Better Crops with plant food

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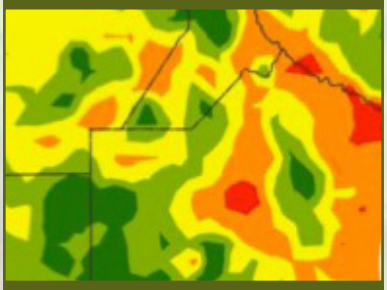
How Can Soil P Balance Influence Soil Test P? A case study from the Argentinian Pampas

In This Issue:



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Better Crops with plant food

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Our cover: Soybean planted into wheat residue, Argentinian Pampas.
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IPNI thanks the Government of Saskatchewan for their support of this publication through its resource tax funding.

IPNI Scholar Award Recipients - 2018

IPNI has selected the winners of its annual Scholar Award Program. In 2018, 31 graduate students representing 11 countries, were chosen. Each winner receives the equivalent of US$2,000.

"Every year we assemble a very impressive group of scholars from across the globe," said Dr. Terry L. Roberts, IPNI President. "Each individual selected should be very proud of this accomplishment. They are already contributing greatly to the field of plant nutrition," added Roberts.

Graduate students attending a degree-granting institution located in any country within an IPNI 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.

The winners are listed below with their university/institution affiliations and are organized by IPNI Program. **BC**

NORTH & WEST AFRICA

Ms. Boughanem
Algeria

Mr. Agbodan
Togo

Ms. Wassila Boughanem, Djilali Bounaama University, Khemiss Meliana, Algeria, is earning her Ph.D. in crop improvement. Her dissertation title is *"Improving nutrients use efficiency for pulses in symbiotic associations with rhizospheric microorganisms."* Ms. Boughanem's goal is to complete her Ph.D. and then join her university as a scientist/professor to continue to improve her knowledge and skills in the agricultural field.

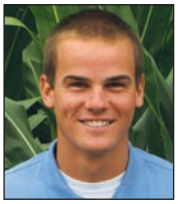
Mr. Kodjovi Mawuégnigan Léonard Agbodan, University of Lomé, Lomé, Togo, is working towards his Ph.D. in plant conservation biology. His dissertation title is *"Characterization of soil fertility by bio-indicator plants in southern Togo."* Mr. Agbodan's research will enable farmers to identify through bio-indicator plants the initial fertility of the soil, which will help guide their choice of fertilizer to assist in boosting food production. After his Ph.D., he would like to pursue post-doctoral research in agronomy with the aim of identifying the fertilizer doses to be applied to each type of soil and crops.

EAST & SOUTHERN AFRICA

Ms. Moreblessing Chimweta, Bindura University of Science Education, Bindura, Zimbabwe, is earning her Ph.D. in flood-recession cropping. Her dissertation title is *"Optimizing maize yield under flood-recession cropping in the Zambezi valley floodplains, northern Zimbabwe."* One of her research objectives is to study plant available nitrogen dynamics during the flood-recession cropping season. Following her Ph.D., Ms. Chimweta looks forward to being a renowned scientist in sustainable agriculture for ensured prolonged food security.

Ms. Chimweta
Zimbabwe

NORTH AMERICA



Mr. Bernhard
United States

Ms. Croat
United States

Ms. de Oliveira Silva
United States

Ms. Olmedo Pico
United States

Mr. Ortez
United States

Mr. Brad Bernhard, University of Illinois at Urbana-Champaign, United States, is working towards his Ph.D. in crop sciences. His dissertation title is *"Nitrogen and phosphorus management to increase nutrient use efficiency and corn grain yield."* Mr. Bernhard's work focuses on nitrogen and phosphorus management in corn (maize) using the best management practices approach to obtain the greatest yields. Following his Ph.D., he wants to pursue and promote the best

NORTH AMERICA continued

management practices to producers, equipment manufacturers, and fertilizer companies so they can persist in their quest to feed the world sustainably.

Ms. Samantha Croat, North Dakota State University, United States, is earning her M.Sc. in soil science. Her thesis title is *"Phosphorus dynamics and crop productivity in Bakken crude-oil remediated soils."* Ms. Croat's research centers around phosphorus behavior in soils treated by the remediation method known as thermal desorption. Following her M.Sc., she plans to pursue a career in soil science consulting.

Ms. Amanda de Oliveira Silva, Kansas State University, United States, is earning her Ph.D. in Agronomy with emphasis on crop physiology, plant nutrition, and soil fertility. Her dissertation title is *"Impacts of management practices on yield and nutrient use efficiency in modern winter wheat genotypes."* Ms. de Oliveira Silva's research provides detailed plant nutrient evaluation throughout the entire season in various environments at various inputs, and investigated ways to increase nutrient use efficiency while alleviating environmental pollution through appropriate fertilizer management. After her Ph.D., her goal is to continue developing research investigating environmental and biological factors impacting yield and nutrient use efficiency.

Ms. Lia Belen Olmedo Pico, Purdue University, United States, is working towards her Ph.D. in crop physiology. Her dissertation title is *"Nitrogen management effects on potential kernel weight determination in maize: underlying mechanisms of yield responses."* Ms. Olmedo Pico's research focuses on studying the physiological mechanisms behind potential kernel weight determination in maize as affected by nitrogen availability. After finishing her Ph.D., she plans to return to northern Argentina to work for the National Institute of Agricultural Technology (INTA) where she would like to become a crop physiology researcher focused on abiotic stresses.

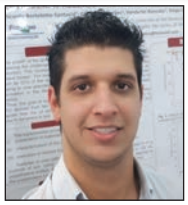
Mr. Osler Ortez, University of Nebraska-Lincoln, United States, completed his Master's degree in agronomy at Kansas State University where his thesis title was *"Study of nitrogen limitation and seed nitrogen sources for historical and modern genotypes in soybean."* Afterward, he started his Ph.D. in agronomy and crop production at the University of Nebraska-Lincoln where his research focuses on identifying and isolating factors responsible for ear formation issues and yield losses in corn, which became a regional concern in recent years. After completing his Ph.D., Mr. Ortez plans to work in close collaboration with the academy, industry, and community in general, for continuing the study of ways to improve agriculture.

SOUTH AMERICA


Mr. Arata
Argentina


Ms. Girón
Argentina


Mr. Romero
Argentina


Mr. Bortoletto-Santos
Brazil


Mr. Sarfaraz
Brazil


Mr. Saturnino-Pinto
Brazil


Mr. Sattolo
Brazil


Mr. González-Osario
Colombia

Mr. Agustín Francisco Arata, National University of the Center of Buenos Aires Province, Argentina, is working towards his Ph.D. in agricultural sciences at the University of Buenos Aires. His dissertation, *"Changes in the source-sink relationship in post-flowering: effects on composition and grain quality in contrasting wheat genotypes in their allelic profile for prolamins,"* analyzes the effect of variations in assimilate availability during grain filling and their interaction with nitrogen-sulfur fertilization on the industrial quality of Argentine wheat varieties belonging to different quality groups. Results would provide knowledge for the design of fertilization strategies and the selection of genotypes adapted to specific environments, improving the sustainability of production and adding value in the wheat crop. The goals of Mr. Arata are to work in teams related to science, technology, and education in the discipline of crop production for balanced, responsible, and inclusive development.

Ms. Paula Girón, University of Buenos Aires, Argentina, is working towards her M.Sc. in soil science. Her thesis looks at site-specific management of nitrogen in maize at northwestern Buenos Aires province. Ms. Girón's research would contribute to characterize spatial variability effects on nitrogen response and to develop criteria to determine economically

optimum nitrogen rates for maize according to management zones. Her goal is to assist famers and professionals in improving nutrient use efficiency in cropping systems of the Pampas to provide for better profits and reduce environmental impact.

Mr. Juan Ignacio Romero, University of Tucuman, Argentina, is working towards his M.Sc. in agricultural sciences. His thesis title is *"Absorption, partition and extraction of nutrients in rainfed sugarcane and with drip irrigation in Tucumán-Argentina."* Sugarcane is a regional crop of great economic, social, and environmental impact in the provinces of Tucumán, Salta, and Jujuy (Argentina), and this work would evaluate the absorption dynamics and the extraction of macronutrients from the new varieties of sugarcane providing for the definition of 4R nutrient management, specifically right rate and time, for sugarcane. Mr. Romero would like to contribute, through teaching and research, with appropriate recommendations and technologies for improving farmer´s profits and environmental protection.

Mr. Ricardo Bortoletto-Santos, University of São Paulo, Brazil, is working towards his Ph.D. in chemistry with the Brazilian Agricultural Research Corporation (Embrapa Instrumentation). His dissertation title is *"Role of Polymeric Coating on the Nitrogen and Phosphate from Fertilizers: Insight from Nitrogen and Phosphate Release by Castor Polyurethane Coatings."* His research will provide valuable information to understand how different materials used for coating affect the diffusional dynamics of nitrogen and phosphorus in fertilizer granules and their agronomic effectiveness. Mr. Bortoletto-Santos' future goals include completing his Ph.D. and becoming a leading researcher in fertilizer chemistry in an academic position. He plans to be a researcher in the soil fertility and plant nutrition field.

Mr. Qamar Sarfaraz, Federal University of Santa Maria, Santa Maria, Rio Grande do Sul, Brazil, is working towards his Ph.D. in soil fertility and plant nutrition. His dissertation title is *"Examining the carbon and nitrogen turnover from different biochars types."* Mr. Sarfaraz's proposed research will improve the knowledge of the transformation of soil carbon and nitrogen when it is applied in the form of biochar, instead of the traditional application of animal manures and plant residues that are causing environmental pollution and increasing concentration of greenhouse gases in the atmosphere in Southern Brazil. Following his doctoral completion, Mr. Sarfaraz plans to return to his home country (Pakistan) and pursue a career as a researcher at a research institute to contribute to the improvement of nutrient management practices for sustainable agriculture or wants to teach at a university to explore knowledge about plant nutrients management.

Mr. Webert Saturnino-Pinto, the Federal University of Viçosa, Brazil, is working towards his D.Sc. in soils and plant nutrition. His dissertation title is *"Soil availability, accumulation, and kinetics of zinc uptake in corn."* Mr. Saturnino-Pinto hopes his project will help with reducing zinc hidden hunger due to corn being the model plant and its use as an important global staple food crop. Following his dissertation, he plans to become a researcher and hopes to be able to make a significant contribution to science for the well-being of society.

Mr. Thales Sattolo, University of São Paulo, Brazil, is working on a Ph.D. in soil fertility. Mr. Sattolo obtained his M.Sc. at the College of Agriculture "Luiz de Queiroz", Univeristy of São Paulo (ESALQ/USP). His dissertation, under supervision of Professor Rafael Otto, is on soil carbon and nitrogen dynamics. His work examines the effects of nitrogen fertilization and crop rotation on soil carbon and nitrogen transformations and stocks in soils cropped to soybean, maize, and sugarcane.

Mr. Hernán González-Osario, Universidad Nacional de Colombia, Colombia, is working on a Ph.D. in biotechnology. His dissertation, *"Biotechnological alternatives to improve phosphorus supply in coffee",* focuses on the use of native microbes and flora to increase the efficiency of phosphorus uptake for coffee in multiple regions of Colombia. Mr. González-Osario has keen interest in advancing more research on the role of mycorhizae in phosphorus uptake and to combine this knowledge with the best recommendations of fertilizers to boost yields and quality of coffee.

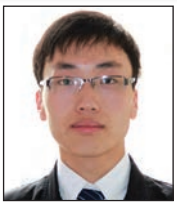
Funding for the scholar award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

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

CHINA


Mr. Cai
China

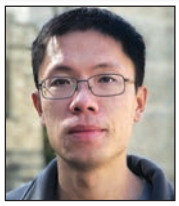

Mr. Guo
China


Mr. Ma
China


Mr. Riaz
China


Mr. Tang
China


Mr. Yang
China


Mr. Yao
China


Ms. Zhang
China

Mr. Zejiang Cai, Chinese Academy of Agricultural Sciences, China, is earning his Ph.D. in soil science. His dissertation title is *"Effectiveness and mechanisms of organic materials in ameliorating red soil acidification from chemical nitrogen fertilizer."* Mr. Cai's research focus is based on the need for a better understanding of the process, mechanisms, and the quantity needed for animal manure and crops straws to be effective to alleviate soil acidification process. Following his Ph.D., he plans to become a leading professional to make important contributions to developing sustainable agricultural productions systems.

Mr. Junjie Guo, Nanjing Agricultural University, China, is earning his Ph.D. in plant nutrition. His dissertation title is *"Studies on microbiological mechanisms of the effects of fertilization regimes on crop productivity and soil fertility."* Mr. Guo's research mainly focuses on the potential and related mechanisms of increasing soil fertility and crop yield with organic amendments. His career goal is to become an agricultural scientist to maintain soil fertility and improve crop yield.

Mr. Qingxu Ma, Zhejiang University, China, is completing his Ph.D. in plant nutrition. His dissertation title is *"Environment factors regulate soil organic nitrogen bioavailability and its mechanism."* Mr. Ma's research examined the effects of environmental factors such as pH and elevated carbon dioxide concentration on the relative uptake of ammonium, nitrate and amino acids, and the mechanisms associated with the uptake and metabolism of amino acids. Following his graduation, he plans to do a postdoc in the United Kingdom or United States.

Mr. Muhammad Riaz, Huazhong Agricultural University, China, is working towards his Ph.D. in plant nutrition. His dissertation title is *"Boron supply develop tolerance to aluminum-induced inhibition of root growth in trifoliate orange."* Mr. Riaz's research will explain how boron (micronutrient) is useful for plant growth, its related mechanisms and the role of boron in the alleviation of aluminum-induced inhibition of root growth. After his Ph.D., he would like to continue his postdoctoral research.

Mr. Zheren Tang, Fudan University, China, is earning his Ph.D. in environmental engineering. Mr. Tang's M.Sc. thesis involved an application study using a bio-mineral composite material in agricultural waste composting. Following his Ph.D., Mr. Tang plants to join the public welfare department in an international organization to help solve the problems of hunger, poverty, health, and education in less developed countries or regions.

Mr. Xiao Yang, Shanghai Jiao Tong University, China, is working towards his Ph.D. in horticulture. His dissertation title is *"Effect of glycine nitrogen on polyphenol biosynthesis and antioxidant activity in lettuce."* In this research study, glycine was used as a model nutrient of organic nitrogen and different concentrations of exogenous glycine nitrogen were added to examine the metabolic and physiological responses in lettuce's perspective. Mr. Yang's career goal is to become an agricultural scientist in the near future.

Mr. Zhiyuan Yao, Northwest Agriculture and Forestry University, China, is earning his Ph.D. in plant nutrition. The title of his dissertation is *"Effects of legume green manure incorporation on the environment of dryland wheat field in the Loess Plateau."* Mr. Yao chose this topic because it focuses not only on the challenge of closing the yield gap, but how the environmental impact of crop production should also be mitigated to propel the sustainable development of agriculture. After completing his Ph.D., he hopes to continue his research topic and further study possible ways for sustainable agriculture.

