of Brazil are also successfully integrating their livestock production with annual crop or tree production systems. For example, *Brachiaria* can be established along with maize (second crop) in the Cerrado. The strategy results in a well-established forage grass soon after maize harvest. Similarly, grasses are grown as a second crop after soybean and are grazed for five months before the next cropping season; or are grown along with tree species where annual crops are no longer in the system.

Summary

There are many ways to improve the efficiency of livestock farming systems, including the use of fertilizers to correct soil nutrient deficiencies. Brazil's beef productivity will have to increase with time, which means pasture lands must be managed better. Livestock producers face the economic choice to either decide to stay in business, or concede to the increasing pressure to convert more land into grain production. Certainly, the use of nutrients associated with best management practices is a profitable path for livestock producers.

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Table 5. Comparison of livestock farming systems in the state of Mato Grosso do Sul, Brazil.

System[1]	DM yield, t/ha/yr	Stocking rate, kg/ha	Stocking rate, heads/ha	ADG[2], kg/day	Beef yield, kg/ha/year	Total cost, R$/kg	Operating profit, R$/ha/year
State	unknown	400	1.30	0.35	82.9	3.38	216
Low-tech	4.3	380	1.24	0.46	118.0	3.50	295
High-tech	38.1	3,720	10.7	0.62	1,287	3.22	3,559

[1]Systems: State average, low input of technology, high input of technology (liming, fertilizer application, and irrigation).
[2]Average daily gain of weight.
Source: Adapted from Aguiar (2015).

The Overlooked Plant Nutrient?

It's well understood that plants require the right combination of the 14 essential mineral nutrients to sustain their growth. However, it frequently seems like just a few of the nutrients get most of the attention due to their cost or their environmental impacts. Potassium is too often overlooked as a key component in every successful farming operation.

The upcoming Frontiers of Potassium Science conference will take a close look at all aspects of potassium behavior in soils and plants, and how to improve potash fertilizer management.

Potassium is an essential mineral that is deficient in most human diets. Since potassium is not stored in the body, it must be regularly replaced by eating potassium-rich foods. Farmers often fail to account for the nutritional value of the food they produce.

Potassium is also essential for plant health and there must be a continual supply in the soil to obtain desired yields. The emphasis on agricultural intensification requires answers on how potassium management differs in diverse cropping systems and growing conditions.

When the potassium supply is limited, plants have reduced yields, poor quality, utilize water less efficiently, and are more susceptible to pest and disease damage. However, accurately predicting which soils require additional potassium and how crops will respond to added fertilizer is not simple. The selection of a particular fertilizer and where to put it for maximum efficiency is not always easy to determine. The extent of global potash resources needs to be regularly surveyed to ensure an uninterrupted supply.

Ultimately, the purpose of gathering the world-leading potassium scientists is not complete until theory gets transferred to the farmer. This conference serves as the kick-off for a comprehensive book, video presentations, regional agronomy meetings, and practical educational material that includes field-ready advice.

A closer look at potassium in agriculture is certainly overdue. I hope you will join IPNI in taking a closer look at this neglected nutrient in the years to come.

Rob Mikkelsen

Robert L. Mikkelsen
IPNI Vice President of Communications
& North American Program Director

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