Ms. Jiajia Zhang, Chinese Academy of Agricultural Sciences, China, is working towards her Ph.D. in plant nutrition. Her dissertation title is *"Study on the recommended fertilization based on yield response and agronomy efficiency and limitation standards for root vegetables."* Her project included published literature and field experiments conducted with her research team that were used to determine yield response, agronomic efficiency, and soil indigenous nutrient supply in the main radish production areas in China and analyze the interrelationships among them. Ms. Zhang plans to contribute to agricultural development in China and become an expert agriculturist.

SOUTH ASIA


Mr. Didal
India


Mr. Praharaj
India


Ms. Rani
India


Mr. Sarkar
India


Ms. Thakur
India


Mr. Ishfaq
Pakistan

Mr. Vijay Kumar Didal, the Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana, India, is working towards his Ph.D. in agronomy. His dissertation title is *"Enhancing nitrogen use efficiency in different establishment methods of rice (Oryza sativa L.)."* Mr. Didal's research work focused on the application of the right dose of nutrients, as per the guidance of Nutrient Expert and recommended dose of fertilizer, with neem-coated urea and vermicompost in different establishment methods of rice (normal transplanting and mechanized system of rice intensification). Following his Ph.D., he wants to pursue postdoctoral research and continue research in the areas of enhancing nutrient use efficiency and biofortification for producing nutrient-enriched crops through the adoption of 4R practices.

Mr. Subhashisa Praharaj, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India, is working towards his Ph.D. in agronomy. His dissertation title is *"Agronomic biofortification of bread wheat (Triticum aestivum L.) with zinc."* His research is focused on alleviating the malnutrition problem (induced by zinc deficiency) through the agronomic biofortification approach. Mr. Praharaj would like to be actively engaged in research to further find solutions for addressing micronutrient malnutrition problems, especially in developing countries.

Ms. Sarita Rani, CCS Haryana Agricultural University, Hisar, Haryana, India, is earning her Ph.D. in agronomy. Her dissertation title is *"Integrated nutrient management for pearl millet-wheat cropping system under saline conditions."* One of the objectives of her research is to study the effect of different integrated nutrient management treatments on growth, yield attributes, yield, and quality parameters of pearl millet-wheat cropping system under saline conditions. After completing her Ph.D., she would like to join Agriculture Research Services and assist her country in developing new technologies.

Mr. Sukamal Sarkar, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India, is working towards his Ph.D. in crop husbandry. His dissertation title is *"Cropping system intensification through inclusion of pulses in rice-based system in the salt-affected coastal zone of West Bengal."* One of the major themes of his Ph.D. is optimizing the sowing date of rice for escaping inundation during initial growth. Mr. Sarkar's continued interest is in developing climate resistant rice based cropping systems, through the reorientation of the crop calendar and inclusion of pulses in coastal saline zone of West Bengal.

Ms. Jagriti Thakur, Dr. YS Parmar University of Horticulture & Forestry, Solan, Himachal Pradesh, India, is earning her Ph.D. in soil science. Her dissertation title is *"Standardization of irrigation and fertigation schedules for apple under high density plantation."* One of the objectives of Ms. Thakur's research is to determine the optimum irrigation schedule and fertilizer level for fertigation of high-density apple. Following her Ph.D., she would like to render her services as a global competent soil conservationist and help people to think about environmental stewardship and ecosystem sustainability.

Mr. Muhammad Ishfaq, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan, is earning his Ph.D. in soil science. His dissertation title is *"Soil-potassium dynamics-based fertilizer recommendations in three alluvial soils differing in clay content."* One of Mr. Ishfaq's research objectives is to develop precise and site-specific potassium recommendation for different regions of Pakistan. He plans to develop himself as a productive researcher, who can contribute to soil sustainability and food security related challenges.

EASTERN EUROPE & CENTRAL ASIA


Mr. Timokhin
Russia

Mr. Artyom Timokhin, Omsk State Agrarian University, Russia, is working on his M.Sc. at the Faculty of Agrochemistry, Soil Science, Ecology and Environmental Engineering. His research centers around the *"Influence of Various Nutritional Conditions on Productivity and Quality of Leguminous Seeds."* Artyom is an author and co-author of more than 35 publications. He has participated in many seminars, international conferences and competitions on legume and oilseed crops and soil fertility management. He is looking forward to earn his M.Sc. and to continue research activities on the maintenance of soil fertility, crop nutrition, and protein concentrations in food and forage crops.

Connecting Crop Nutrient Use Efficiency to Future Soil Productivity

By Fernando O. García, Andrés Grasso, María Fernanda González Sanjuan, Adrián Correndo, and Fernando Salvagiotti

Argentina has seen significant change in its grain crop production over the past 25 years. Global demand for food, feed, fiber, and biofuels since the 1990s has driven a strong (3.7 times) increase in grain production. However, this growth has been mainly achieved by the country's expansion of planted area (especially soybean) rather than yield improvement (**Figure 1**).

Fertilizer use in Argentina has been low historically, but it has increased sharply from 360,000 t in 1993 to 3.6 million (M) t in 2017 (**Figure 2**). The trends show a steady increase up to 2007, followed by a slow down between 2008 and 2015, and then an apparent recovery in 2016-17. This evolution in fertilizer consumption has been related to area expansion, fertilizer and grain prices, and also governmental policies. Field crop fertilization (i.e., soybean, maize, wheat, sunflower, barley, and sorghum) accounts for about 80% of Argentina's total fertilizer use—the current average is 75 kg fertilizer product per ha.

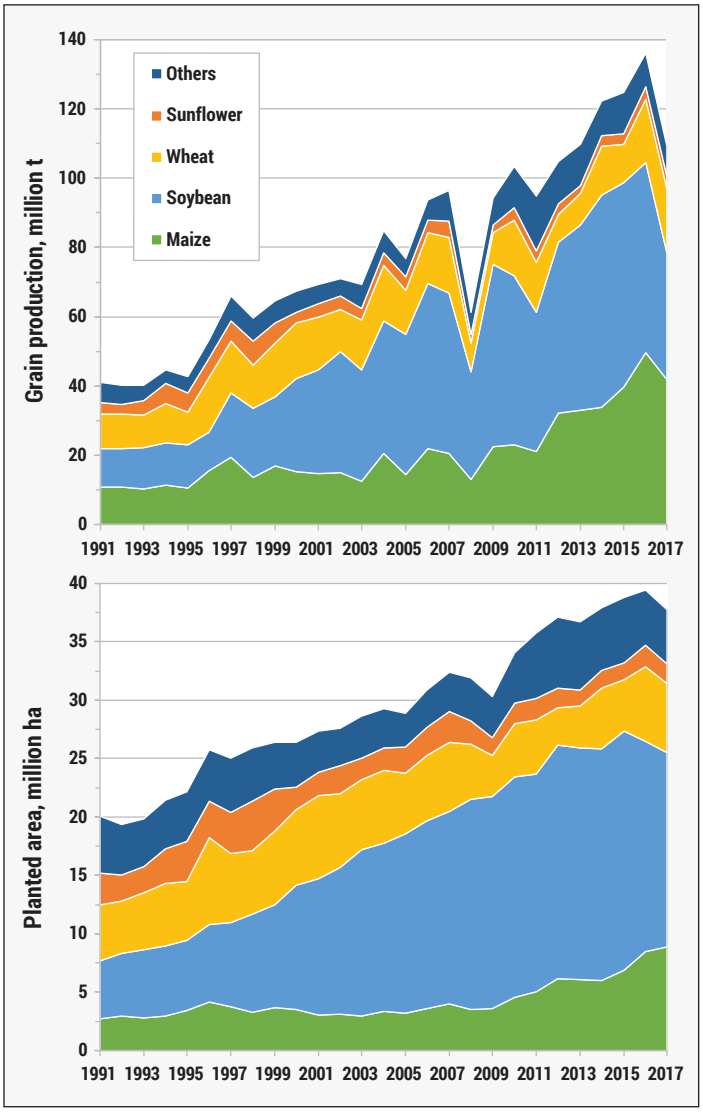


Figure 1. Grain production (top) and area planted (bottom) in Argentina (1991 to 2017). FAOSTAT-MinAgro.

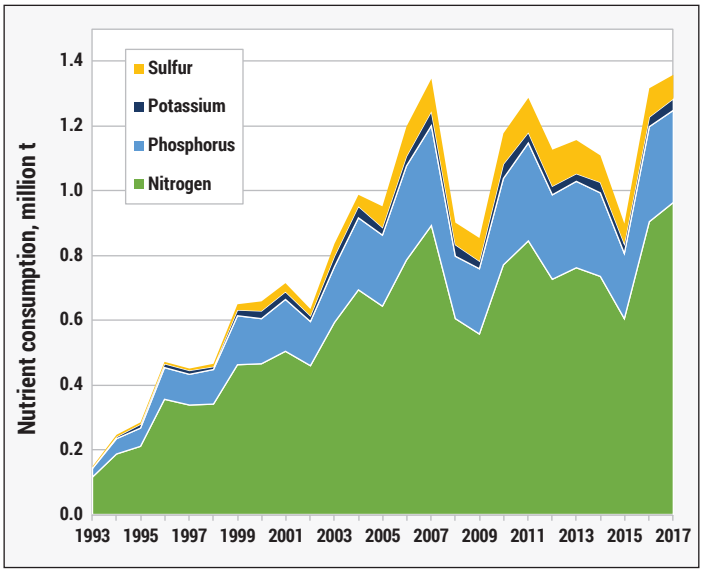


Figure 2. Fertilizer consumption in Argentina (1993 to 2017). MinAgro and Fertilizar Civil Association.

This significant growth in fertilizer use has improved nutrient budgets for field crops somewhat, but they are still far from reaching levels considered sustainable. Removal of N, P, K, and S by grains from 1990 to 2016 was estimated at 26.6, 7.7, 18.6, and 4.1 M t, respectively. During this same time period, the application of N, P, K, and S in these crops amounted to only 40%, 48%, <1%, and 26% of these nutrient removals.

Values for the nutrient use efficiency index referred to as partial nutrient balance (PNB, removal-to-use ratio) also

SUMMARY

Trends over the past 25 years indicate that Argentina's growth in its grain crop productivity has largely been supported by the depletion of the extensive fertility of its Pampean soils. Long-term research provides insight into sustainable nutrient management strategies ready for wide-scale adoption.

KEYWORDS:

Bray P; organic matter; nutrient use; sustainability; on-farm experiments.

ABBREVIATIONS AND NOTES:

N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Grains included soybean and sunflower, as well as cereals (wheat, maize, sorghum and barley).

IPNI Project ARG-12

http://doi.org/10.24047/BC10248

Table 1. Accumulated grain yield and net profit after 12 years of experimentation at five field experiments in the central Pampas. Source: CREA Southern Santa Fe-IPNI-Nutrien Ag Solutions.

Site	Crop rotation	Accumulated grain yield, kg/ha		
		Check	NPS	US$/ha/yr
Balducchi	Maize-Wheat/Double-cropped soybean	57,670	127,750	370
San Alfredo		91,130	143,125	210
La Blanca	Maize-Soybean-Wheat/Double-cropped soybean	73,505	109,750	160
La Hansa		54,220	93,925	180
Lambare		88,640	112,075	80

Check = zero application; NPS = N at 90 to 175 kg/ha for maize or wheat, depending on crop yield; and P and S rates as crop removal plus 5 to 10%.

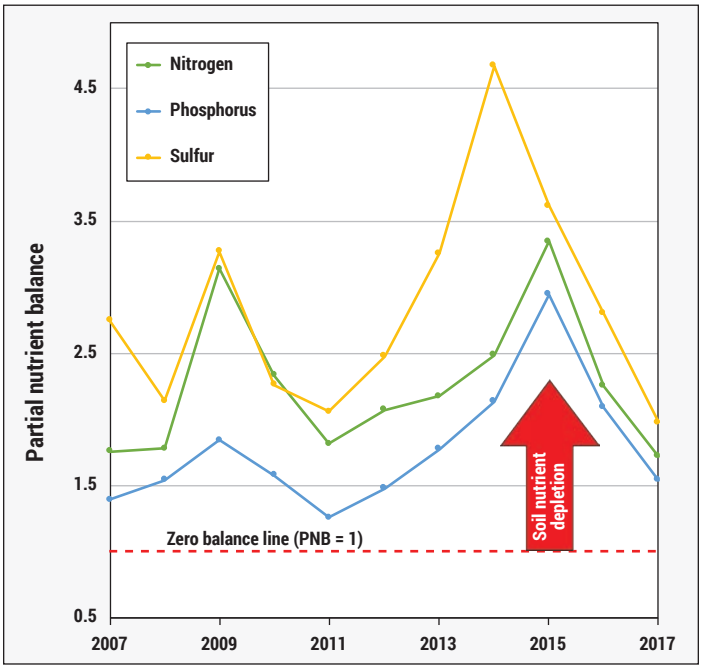


Figure 3. Partial nutrient balance of N, P, and S, for the main grain crops of Argentina (2007 to 2017). Note: For PNB of N, 60% of total soybean N uptake was attributed to biological N fixation.

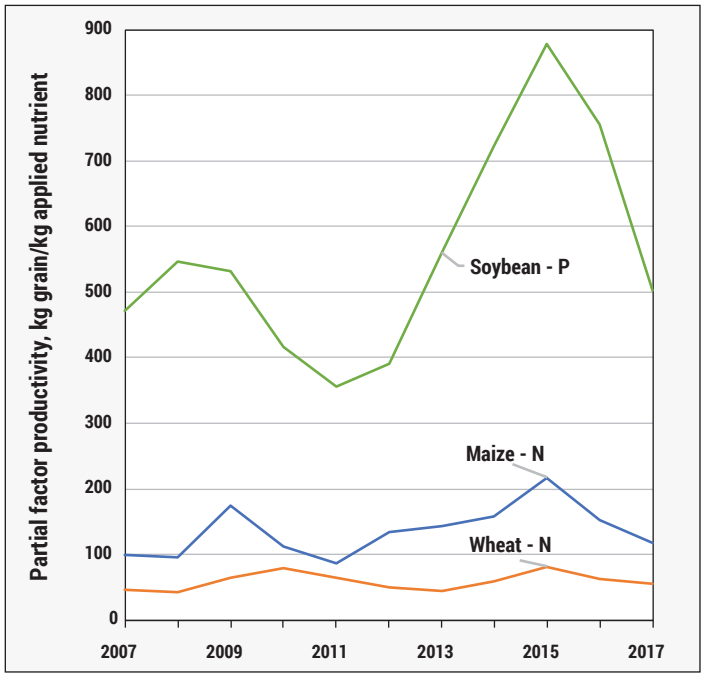


Figure 4. Partial factor productivity of N (maize and wheat), and P (soybean) in Argentina (2007 to 2017).

point to soil nutrient depletion for grains grown between 2007 and 2017, when periods of lower fertilizer use (**Figure 2**) correspond to more intensive removal (**Figure 3**). Partial factor productivity (PFP, grain yield/unit of applied nutrient) values averaged 156 and 74 kg grain per kg N applied in maize and wheat, respectively; and 695, 386, and 265 kg grain/kg P applied in maize, soybean, and wheat, respectively (**Figure 4**).

Net removal of N and P (as well as K and S) with harvested grain comes at the expense of various pools of soil nutrients and a net mineralization of soil organic matter. Accordingly, soil survey maps (**Figure 5**) provide the evidence of progressive deterioration in soil fertility with losses of 30 to 50% for native soil organic matter, and the spread of soils testing low in Bray P (Sainz Rozas, et al. 2011).

All this evidence suggests a need for profitable nutrient application rates that can sustain high crop yields and soil productivity. Long-term on-farm research in the central Pampas by CREA Southern Santa Fe (a farmer´s organization), has shown grain yield increases with balanced NPS fertilization of 27 to 120%, depending on the initial fertility condition of each site (**Table 1**). These responses generated system-sustaining gains between US$80 and US$370/ha/yr. Moreover, balanced NPS fertilization has increased soil organic C by 7%, soil glomalin concentration (indicator of microbial activity) by 23%, and soil microbial respiration by 50% (Ferreras, et al. 2018).

Conclusion

Continued development and implementation of adequate and balanced nutrient management practices will be key for Argentinean to sustain its extensive grain crop production systems. **BC**

Acknowledgement

Summary of the paper presented at the XXVI World Congress of Soil Science. IUSS-SLCS-SBCS. Rio de Janeiro, Brazil, 12-17 August 2018.

Dr. García is Director, IPNI Latin America-Southern Cone Program, Buenos Aires, Argentina (e-mail: fgarcia@ipni.net); Drs. Grasso and González Sanjuan are with Fertilizar Asociación Civil, Buenos Aires, Argentina; Mr. Correndo is with Department of Agronomy, Kansas State University, Manhattan, Kansas; and Dr. Salvagiotti is with EEA INTA Oliveros, Oliveros, Santa Fe, Argentina.

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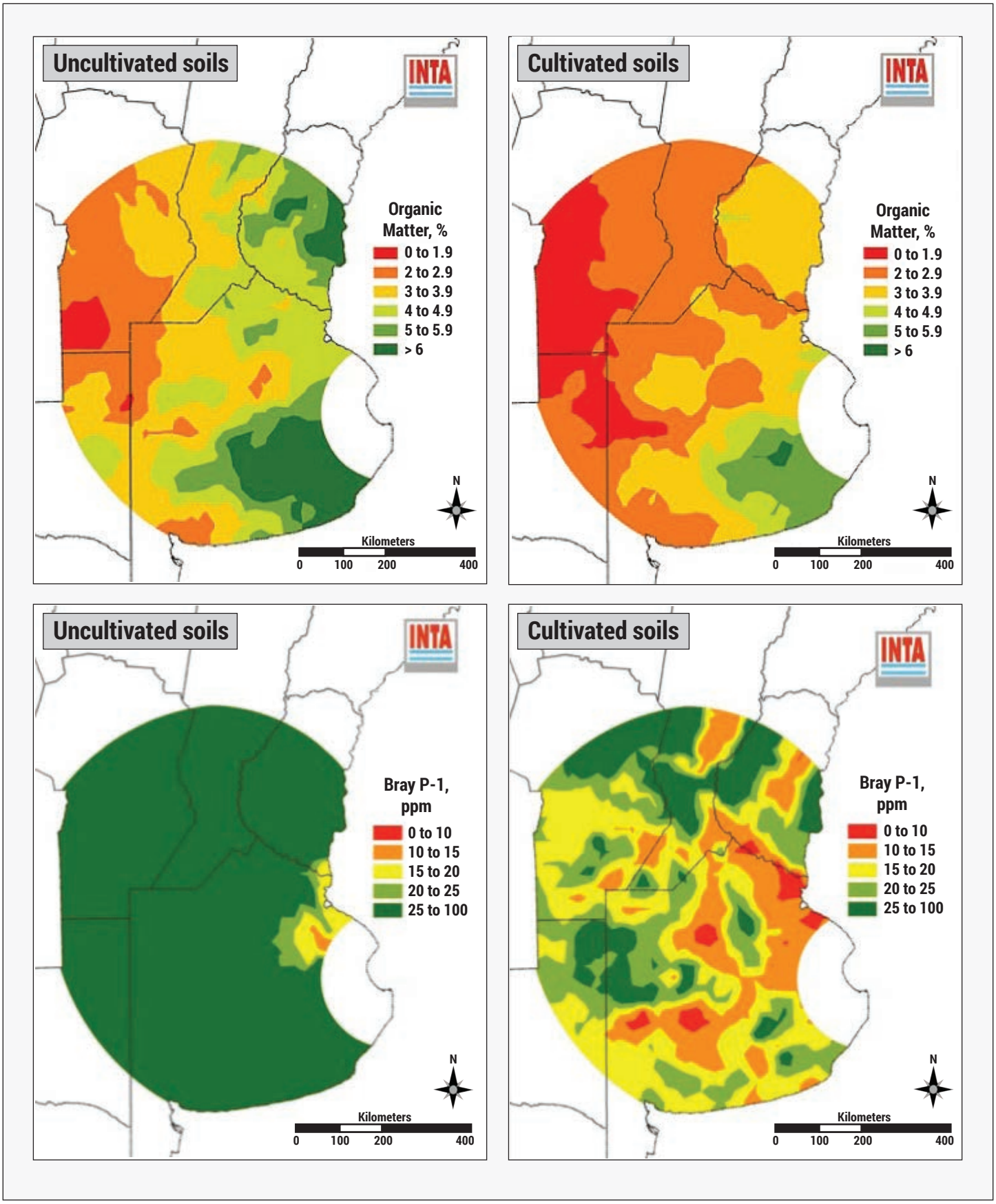
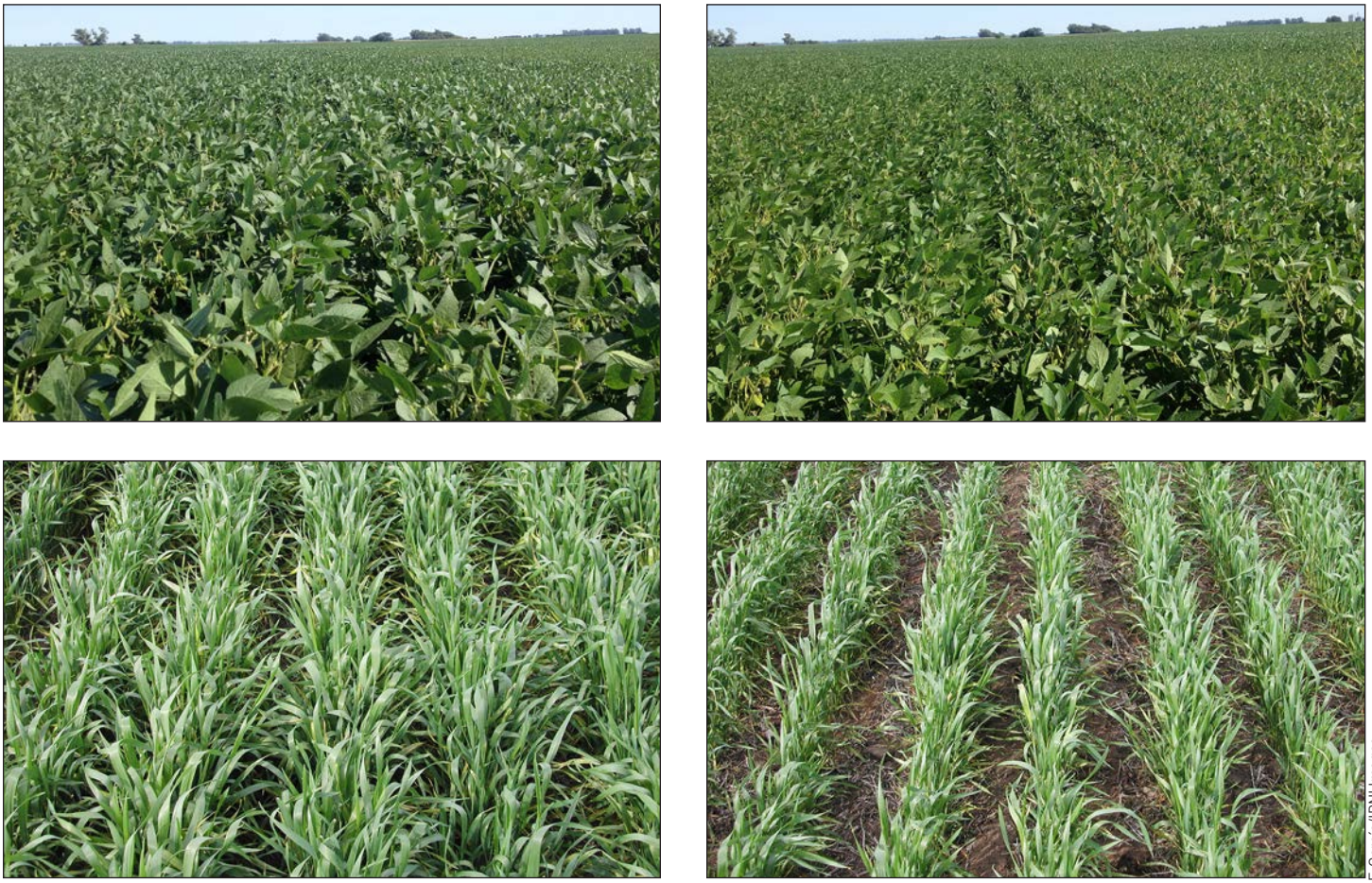


Figure 5. Soil maps comparing organic matter (top) and Bray P (bottom) in uncultivated and cultivated soils of the Pampas region of Argentina. Source: Sainz Rozas, et al. (2011) and Instituto Nacional de Tecnología Agropecuaria (INTA).

How Can Soil P Balance Influence Soil Test P? A case study from the Argentinian Pampas

By Florencia A. Sucunza, Flavio H. Gutiérrez Boem, Fernando O. García, Miguel Boxler, and Gerardo Rubio



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Visual responses to fertilizer P in soybean (Balducchi site) and wheat (La Blanca site). Plots on the left received N+P+S; plots on the right received N+S.

Knowing how soil test P varies with the P balance within a cropping system is a key part of planning P management strategies. Models that predict how soil test P declines once P applications stop, provide useful information about the dynamics of plant-available P, and help determine when to apply more. Models that are conversely able to predict the increase in soil test P under a positive P balance, allow for the identification of maximum P rates, and lessen the risk for environmental pollution.

Most fertilizer P is retained by the soil matrix and only a fraction is absorbed by the target crop. Phosphorus retained in the soil matrix will eventually be available for subsequent crops. The P balance is generally calculated by subtracting the main output (P removed in harvested products: grain, forage) from the main input (fertilizer P or manure P). Due to the strong interaction of phosphates with the soil, the relationship between P balance and soil test P is often not straightforward (Ciampitti et al., 2011). Some reports suggest that the net balance of P in the system is the key factor regulating the dynamics of soil test P. Long-term field ex-

SUMMARY

Data from long-term crop rotation study sites were combined to evaluate the effect of long-term application (and omission) of P fertilizers. The impact of maintaining either a negative or positive P balances on soil test P at five distinct sites was described by single response functions despite a range of differences in soil properties.

KEYWORDS:

Bray P; double-cropping; critical values; depletion; on-farm experiments.

ABBREVIATIONS AND NOTES:

N = nitrogen; P = phosphorus; K = potassium; S = sulfur.

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Table 1. Soil classification, location and properties (0 to 20 cm depth) at the beginning of the experimental period (September, 2000) for the five experimental sites.

Site	Balducchi	San Alfredo	La Blanca	La Hansa	Lambare
Soil	Typic Hapludoll	Typic Argiudoll	Typic Hapludoll	Aquic Argiudoll	Typic Argiudoll
Location	34º09.461`S; 61º36.465`W	33°51′35.57″S; 61°28′7.84″W	33º29.923`S; 62º37.958`W	32º38.405`S; 61º19.967`W	32º 10.236`S; 61º 48.674`W
Bray P, mg/kg	11	12	16	18	68
Organic C, %	1.4	2.0	1.3	1.2	1.9
pH	5.9	6.0	6.6	5.5	5.6
Ca, cmol/kg	8.1	11	7.2	7.6	9.9
Mg, cmol/kg	2.0	2.1	2.0	1.6	3.0
K, cmol/kg	1.4	1.7	1.9	1.7	2.6
Clay, %	12	18	16	18	21
Silt, %	53	62	56	79	76
Sand, %	35	20	28	3	3
Rotation	Bi-annual: maize-wheat/soybean		Tri-annual: maize-soybean-wheat/soybean		

periments arise as the best tool for quantifying the impact of P balance and P fertilization practices on the dynamics of soil test P. This article evaluates the effect of long-term applications of P fertilizers on soil P balance and soil test P.

Study Description

The Pampean region occupies more than 500,000 km^2 in the east central part of Argentina. Around half of the Pampas is dedicated to cereal or oil crops (mainly maize, wheat, and soybean; Rubio et al., 2019). The climate is temperate and the rainfall regime is humid in the east and semi-arid in the west. In 2000, a long-term fertilization study was established by the Southern Santa Fe Regional Consortium of Agricultural Experimentation (CREA), which is comprised of groups of 10 to 15 farmers, located in the southern sector of Santa Fe, southeastern Cordoba, and northern Buenos Aires Provinces in the northern Pampas of Argentina. The experimental sites showed a variation in soil types (Typic Argiudolls or Typic Hapludolls), soil test P (Bray P), and soil management history (**Table 1**). Each site followed one of the following two crop rotations: 1) bi-annual rotation: maize (first year) and double-cropped wheat/soybean (second year); 2) tri-annual rotation: maize (first year); full season soybean (second year), and double-cropped wheat/soybean (third year).

Treatments compared in this research were: 1) a control without P, and 2) continuous P fertilization. The plots were 25 to 30 m wide and 65 to 70 m long. The P rate was decided annually according to the expected crop removal plus 5 to 10% in order to maintain a slightly positive P balance. On average, the annual P rate was 37 kg P/ha. Monoammonium phosphate was the P source and was incorporated at a 5-cm depth before sowing. Nutritional limitations for crop yield other than P were avoided through N and S applications.

Soil P balances were calculated as the difference between P inputs and outputs. Inputs were calculated using the P rate and concentration of the fertilizer applied. Outputs were calculated using crop yields and measured grain P concentrations.

Phosphorus Effects on Crop Yields

Crop yields ranged from adequate to high compared to local standards. Yield (t/ha) for non-fertilized crops ranged between 7.3 to 16 (maize), 3.1 to 6 (full season soybean), 1.7 to 5.2 (double-cropped soybean), and 1.5 to 5.1 (double-cropped wheat). Yields for these fertilized crops ranged between 8.5 to 16, 3.8 to 6, 1.7 to 5.3, and 1.7 to 5.8 t/ha. Wheat was the crop most responsive to P, and P responses for maize and soybean were smaller and somewhat equivalent. As expected, the site with the lowest initial Bray P (Balducchi) had the highest responses to P whereas the site with the highest initial concentration (Lambare) had the lowest P response.

What Happens if P Fertilization is Interrupted?

Differences among soil properties (**Table 1**) were not large enough to affect the dynamics of Bray P in the non-fertilized treatments. In these plots, the rate of Bray P decline was best described by exponential decay functions (**Figure 1**) rather than by linear functions. The equation obtained is

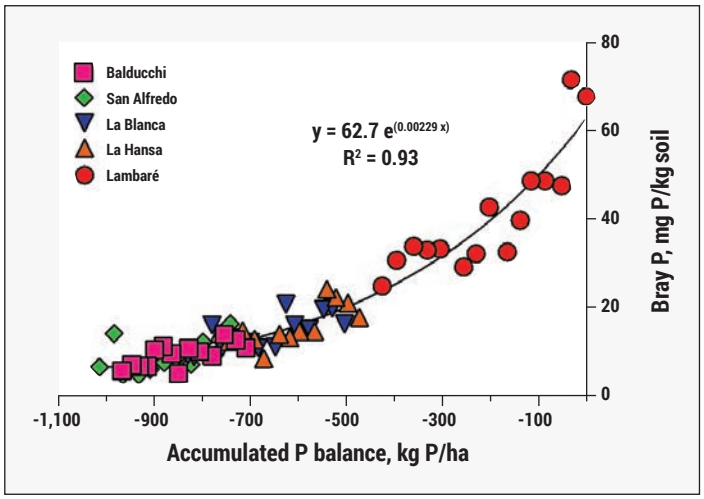

Figure 1. Relationship between Bray P and accumulated P balance for the treatment without P fertilization (control treatment) at five locations of the Northern Pampean Region. The five sites had a common relative rate of decay. In this figure each site was horizontally shifted in order to bring the individual curves into coincidence in a combined curve of Bray P as a function of a modified x-axis (i.e., an extended negative P balance).

appropriate to predict the decline in soil test P after stopping P fertilization. A net extraction of 327 kg P/ha was needed to reduce the initial soil test P values by half regardless of the initial Bray P value of the soil. The ratio of change in Bray P to P removed by the crop increased as initial Bray P values increased, which indicates that soil P pools other than Bray P would have exerted a greater contribution to crop P nutrition in the P-poor soils. This means that a greater proportion of the P taken by the crop came from the soil P reserves (i.e., soil P not recovered by the Bray extractant) at low P concentrations than at high P concentrations. As observed in U.S. soils by Dodd and Mallarino (2005), the decline in Bray P was steeper in P-rich soils and tended to stabilize as the soil became impoverished in P, whereas P-poor soils had slower and somewhat steady declines. The curvilinear decline of extractable P would be associated with the increase in the diffusive flux towards this fraction from other less labile P fractions as the size of the extractable-P pool diminishes.

What Happens if P Fertilizer Rates are Higher than P Exported by Harvested Products?

After 14 years of continuous P fertilization, the progressive accumulation of positive P balances increased Bray P following straight line functions in all sites. No significant differences were found between the fitted slopes for each site, suggesting that the increase in Bray P did not depend on initial Bray-P but on the magnitude of the accumulated positive P balance. The relationship between Bray P and P balance could be described by a simple linear regression model (**Figure 2**). The combined function was plotted on an extended x-axis ranging between 0 to 240 kg of positive P balance and indicated that a positive balance of 3.2 kg P/ha was necessary to increase Bray P by 1 mg/kg. At the end of the experiment, the five sites reached Bray P values above the critical values (12 to 19 mg/kg). This means that fertilization is no longer required to increase profitable yields on these plots. However even in these cases, farmers should not abandon soil testing because it provides key information for soil P fertility and environmental management.

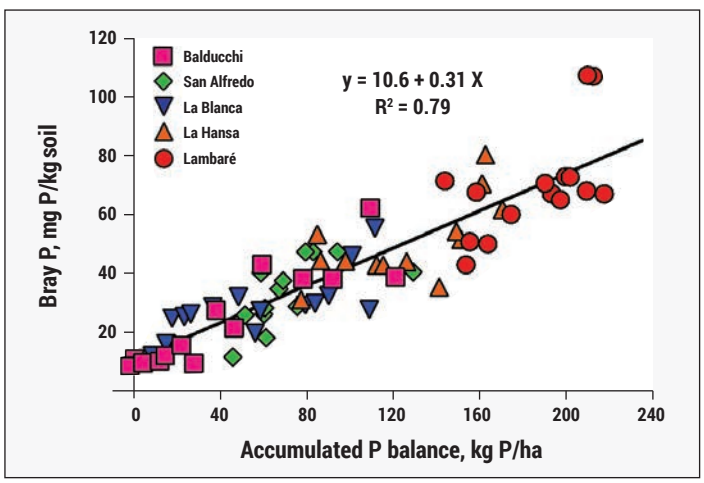

Figure 2. Relationship between Bray P and accumulated P balance for the fertilized treatments at five locations of the Northern Pampean Region. The five sites had a common slope. Each site was horizontally shifted in order to bring the individual lines into coincidence in a combined line of Bray P as a function of the modified x-axis (i.e., an extended positive P balance).

TAKE IT TO THE FIELD

Continued draw-down of soil available P leads to the depletion of more slowly available pools not accounted for by routine soil testing. Even slightly positive P balances maintained over a relatively short time frame can raise soil test P beyond critical values.

Conclusion

The data obtained on rates at which soil P test decreases or increases according to the P balance constitute a useful tool to monitor future changes of soil P concentrations and to estimate the P demand of croplands in Mollisols, and related soil types. It also helps in the planning of strategies that ensure that yields are not constrained by a lack of plant-available P, and the risk of P loss to the environment is minimized. **BC**

Acknowledgments

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IPNI Expands Its African Programs

The International Plant Nutrition Institute (IPNI) has recently expanded its activity in Africa, a move that has established a new program in West Africa and added new agronomic staff to its East and Southern Africa (formerly Sub-Saharan Africa) program. The expansion has been spurred by a grant provided by OCP S.A.

"We are pleased to start this special relationship with OCP S.A., which allows our Institute to better address the needs for research and education throughout the African continent," said Dr. Terry Roberts, IPNI president. "This expanded capacity will be a great complement to our current activities in North (led by Dr. Mohamed El Gharous since 2013) and East and Southern Africa (led by Dr. Shamie Zingore since 2010) and will benefit all IPNI members."

New Program in West Africa

IPNI has established a new West African program, a region covering the countries of Benin, Burkina Faso, Cameroon, Cote D'Ivoire, Gambia, Guinea, Liberia, Mali, Niger, Sierra Leone, and Togo.

Dr. Thérèse Atcham Agneroh has been hired as deputy director of this new program based out of the National Polytechnique Institute Félix Houphouët-Boigny (INP-HB) in Yamoussoukro, Côte d'Ivoire. Dr. Ageroh is currently Associate Professor and Head of the Laboratory of Phytopathology and Plant Biology at INP-HB. She holds M.Sc. and Ph.D. degrees in Phytopathology from the University of Minnesota-Saint Paul, USA. "Dr. Agneroh is an experienced agronomist and educator with a strong background in multidisciplinary research and extension, including working with NGOs and farmers in the Ivory Coast."explained Roberts. "She is fluent in French and well positioned to help IPNI start a program in West Africa."

The West Africa program has also hired Dr. Kokou Adambounou Amouzou as an agronomist. Dr. Amouzou holds a Ph.D. in Agricultural Sciences, which he obtained from University of Bonn, Germany. He has M.Sc. degree in Agricultural Resources and Environmental Engineering from the Ecole Supérieure d'Agronomie, Universitéde Lomé, Togo.

New Deputy Director for East and Southern Africa Program

Dr. James Mutegi was appointed program deputy director for East and Southern Africa based in Nairobi Kenya. Dr. Mutegi has been working for IPNI as a Soil Scientist and Farming System Analyst. He, amongst other responsibilities, coordinated the Soil Health Consortia and the Fertilizer Stakeholder Forum spanning across eight countries in Eastern and Southern Africa for five years. James holds a Ph.D. in Soil Fertility and Climate Change from the University of Aarhus, Denmark and a M.Sc. in Environmental Science from Kenyatta University. He has over 10 years of experience as a scientist and a consultant with national and international institutions in Africa. **BC**

Dr. Thérèse Atcham Agneroh
Deputy Director, IPNI West Africa

Dr. Kokou Amouzou
Agronomist, IPNI West Africa

Dr. James Mutegi
Deputy Director, IPNI East & Southern Africa

Dr. T Scott Murrell
IPNI Potassium Director

IPNI Staff Honored by American Society of Agronomy

Dr. T. Scott Murrell was named a Fellow of the American Society of Agronomy (ASA) — the highest recognition bestowed by the ASA. Dr. Murrell is Director of the Potassium Program for IPNI. In this role, Dr. Murrell provides leadership in on issues related to nutrient management with a focus on potassium. Members of the ASA nominate colleagues based on their professional achievements and meritorious service including outstanding contributions in research, teaching, extension, service, or administration and whether in public, commercial, or private service activities. Up to 0.3 percent of the Society's active and emeritus members may be elected Fellow. Dr. Murrell received his award at the 2018 ASA-CSSA Annual Meetings held in November at Baltimore, Maryland. **BC**

New Edition Available for Popular Fertigation Manual

The widely distributed book on all topics related to fertigation has been recently released in its second edition. The book has now been updated and revised into a complete manual on adding specific nutrients for crop production. The book contains over 250 pages of practical information for dealing with specific water, soil, and crop conditions likely encountered with fertigation.

Fertigation (2nd Edition). 2018. By Charles M Burt.

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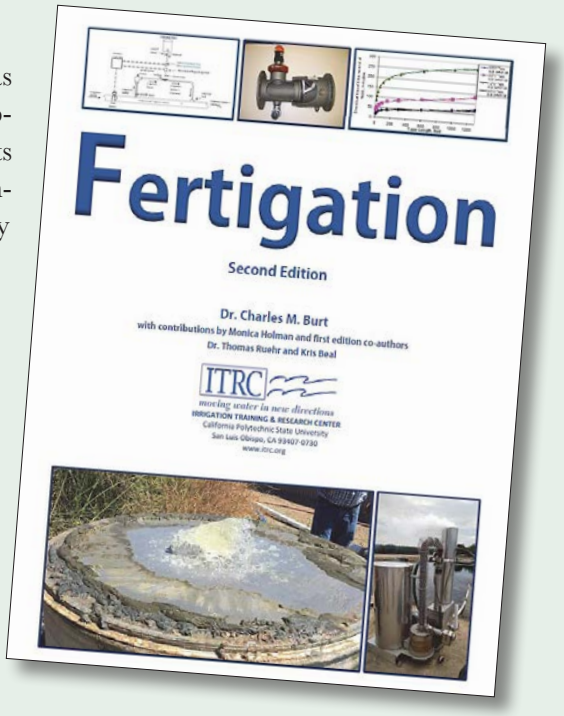

The Identification of Management Strategies that Target Multiple Nitrogen Loss Pathways (Part 3 of 3)

By Tai McClellan Maaz and Cliff Snyder

In the previous two articles, we presented recent research that highlighted the limitations of using N rate as the sole means to calculate N_2O fluxes, and provided source, timing, and placement recommendations to further reduce emissions. Both Omonode et al. (2017) and Eagle et al. (2017) provided evidence that stabilized N sources reduced N_2O emissions in corn production in the North American Midwest. Stabilized N refers to N fertilizers that have been treated with urease and/or nitrification inhibitors. Urease and nitrification inhibitors target different processes in the N cycle (**Figure 1; Table 1**) and therefore temporarily regulate different forms of plant available N and downstream loss pathways. Fertilizers (other than those supplying N in the form of nitrate only) can be treated with urease plus nitrification inhibitors to target multiple loss pathways.

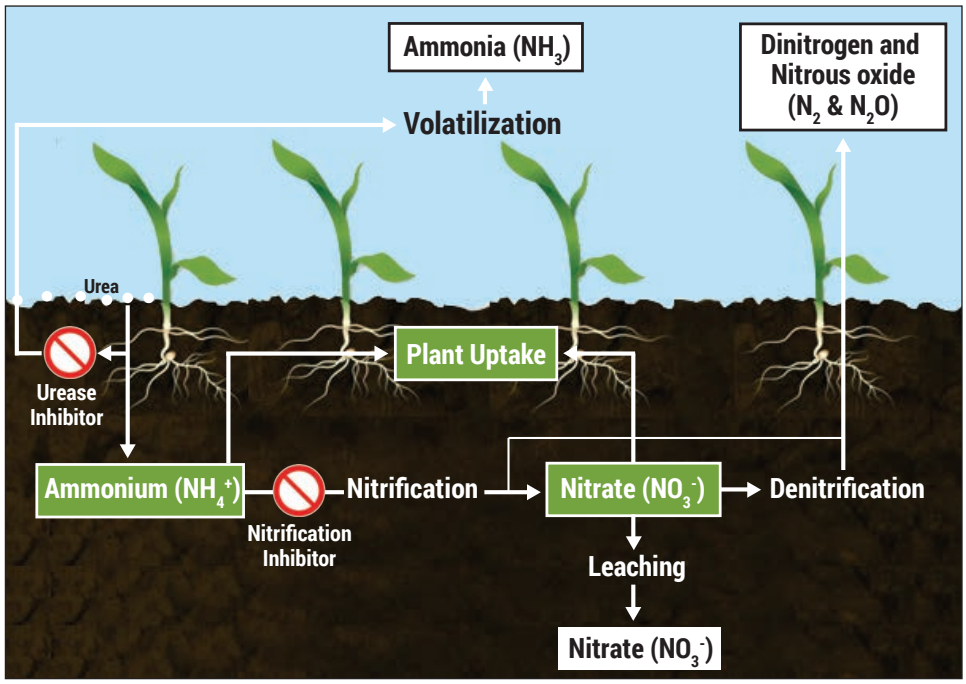

Figure 1. Stabilized urea can contain a urease inhibitor to temporarily prevent ammonia loss via volatilization. Nitrification inhibitors can temporarily prevent rapid conversion of ammonium to nitrate, which in turn is susceptible to loss through leaching and its conversion to gaseous forms of N via denitrification.

In both articles, stabilized N sources reduced N_2O emissions. Omonode et al. (2017) assessed the effect of urease inhibitors with and without nitrification inhibitors, and found 19 to 48% less emission of N_2O. The second paper, by Eagle et al. (2017), examined effects of nitrification in-

Table 1. Modes of action for stabilized N sources.

Stabilized N	Mode of action
Urease inhibitor	Urease inhibitors temporarily block the urease enzyme that is responsible for splitting the urea into NH_3 and CO_2. Therefore, urease inhibitors regulate the pool of plant-available NH_4^+ and can also reduce NH_3 volatilization, which is more likely in soils with high pH, high temperature, and low moisture, particularly for surface-applied urea.
Nitrification inhibitor	Nitrification inhibitors temporarily block the activity of nitrifying bacteria, which are responsible for transforming NH_4^+ to NO_3^-, thereby regulating the pool of plant-available NO_3^-. Studies have determined these inhibitors can reduce losses of NO_3^- leaching in coarser soils and N_2O emissions in poorly-aerated, wet, warm soils.
Urease plus nitrification inhibitor	Some products combine nitrification inhibitors with urease inhibitors for multiple modes of action.

SUMMARY
Stabilized N sources are N fertilizers treated with urease inhibitors, nitrification inhibitors, or a combination of both. They can comprise "right source" in many situations in which 4R Nutrient Stewardship is implemented. Several meta-analyses demonstrate that nitrification inhibitors with and without urease inhibitors consistently reduce N_2O emissions. Nitrification inhibitors are effective at decreasing NO_3^- leaching but can increase ammonia volatilization, while urease inhibitors are effective at preventing volatilization losses.

KEYWORDS:
stabilized N; N emission; N volatilization; N leaching

ABBREVIATIONS AND NOTES:
N = nitrogen; N_2O = nitrous oxide; NH_3 = ammonia; NH_4^+ = ammonium; NO_3^- = nitrate

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hibitors, which these authors reported reduced N_2O emissions by 31%. However, stabilized N sources had unexpected relationships with crop N recovery or with NO_3^- leaching. Omonode et al. (2017) reported that reductions in N_2O emissions did not correspond with increases in crop N recovery. Eagle et al. (2017) reported that NO_3^- leaching did not respond to applications of nitrification inhibitors. Both of these findings are a concern since reductions in N_2O emission may come at the expense of other loss pathways that can limit yields. Since these papers did not assess effects of stabilized N sources on yield or NH_3 volatilization, these findings led to the following research questions:

1. In other recent reviews, do stabilized N sources consistently reduce direct N_2O emissions?
2. What are the effects of stabilized sources of N on yield, NO_3^- leaching, and NH_3 volatilization?

Do stabilized N sources consistently reduce N_2O emissions?

In 2017, Snyder published a paper reviewing recent meta-analyses examining the impact of stabilized N sources on crop yield, NO_3^- leaching, NH_3 volatilization, and/or N_2O emissions (**Table 2**). Nitrification inhibitors alone or combined with urease inhibitors consistently reduced N_2O emissions, with the average effects ranging from 8 to 100% (Snyder et al., 2009; Thapa et al., 2016; Lam et al., 2017; Qiao et al., 2015; Li et al., 2018). One of these studies reported that nitrification inhibitors reduced N_2O emissions across different land uses, climatic conditions, and for a range of soil texture and pH (Li et al., 2018). These findings were supported by a second meta-analysis, which reported that these effects were consistent for nitrification inhibitors combined with urease inhibitors for corn and wheat; across a range of soil pH and texture; under rain-fed or irrigated conditions; when broadcasted or banded; and under tilled and no-tilled conditions (Thapa et al., 2016). However, when applied alone, urease inhibitors were not always effective at reducing N_2O emissions (Akiyama et al., 2010; Thapa et al., 2016; Li et al., 2018). Urea treated with urease inhibitors was more effective at reducing N_2O emissions re-

Table 2. Recently reported effects of urease and nitrification inhibitors on crop yield, NO_3^- leaching, NH_3 volatilization, and N_2O emissions (Snyder, 2017). Negative values indicate a reduction in yield or increase in N loss relative to conventional N source.

		Range or average effect of stabilized N versus reference conventional N source			
Stabilizer or mode of action	Review or meta-analysis	Crop yield increase	Reduction in NO_3^- leaching	Reduction in NH_3 volatilization	Reduction in N_2O emission
Nitrification inhibitor	Quemada et al., 2013	3%	17%		
	Abalos et al., 2014	4.5%			
	Linquist et al., 2013	7%			
	Thapa et al., 2016	7%			38%
	Qiao et al., 2015	5 to 14%	48%	-20%	44%
	Snyder et al., 2009				19 to 100%
	Lam et al., 2017			-3 to -65%	8 to 57%
	Pan et al., 2016			-38%	
	Burzaco et al., 2014	2%			
	Li et al., 2018	5%	44%	-18%	57%
Urease inhibitor	Thapa et al., 2016	2%			
	Linquist et al., 2013	5%			
	Abalos et al., 2014	10%			
	Saggar et al., 2013			25 to 100%	
	Snyder et al., 2009				0 to 5%
	Pan et al., 2016			54%	
	Li et al., 2018	6%	39%	63%	21%
Urease plus nitrification inhibitors	Thapa et al., 2016	0%			30 to 34%
	Linquist et al., 2013	3%			
	Abalos et al., 2014	9%			
	Snyder et al., 2009				37 to 46%
	Li et al., 2018	5%	29%	53%	49%

T. Jensen/IPNI

Surface broadcast urea granule in No-till crop residue.

lated to untreated urea in coarse-textured soils, under split application of fertilizers, and irrigated conditions (Thapa et al., 2016), as well as neutral or alkaline soils, and subsurface placement (Li et al., 2018).

How do these inhibitors impact yield, NO_3^- leaching, or NH_3 volatilization?

Several meta-analyses agree that stabilized N sources contribute to modest increases in crop yield, as well as sizeable, but variable, reductions in specific environmental N loss pathways. However, it is increasingly apparent that yield increases and reductions in N losses are site-specific. Yield increases are also not expected if the N rate does not limit yields. For instance, Abalos et al. (2014) reported that yields and N use efficiencies increased when applying stabilized N. However, enhancements in productivity were greater at high N rates and for acidic soils, coarser soils, and irrigated conditions. In the following section, we summarize the findings of the impact of specific modes of actions on yield, NO_3^- leaching, and NH_3 volatilization.

Nitrification Inhibitors

The impact of nitrification inhibitors on yields were consistently positive but small (<10%) (Linquist et al., 2013; Thapa et al., 2016; Burzaco et al., 2014; Qiao et al., 2015). Burzaco et al. (2014) reported that nitrification inhibitors improved yields with a 56% probability, which was not necessarily due to increased uptake efficiencies. Fertilizer management, water management, and soil type can also influence their effectiveness. For instance, nitrification inhibitors were more beneficial for cereal production in neutral to alkaline soils, fine or coarse soil, broadcast or split applied, and under irrigated conditions (Thapa et al., 2016) and in alkaline soils or when applied in advance of permanent flooding for rice (Linquist et al., 2013). Nitrification inhibitors also reduced NO_3^- leaching by 48%, decreased total N losses by 16%, and increased plant N recovery by 58% (Qiao et al., 2015). In irrigated systems, nitrification inhibitors reduced leaching losses by 19% but did not consistently increase yields (Quemada et al., 2013). Nitrification inhibitors mitigated losses due to NO_3^- leaching in both grassland and dryland systems, across a precipitation gradient, and for a range of soil properties according to one meta-analysis (Li et al., 2018). However, Eagle et al. (2017) found no evidence that nitrification inhibitors reduced NO_3^- leaching based on

TAKE IT TO THE FIELD

Stabilized N sources reduce N_2O emissions across a range of soils and fertilizer management. These inhibitors result in modest yield gains, but effectiveness depends on soil and management factors. Urease and nitrification inhibitors have different modes of action, which make urease inhibitors effective at reducing ammonia volatilization and nitrification inhibitors effective at decreasing NO_3^- leaching.

data provided in four studies conducted in Midwestern corn systems.

There is also a potential tradeoff between N_2O emissions and NH_3 volatilization when applying nitrification inhibitors. In a review of six studies, Lam et al. (2017) reported that NH_3 volatilization often increased with the application of nitrification inhibitors, coinciding with consistent decreases in N_2O emissions (Qiao et al., 2015; Pan et al., 2016; Li et al., 2018). Therefore, unless ammonia volatilization is mitigated by deep subsurface placement, combining a urease inhibitor with a nitrification inhibitor may offset ammonia losses associated with the nitrification inhibitors.

Urease Inhibitors with or without Nitrification Inhibitors

Like nitrification inhibitors, urease inhibitors can be effective at increasing yields, but these effects are often also small and variable (Thapa et al., 2016; Linquist et al., 2013; Abalos et al., 2014). Unlike nitrification inhibitors, urease inhibitors are highly effective at reducing NH_3 volatilization (Saggar et al.,2013; Pan et al., 2016). Pan et al. (2016) reported that urease inhibitors decreased NH_3 emissions by 54%, whereas Saggar et al. (2013) reported decreases of 45%. Urease inhibitors mitigated NH_3 volatilization across a range of soil types and pH, land use, and annual precipitation gradient (Li et al., 2018). Urease inhibitors can also benefit rice systems particularly when N fertilizers are applied well in advance of permanent flooding (Linquist et al., 2013). However, high soil carbon content and temperatures can reduce the efficacy of urease inhibitors (Saggar et al., 2013).

Little is known about the effect of urease inhibitors on NO_3^- leaching, and therefore its effect is currently inconclusive. A recent study analyzed the results of three studies with only five observations (Li et al., 2018). Urease inhibitors reduced NO_3^- leaching by 39% on average, but its effect was highly variable and therefore not significant.

When combined, urease inhibitors plus nitrification inhibitors can increase yields but effects are also small and variable (Thapa et al., 2016; Abalos et al, 2014; and Linquist et al., 2013; Li et al., 2018). The combination of inhibitors can be more beneficial for neutral to alkaline soils, medium to coarse soil, and under irrigated conditions (Thapa et al., 2016). Li et al. (2018) reported that double inhibitors can reduce both N_2O and NH_3 emissions, but were ineffective at combatting NO_3^- leaching in a handful of observations for dryland systems. However, Snyder's (2017) review exposes the challenges of reporting data from studies measuring multiple N loss pathways, and there is no consensus due to lack of data whether combining urease and nitrification inhibitors can simultaneously decrease N_2O emission, NH_3 volatilization, and leaching losses (Snyder, 2017).

The lack of such critical data makes assessments of trade-offs among pathways difficult under site-specific conditions. If the quantities of N losses are not known, Snyder (2017) recommends the adoption of stabilized N sources should depend on:

- Current cropping system management abilities
- Agronomic and environmental knowledge of crop adviser or nutrient manager
- Crop and fertilizer economics
- Compatibility of current soil and water conservation practices
- Availability of nutrient management technology
- Risks and magnitude of dominant N loss pathway(s)
- Regulatory policies
- Trends in N use efficiency over time

These considerations recognize the agronomic, economic, social, and environmental goals must be simultaneously assessed for effective N_2O emission mitigation using stabilized N sources. **BC**

Part 1: *Can Lower Nitrogen Balances and Greater Recovery by Corn Reduce N_2O Emissions?* is available at https://doi.org/10.24047/BC102227

Part 2: *Effects of 4R Management, Climate, and Soil Variables on Nitrogen Losses* is available at https://doi.org/10.24047/BC102315

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Response of Cacao Seedlings to Fertilizer

By Thomas Oberthür, Marianne Samson, Noel Janetski, Kate Janetski, and Myles Fisher

Cacao nursery owner and "Cocoa Carer" Mr. Aris (far right) inspecting seedlings in the trial with (left to right) Mr. Noel Janetski, Dr. Thomas Oberthür, and Ms. Kate Janetski.

Production of cacao in Indonesia has increased from 27,000 t in 1984 to almost 730,000 t in 2014 (FAOSTAT 2017), yet average yields of the smallholders, who produce about 96% of the crop, are very low at 400 kg/ha. The yield potential of cacao has been estimated to be 11,000 kg/ha (Corley, 1983). Despite the lack of research on cacao (Carr, 2012; van Vliet and Giller, 2017), there is an obviously large yield gap that can be exploited. The narrowing of the yield gap depends on improved management at all growth stages of the crop. In small-plot trials, high-yielding clones produce more than 6,000 kg beans/ha (Chan and Lim, 1986), while commercial growers may exceed 4,000 kg/ha (Bosshard and Von Uexküll, 1987).

Little is known about the effect of different management practices in nurseries on seedling growth and subsequent performance in the field. Seedlings are typically grown in nurseries for six months before they are transplanted to the field. Commercial nurseries use best-guess fertilizer schedules, but do not measure plant growth or other performance indicators, seeking mainly to minimize costs. Based on expe-

SUMMARY

Researchers combined a suite of good agricultural practices with fertilizer application. Modest amounts of fertilizer applied to cacao seedlings in the nursery increased seedling growth and nutrient concentrations. There were no significant responses if fertilizer application rates were doubled. Results find it likely that adequate and well-timed supplies of fertilizer nutrients in the nursery will translate into better long-term agronomic performance in farmers' fields.

KEYWORDS:

cacao fertilization; seedling growth; good agricultural practices

ABBREVIATIONS AND NOTES:

N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; B = boron.

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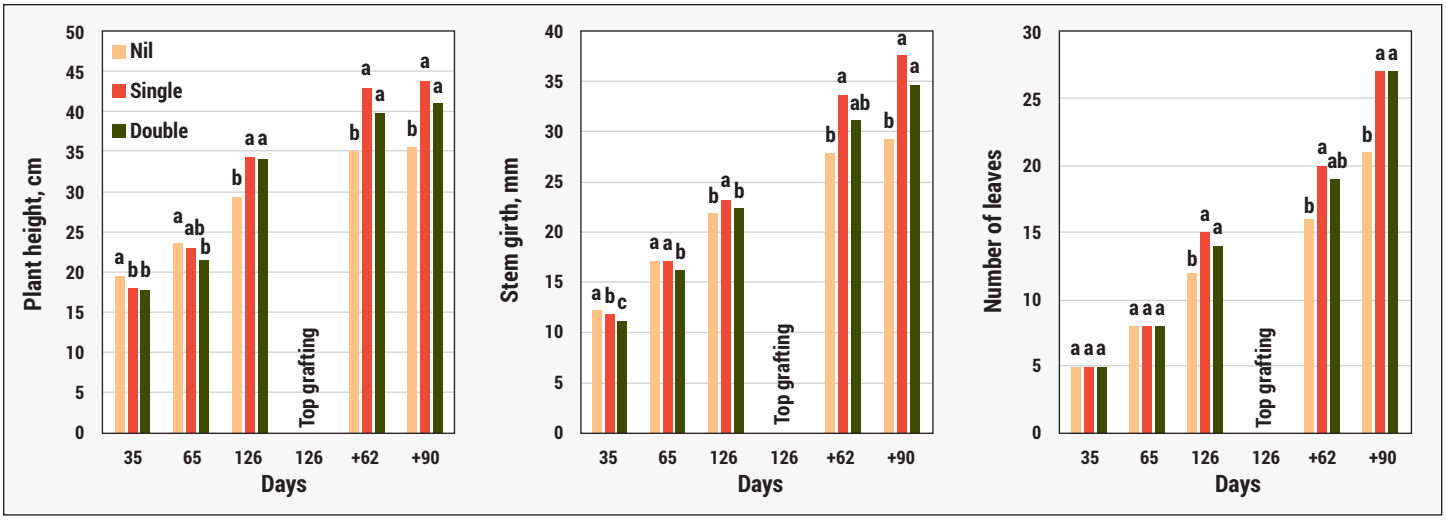

Figure 1. Effect of fertilizer on the growth of cacao seedlings. Numbers on the x-axis are days since germination and those since grafting on day 126. Columns with the same letter and date did not differ significantly (*p*>0.05).

rience with other crops, literature, and considering soil analyses (**Table 1**), a balanced fertilizer mixture was formulated that was judged to allow for near-optimum performance.

Table 1. Soil properties.

pH	Organic matter, %	Total N, %	Bray 2 P, ppm	B, ppm	Exchangeable cations, cmol/kg K	Mg	Ca	Texture, % Clay:sand:silt
7.4	2.0	0.09	74	11	0.31	3.4	22.1	41:42:17

Commercial-scale batches of seedlings were grown to assess the performance of cacao seedlings at two fertilizer rates, compared with an unfertilized control.

A randomized block experiment with four replicates was conducted in a cacao nursery in Soppeng, South Sulawesi. The treatments were three levels of applied N, P, K, Mg, and Ca:

1) No fertilizer
2) Single rate: 1.2 g N, 0.5 g P, 1.4 g K, 0.4 g Mg, and 1.3 g Ca (total per plant)
3) Double rate: 2.3 g N, 1.0 g P, 2.7 g K, 0.8 g Mg, and 2.6 g Ca (total per plant)

The fertilizer sources were an NPK compound (15-15-15), ammonium sulfate, potassium chloride, dolomite, and kieserite. Soil was mixed with 25% of the fertilizer treatment before filling each bag and the remainder was applied to the soil surface—25% after grafting, and the remainder six weeks later.

Polybags (20 cm x 25 cm) were filled with a mixture of sieved local topsoil and sand (**Table 1**). The final texture marginally exceeded 40% clay. A single pre-germinated seed of PBC123 variety was placed in each bag on 3 August, 2017. The seedlings emerged 3 to 6 days later. All seedlings were grafted with a high-yielding TR 45 clone at three months of age and the experiment ended after about seven months, the age at which nurseries sell grafted seedling to farmers.

Each treatment replicate consisted of 50 seedlings. Twenty seedlings were selected at random within each treatment replicate for detailed measurement. Ten seedlings were harvested at grafting and the remaining ten at the end of the experiment, which were divided into roots, stems, and leaves. Fresh and dry weight were measured for each component and subsamples were analyzed for N, P, K, Mg, Ca, and B. Plant height, stem diameter (used to calculate the

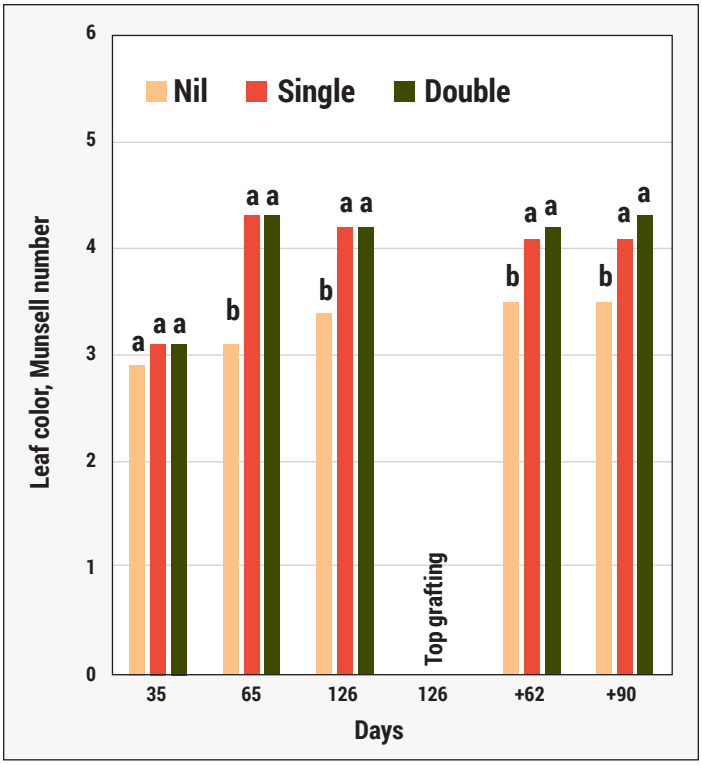

Figure 2. Effect of fertilizer on the greenness of cacao seedlings. Numbers on the x-axis are days since germination and those since grafting on day 126. Columns with the same letter and date do not differ significantly (*p*>0.05).

stem girth data reported), and leaf number were measured each month before grafting and the remaining ten measurement seedlings twice more after grafting. The greenness of the youngest fully-expanded leaf was estimated using Munsell color chips.

Results

The experiment had two stages, growth of the rootstock before grafting, 126 days after emergence, and subsequent growth of the scion, to which continued growth of the rootstock contributed.

Rootstocks of cacao seedlings grown with fertilizer prior to grafting were taller, more robust (**Figure 1** and **2**) and had higher tissue concentrations of the nutrients that were applied (**Tables 2** and **3**). Doubling the amount of applied fertilizer gave no significant increase.

TAKE IT TO THE FIELD

Application of mixed fertilizer to cacao seedlings gave more robust, taller, leafier and greener plants at sale time compared with unfertilized controls. Doubling the amount of fertilizer rate had no agronomic advantage and so gives no increased economic advantage.

The length of the grafted scion or the level of the graft were not recorded, so it is difficult to draw conclusions from the plant height data from the post-grafting stage. However, the fertilizer treatments were greener, the rootstock had thicker girth and the scion grew more leaves in the last month in the nursery than the nil control (**Figure 1**). Doubling the rate of fertilizer gave no significant advantage.

Although we have analyses for all three plant components (i.e., leaves, stems, and roots), data for the leaves demonstrate the important features. We caution that these are data for representative samples of all the leaves from the seedlings within each replicate of each treatment. They are not comparable with the data for the last fully-expanded leaf used to assess nutrient sufficiency in mature plants.

Fertilizer increased dry matter yield by about 50%, but increases in mean nutrient element concentrations of the whole leaf fraction was somewhat less (**Tables 4** and **5**). There was no significant response in nutrient element uptake at the double rate compared with the lower, single rate.

Discussion

The improved growth, height, yield, and nutrient concentration given by fertilizer applied at the single rate produced plants at the end of the experiment that were more visually attractive. It seems logical that these plants may offer long-term agronomic advantages (faster establishment, earlier fruiting, higher yield potential). If so, they should be financially attractive for the farmers, who may therefore be willing to pay a premium for them. They should also be advantageous for the nursery in terms of a more attractive product that commands a premium price. It may also be more profitable, although that would depend on the overall business plan and the local regulato-

Table 2. Dry matter yield and nutrient uptake of the rootstocks immediately before grafting at 126 days after emergence.

Treatment	Dry weight	N	P	K	Mg	Ca	B
	g/plant						
Nil	8.3 a	0.09 b	0.012 b	0.10 a	0.033 a	0.071 b	0.019 a
Single	10.2 a	0.16 a	0.017 a	0.13 a	0.035 a	0.112 a	0.017 a
Double	9.4 a	0.16 a	0.015 a	0.11 a	0.033 a	0.100 ab	0.016 a

Numbers within columns followed by the same letter do not differ significantly ($p<0.05$).

Table 3. Concentration of nutrient elements in the whole leaf fraction immediately before grafting at 126 days after emergence.

Treatment	N	P	K	Mg	Ca	B
	%					*ppm*
Nil	1.66 b	0.18 a	1.20 b	0.488 a	1.22 a	35.7 a
Single	2.25 a	0.18 a	1.35 a	0.330 b	1.12 a	20.7 b
Double	2.46 a	0.18 a	1.36 a	0.383 b	1.10 a	20.8 b

Numbers within columns followed by the same letter do not differ significantly ($p<0.05$).

Table 4. Dry matter yield and nutrient uptake at the end of the experiment, on 10 March 2018, 216 days after emergence and 90 days after top-grafting the scion (equivalent to the ready-to-sell stage).

Treatment	Dry weight	N	P	K	Mg	Ca	B
	g/plant						
Nil	14.5 c	0.14 b	0.029 a	0.16 b	0.052 b	0.16 b	0.038 b
Single	22.9 a	0.34 a	0.033 a	0.30 a	0.080 a	0.28 a	0.062 a
Double	19.4 b	0.29 a	0.031 a	0.25 ab	0.069 a	0.27 a	0.056 a

Numbers within columns followed by the same letter do not differ significantly ($p<0.05$).

Table 5. Concentration of nutrient elements in the whole leaf fraction at the end of the experiment.

Treatment	N	P	K	Mg	Ca	B
	%					ppm
Nil	1.61 b	0.18 a	1.35 a	0.520 a	1.62 a	47.8 a
Single	2.12 a	0.16 a	1.42 a	0.458 b	1.55 a	44.0 a
Double	2.12 a	0.18 a	1.46 a	0.475 ab	1.70 a	46.6 a

Numbers within columns followed by the same letter do not differ significantly ($p<0.05$).

ry climate. It would also require more investment of money and labor and hence increase the nursery's financial risk.

Both possibilities are plausible, but we could find no relevant evidence on the topic to allow us to discuss the issue further. Further monitoring in the field is required, which we propose to do over the next 3 to 4 years. The data presented here provides the justification for this plan.

One of the four full fertilizer treatment replicates with 50 top grafted cacao seedlings.

Conclusion

Most nurseries in the region will not use fertilizer at all. Hence, our "zero fertilizer control" treatment represents the usual practice. Nurseries try to reduce costs where possible. On the other hand, previously accepted "best practice", which has the addition of SP36 (double superphosphate) in the planting media, combined with the use of foliar applications, has been used and is still used where a premium product may be sold. Our nursery "cocoa carer", Mr. Aris, was impressed by the single fertilizer rate results when compared to the previously accepted "best practice." The consensus was that the fertilizer treatment gave much better results. An initial analysis suggests that the fertilizer treatments cost much less for materials and labor than the accepted "best practice." Specifically, the application frequency was reduced to three soil-based fertilizer application rounds, compared to one soil and up to ten foliar applications performed in the previously accepted "best practice." The nursery of Mr. Aris has already started to incorporate the practice, which gives practical support for our conclusions. **BC**

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Nutrient Uptake and Distribution in Black Pepper

By Nerrisa Paduit, Mirasol Pampolino, Tin Maung Aye, and Thomas Oberthür

Since the early days of trade between Asia and Europe, Black pepper (*Piper Nigrum* L.) has been known as the "King of Spices." Still the most widely traded spice in the world, its berries are grown extensively for use in food and medicine. Today the world's total harvested area for black pepper is over 500,000 ha (**Table 1**). The largest areas are in Asia: Indonesia (32%), India (24%), Vietnam (16%), and Sri Lanka (8%). Total world production is 546,000 t. Southeast Asia is taking the lead both in terms of production and harvested area.

Table 1. Production, area and yield of top black pepper producing regions in 2016.

Country/Region	Production, t	Area harvested, ha	Yield, t/ha
Brazil	54,425	25,830	2.1
China	34,360	18,175	1.9
India	55,000	129,000	0.4
Indonesia	82,165	168,080	0.5
Malaysia	29,245	10,900	2.7
Sri Lanka	28,900	41,560	0.7
Vietnam	216,430	81,790	2.6
Africa	25,890	39,435	0.7
Asia	453,775	453,315	1.0
Southeast Asia	333,735	263,825	1.3
South America	66,470	33,655	2.0
World	546,260	527,850	1.0

FAOSTAT, 2017

The world's average yield for black pepper is only about 1 t/ha. Low productivity is the main challenge for many regions. This problem can be attributed to maintaining weak and unproductive vines or vines with poor genetic potential, biotic and abiotic stresses, weed competition, and inadequate or imbalanced fertilizer use (Thangaselvabal et al., 2008). Many black pepper farms are owned by smallholder farmers, who often apply inadequate amounts of fertilizer (Rosli et al., 2013). Research shows that without careful fertilizer application and soil fertility management, black pepper yields cannot be improved and it is even difficult to sustain current levels of production. Black pepper farms are predominantly established on soils with poor fertility and low nutrient retention capacity (Srinivasan et al., 2007).

Cultivation systems for black pepper vary among countries. In India and Vietnam, black pepper is often planted as a mixed crop on the homestead or in existing coffee plantations. In Indonesia and Sri Lanka, the crop is intercropped with short duration crops and plantation crops like coffee and coconut (IPC, 2005). Black pepper has also been grown commercially as an intensive monocrop in major pepper production countries such as Thailand, Vietnam, and Brazil (Ravindran and Kallupurackal, 2012).

We estimate that with better nutrient management practices implemented as part of generally good agricultural practices (GAP), yields of current high-yielding varieties can be increased three-fold in many black pepper-growing areas. Black pepper is highly responsive to fertilizer application. Previous fertilizer trials on black pepper have examined crop yield responses to fertilizer application (Sadanandan, 1994). Fertilizer trials in Sarawak, Malaysia demonstrated high responses to N, P, and K (De Waard, 1969). However, there is a large variation among pepper production systems due to differences in crop management practices, soil and climatic conditions, and the socioeconomics of black pepper growers. Srinivasan et al. (2007) suggested the requirement of 6.4 g N, 6.3 g K, 1.1 g Ca, 0.5 g Mg, 0.4 g P, 0.3 g S, 43 mg Fe, 34 mg Mn, and 4.2 mg Zn for every 1 kg increase in black pepper berry yield in Kerala, India. To come up with an effective fertilizer recommendation, the crop's nutrient uptake requirement and removal must be clearly understood. It should be noted that black pepper is a perennial crop and its utilization of nutrients could be different over time.

Nutrient Uptake and Removal

The influence of N, P, K, Ca, Mg, and micronutrients depends on their ratio in the soil and plant system (Srinivasan et al., 2007). Nutrient removal and composition of

SUMMARY
Black pepper is highly responsive to fertilizer application. Supplying adequate amount of nutrients is important to substantially increase growth and yield of the crop. Nutrient uptake and distribution in the different plant parts are key parameters in designing a better and more effective fertilizer management strategy.

KEYWORDS:
nutrient accumulation; nutrient partitioning; yield potential.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Fe = iron; Mg = magnesium; Mn = manganese; Zn = zinc.

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A 4-year old black pepper smallholder farm in Gai Lai province of Vietnam. Photo by Tin Maung Aye.

pepper vines vary with variety, age, soil, season, and crop management. According to Yap (2012), there are three distinct growth stages of pepper—the early stage of development (first 18 months after planting), the period between fruit development and fruit maturity (18 to 26 months), and the period after harvesting or the "recovery" period (28 to 30 months).

Nutrient accumulation up to 30 months after planting is highest for N and K, which is followed by much lower accumulation of Ca, P, and Mg (**Figure 1**; Yap 2012). The crop's demand for nutrients is strongest at around 12 to 20 months after planting with more than 50% of the nutrients taken up during fruit development.

Using data reported by Yap (2012) on fruit biomass, plant population, and nutrient accumulation up to first fruit maturity (26 months after planting), estimates of nutrient uptake indicate that the crop takes up 69 kg N, 5.1 kg P, 51 kg K, 18 kg Ca, and 6.8 kg Mg for every 1 t of berries.

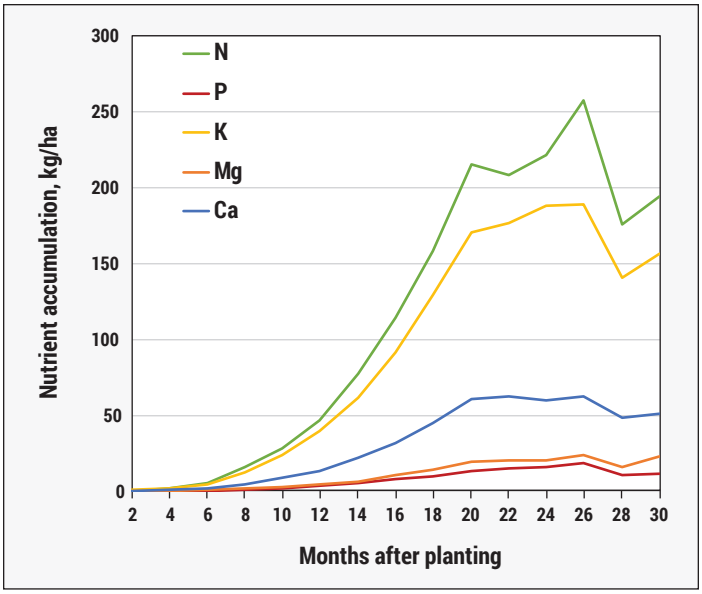

Figure 1. Total uptake of N, P, K, Mg, and Ca at different growth stages of black pepper. Yap, 2012.

Table 2. Estimated nutrient uptake and removal at current (2016) and projected black pepper yields with good agricultural practices (GAP) assumed at 100% increase over 2016 yield levels.

		Current nutrient uptake and removal, kg/ha				
Country/Region	Current yield, t/ha	N	P	K	Ca	Mg
Brazil	2.1	146 (52)*	11 (4.8)	108 (36)	37 (12)	14 (6.5)
China	1.9	131 (47)	9.7 (4.3)	97 (32)	34 (11)	13 (5.8)
India	0.4	30 (11)	2.2 (1.0)	22 (7.4)	7.6 (2.5)	2.9 (1.3)
Indonesia	0.5	34 (12)	2.5 (1.1)	25 (8.4)	8.7 (2.8)	3.3 (1.5)
Malaysia	2.7	186 (66)	14 (6.1)	137 (46)	48 (15)	18 (8.3)
Sri Lanka	0.7	48 (17)	3.6 (1.6)	36 (12)	12 (4.0)	4.7 (2.2)
Vietnam	2.6	184 (65)	14 (6.0)	136 (46)	47 (15)	18 (8.2)
Africa	0.7	46 (16)	3.4 (1.5)	34 (11)	12 (3.8)	4.5 (2.0)
Asia	1.0	69 (25)	5.1 (2.3)	51 (17)	18 (5.8)	6.8 (3.1)
South America	2.0	137 (49)	10 (4.5)	101 (34)	35 (11.4)	13 (6.1)
Southeast Asia	1.3	88 (31)	6.5 (2.9)	65 (22)	22 (7.3)	8.6 (3.9)
World	1.0	71 (25)	5.3 (2.3)	53 (18)	18 (5.9)	7.0 (3.2)
	GAP yield, t/ha	Projected nutrient uptake and removal, kg/ha				
Brazil	4.2	292 (104)	22 (9.6)	216 (72)	75 (24)	29 (13)
China	3.8	262 (93)	19 (8.6)	194 (65)	67 (22)	26 (12)
India	0.9	60 (21)	4.4 (2.0)	44 (15)	15 (5.0)	5.8 (2.7)
Indonesia	1.0	68 (24)	5.0 (2.2)	50 (17)	17 (5.6)	6.6 (3.0)
Malaysia	5.4	371 (132)	28 (12)	274 (92)	95 (31)	36 (17)
Sri Lanka	1.4	97 (34)	7.2 (3.2)	72 (24)	25 (8.1)	9.5 (4.3)
Vietnam	5.3	367 (131)	27 (12)	271 (91)	94 (30)	36 (16)
Africa	1.3	91 (32)	6.8 (3.0)	68 (23)	23 (7.6)	8.9 (4.1)
Asia	2.0	138 (49)	10 (4.6)	102 (34)	36 (12)	14 (6.2)
South America	4.0	274 (98)	20 (9.0)	203 (68)	70 (23)	27 (12)
Southeast Asia	2.5	176 (63)	13 (5.8)	130 (44)	45 (15)	17 (7.9)
World	2.1	143 (51)	11 (4.7)	105 (35)	36 (12)	14 (6.4)

*Values in parentheses refer to the nutrient removal from fruits. Estimates based on data from Yap, 2012.

Assuming that only the fruits are taken away from the plantations, net removal per t of fruits harvested would be 25 kg N, 2.3 kg P, 17 kg K, 5.8 kg Ca, and 3.1 kg Mg.

Estimated nutrient uptake and removal at current and projected yields with improved GAPs are presented in **Table 2**. Projected yields in the top five black pepper producing countries of Vietnam, Indonesia, India, Brazil, and China would result in the removal of about 21,900 t of N, 2,000 t of P, and 15,200 t of K. In Vietnam alone (the highest yielding), that would be 10,700 t of N, 990 t of P, and 7,400 t of K, which are quantities that almost equal the sum of removals for the remaining four top-producing countries.

Nutrient distribution in pepper plant parts during the entire growth cycle indicate that the fruit removes the highest amount of N, P, K, Ca, and Mg (Srinivasan et al., 2007; Yap, 2012). At the point of first fruit maturity, the nutrient content of the fruit + spike represents 37% of total plant N uptake, 46% for P, 36% for K, 48% for Mg, and 35% for Ca (**Figure 2**).

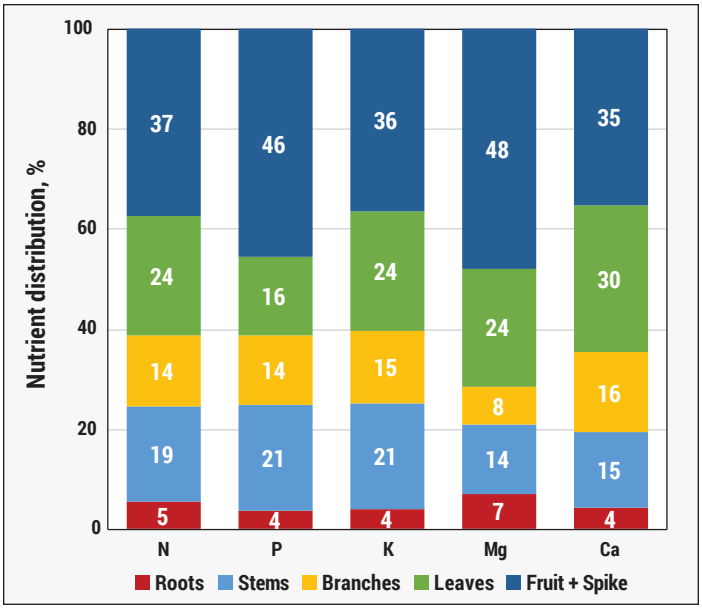

Figure 2. Distribution of N, P, K, Mg, and Ca in the different plant parts of black pepper at 26 months after planting (i.e., first fruit maturity). Yap, 2012.

Conclusion

Large amount of nutrients are required to produce and sustain the economic yield of black pepper. To achieve high yields, growers must apply nutrients in sufficient quantity to satisfy the crop's total nutrient requirement. Knowledge of the crop's total uptake of nutrients and their distribution in the different plant parts (e.g., leaves, branches, fruit, roots, etc.) will be useful for agronomists in designing a fertilizer application strategy based on the principles of 4R Nutrient Stewardship.

The authors note that literature and information on black pepper nutrition are very limited and come from very few locations. Future research will be useful to clarify the following issues: crop stage definition and critical stages for nutrient management, effect of genetic material and environment or site characteristics on nutrient uptake and removal, impact of nutrients on pest and diseases, and impact of nutrients on black pepper quality. **BC**

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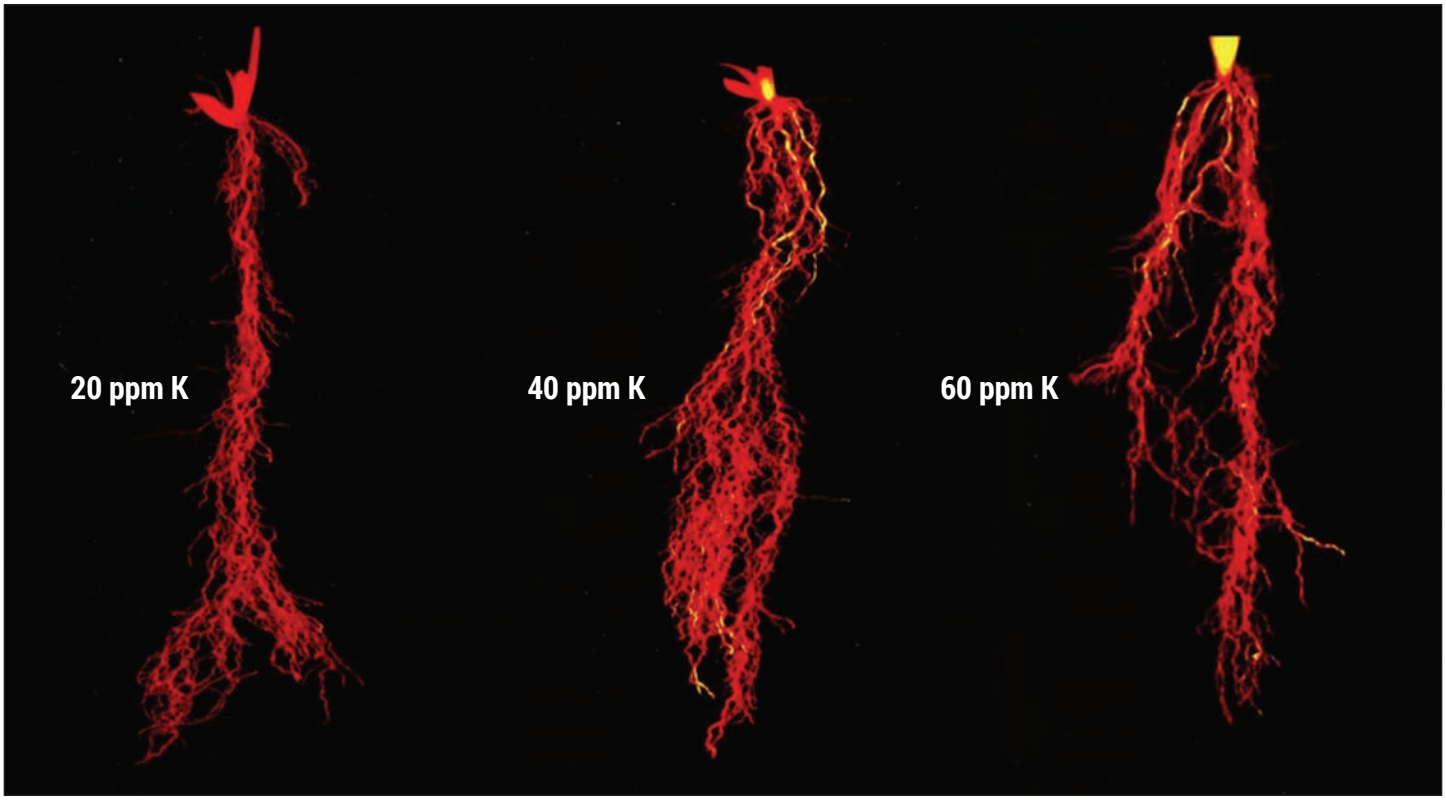
Revealing the Effects of Potassium on Rice Roots under Moisture Stress

By Kirti Bardhan, Dipika S. Patel, and Dhiraji P. Patel



Root system architecture of rice at 21 days after emergence under 20% FC (water limiting) receiving either 20, 40, or 60 ppm K.

Water availability is becoming the primary limiting factor for crop productivity in both developing and developed countries. In India, more than 60% area of arable land is in the arid and semi-arid region, which is characterized by long, dry seasons with inadequate and unpredictable rainfall. Rice is an important staple food crop of India predominantly grown under rain-fed conditions and prevalence of continuous drought spells will have negative implications on sustainable rice production. Moreover, one-third of the world's rice is cultivated in rain-fed low lands, and 13% rice is grown in upland rain-fed fields. Rice productivity has been reduced due to water stress and due to a burgeoning problem of climatic change, which will further aggravate farmers in the coming future. The identification of drought-tolerant traits coupled with drought mitigating, agronomic management practices has been a constant focus for research. One management approach is to increase the supply of K fertilizer to rice. It has a substantial role in alleviating drought effects by osmoregulation, stomatal regulation, and it can enhance photosynthesis, tissue water content, etc.

Plants have evolved diverse adaptation mechanisms for drought stress. Root architecture plasticity, relative change in each root trait under stress, can provide evidence for improved plant performance under moisture stress and is considered one of the mechanisms for mitigating drought

SUMMARY

The role of K in providing drought tolerance in the aerial parts of plants at the cellular, molecular, tissue, and organ level is well established compared to the plant root system. However, it is known that plants acquire soil water from deeper layers by modifying root architecture. The current study investigated the role of K in changing root architecture to facilitate more water acquisition as a mechanism to mitigate drought stress.

KEYWORDS:

Potassium; root architecture; drought stress

ABBREVIATIONS AND NOTES:

K = potassium; K_2SO_4 = potassium sulfate; FC = field capacity; ppm = parts per million

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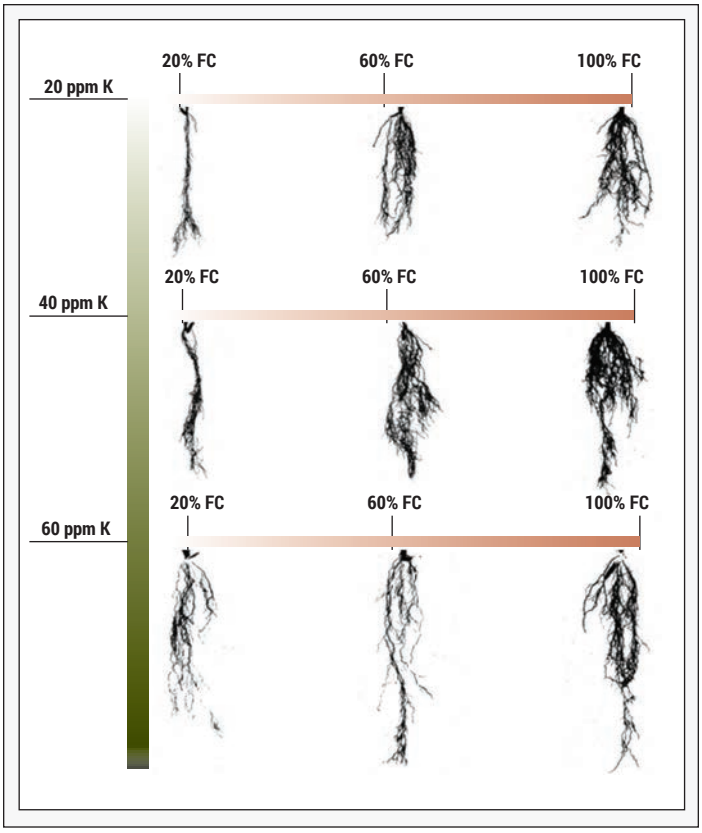

Figure 1. Image depicting the root system architecture of rice under different K concentrations and moisture levels at 21 days after emergence.

in crop plants, including rice. As plant roots are important in the sensing and acquisition of water and K along with other soil resources, and these factors also modulate root growth and architecture of the plant, it becomes crucial to know how changes in K nutrition may facilitate better water acquisition and drought tolerance.

Study Description

Ms. Dipika S. Patel addressed this question in her graduate research through a study on root architectural responses of rice seedling (variety NAUR-1) to K and moisture stress in a greenhouse at Navsari Agricultural University, Gujarat (India). The experiment was laid out in a complete randomized block design with nine treatment combinations and three replications, consisting of three levels each of K and soil moisture contents, or field capacities (FC). Rice seeds were sown in poly bags filled with a mixture of sand (800 g) and perlite (400 g). Moisture stress was imposed after seed emergence and seedlings were grown at 20% FC, 60% FC, and 100% FC. Average daily water loss was measured from four identical bags by weight and the daily water loss was replenished up to the desired FC. Three different types of nutrient solutions were prepared for replenishing the water amount. The nutrient solution was standard Yoshida solution (Yoshida et al., 1976) that was modified for the three different K concentrations. Periodically at 7, 14, and 21 days after emergence (DAE), treatment-wise seedling root

Table 1. Projected root area (mm²) of rice seedling as influenced by various potassium and moisture stress treatments.

	21 Days after emergence			
Treatments	20 ppm (K_1)	40 ppm (K_2)	60 ppm (K_3)	Mean (M)
(M_1) 100% FC	353	505	575	478
(M_2) 60% FC	244	326	351	307
(M_3) 20 % FC	172	229	252	217
Mean (K)	256	354	393	
	K	M	KxM	
S.Em ±	11	11	20	
CD (p=0.05)	34	34	57	
CV %	10			

images were scanned and analyzed by online Digital Imaging Root Traits (DIRT) platform (Das et al., 2015). Aboveground traits such as relative water content and growth parameters were also observed.

Potassium and Moisture Stress Interaction on Rice Root Architecture

Significant differences were observed in root projected area, average root density, maximum width of root system, root top angle, root bottom angle, root depth, and maximum width to depth ratio due to different soil K concentrations, moisture stress levels, and their interactions (**Figure 1**).

Projected root area of rice, as shown in (**Figure 2**), showed significant differences due to the interaction of moisture stress and K concentration (**Table 1**). At 100% FC, increasing K concentrations 20 to 60 ppm increased the projected root area by 62% (from 353 to 575 mm²), while

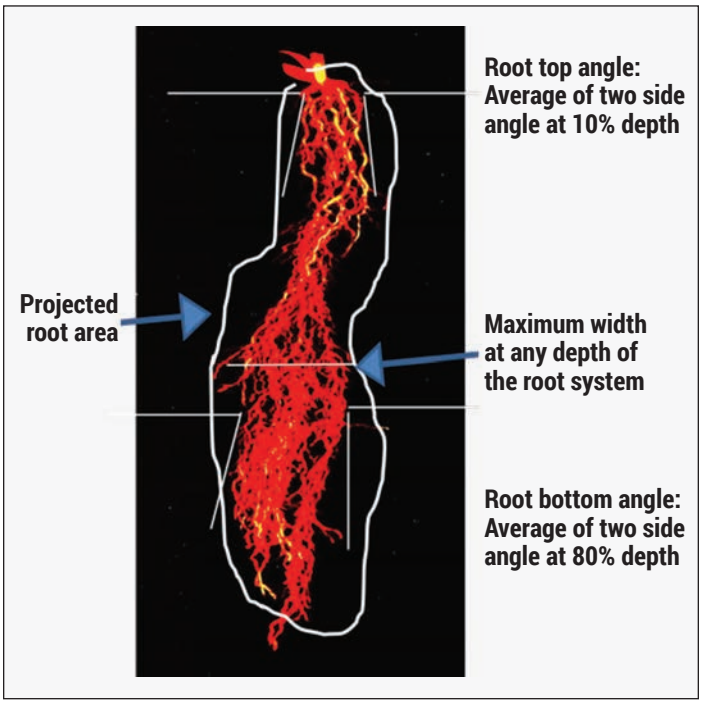

Figure 2. Picture depicting terminology of root architecture.

Table 2. Rooting depth skeleton (mm) of rice seedlings as influenced by various potassium and moisture stress treatments.

	21 Days after emergence			
Treatments	20 ppm (K_1)	40 ppm (K_2)	60 ppm (K_3)	Mean (M)
(M_1) 100% FC	114	137	141	131
(M_2) 60% FC	111	156	170	146
(M_3) 20 % FC	110	159	175	148
Mean (K)	112	151	162	
	K	M	KxM	
S.Em ±	2.8	2.8	4.9	
CD (p=0.05)	8.4	8.4	14	
CV %	6.0			

at 20% FC the projected root area increased by 47% (from 172 to 252 mm^2). On the other hand, increased moisture stress (20% FC) along with lower K concentration (20 ppm K) showed significant reduction in projected root area (172 mm^2) over other two K concentrations (229 mm^2 at 40 ppm K and 252 mm^2 at 60 ppm K). Results further showed that the projected root area decreased by 55% with increasing moisture stress, while it increased by 53% with higher K concentration (**Table 1**), indicating that the root area of rice can be maintained by application of adequate K even if the rice crop is subjected to moisture stress.

Contrary to projected root area, the rooting depth increased with moisture stress and an encouraging effect of K was noticed both at 40 and 60 ppm K. The rooting depth was significantly increased from 137 to 159 mm at 40 ppm K, and 141 to 175 mm at 60 ppm K (**Table 2**), indicating that rice plants are able to absorb nutrients from deeper soil layers due to K induced progression in rooting depth despite subjected to moisture stress.

The study showed that moisture deficit decreased maximum width of the root system, while application of K at 60 ppm nullified the effect of moisture stress as significantly higher maximum width of the root system was observed at all the three levels of moisture stress (**Figure 3**). A similar trend on width of root system was also recorded at 20 ppm K as significantly higher maximum width of the root system was observed at 100% FC, which decreased progressively with increasing moisture stress.

Root top angle was measured between the 10% depth and horizontal soil line (**Figure 2**). A narrower root top angle was observed at 100% FC while broader root top angle was recorded in 20% FC (**Figure 4, top**). Availability of moisture and K, both were found to interact for regulation of the root top angle of rice seedlings. However, at 60% FC, root top angle of seedlings supplied with 40 and 60 ppm K were at par with each other. At 20% FC, root top angle from the seedlings supplied with higher K (60 ppm) was narrower,

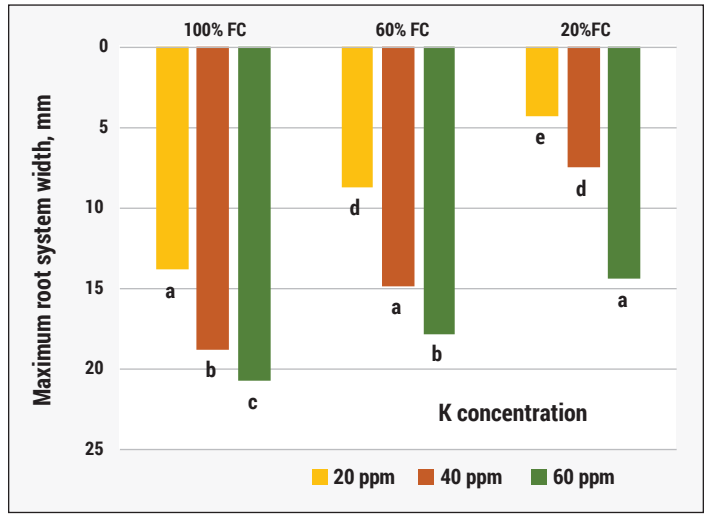

Figure 3. Effect of potassium and moisture availability on maximum width of root system of rice (NAUR-1) at 21 DAE. Any two bars having a common letter does not differ from each other at p=0.05.

and seedlings that were grown with low K (20 ppm) recorded a wider root top angle, indicating that with increasing moisture stress the interaction between moisture and K becomes more profound. Thus, it seems that higher concentration

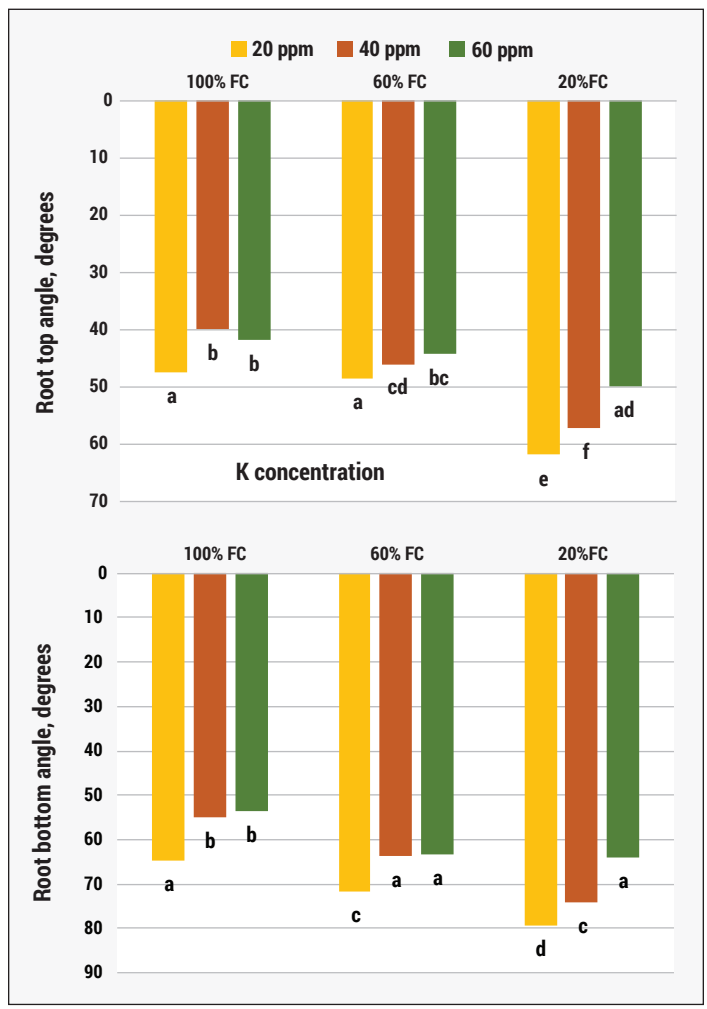

Figure 4. Effect of potassium and moisture availability on root top angle (top) and bottom angle (bottom) of rice (NAUR-1) at 21 DAE. Any two bars having a common letter does not differ from each other at p=0.05.

Figure 5. Comparative growth of rice seedlings under different potassium and moisture levels.

of K under moisture deficit condition, helped roots by resisting the effect of moisture stress on root top angle and restricted roots to become steeper under water limitation. These observations would help rice roots by increasing soil exploration area for efficient acquisition of other nutrients.

Root bottom angle was measured between the 80% depth and horizontal soil line (**Figure 2**). Under no moisture stress, significantly broader root bottom angle was observed in 20 ppm K while root bottom angle under 40 and 60 ppm K were at par with each other (**Figure 4, bottom**). The effect of moisture stress on root bottom angle was more pronounced at low K. At 60 and 20% FC, root bottom angle under 20 ppm K was significantly higher than other two K levels. At 60 ppm K, the high K concentration seems to override the effect of moisture stress as the root bottom angle at 20% FC was significantly lower compared to 20 and 40 ppm. At 60% FC, the root bottom angle difference between 40 ppm and 60 ppm was statistically not significant.

A substantially postive effect of increased K concentration under moisture stress was reflected in the overall growth of seedlings (**Figure 5**) and significantly, maximum dry weight of the most moisture-stressed seedlings was observed under 60 ppm K (**Figure 6**).

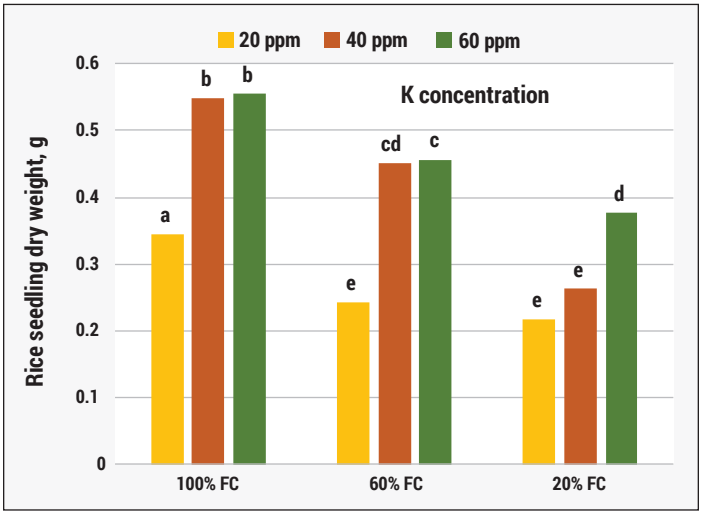

Figure 6. Effect of potassium and moisture availability on seedling total dry weight of rice (NAUR-1) at 21 DAE. Any two bars having a common letter does not differ from each other at *p*=0.05

Conclusion

Under conditions of moisture stress, a higher soil K concentration was found to be helpful in limiting any reduction in root area, promoting the maximum width of the root system, and increasing rooting depth. Decreasing root area is an adaptive feature of rice under moisture stress where the plant can save energy and carbon for increasing root depth to search for water. In our study, K was found to nullify this and rice plants were able to maintain root area along with root depth, which was helpful for exploration of soil profiles for efficient absorption of nutrients. At the higher application of K, rice seedling roots were able to maintain narrow root top and bottom angle under moisture stress which would facilitate exploration of more surface area and encourage increased absorption of other nutrients for maintaining seedling growth. **BC**

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Yoshida, S. et al. 1976. Laboratory Manual for Physiological Studies of Rice, IRRI, 2nd edition.

13th Western Nutrient Management CONFERENCE

Sponsored by

WERA-103

The International Plant Nutrition Institute (**IPNI**) would like to invite you to attend the Western Nutrient Management Conference (WNMC) being held on **March 7-8, 2019** at the **Eldorado Resort** in downtown **Reno, Nevada.**

The Western Nutrient Management Conference is attended by university graduate students, university extension soil fertility and crop production specialists, industry agronomists, crop advisers, and agency personnel, with representation from states encompassing the Western USA region. The goal of the conference is to facilitate sharing of new soil fertility and nutrient management research information and fertilizer industry developments. Presentations highlight ongoing soil fertility research at universities in the Western region.

REGISTRATION OPENS ON DECEMBER 18, 2018

Visit **https://conference.ipni.net/conference/wnmc2019** for all registration details, information on speakers, oral and poster sessions, hotel accommodations, and past conference proceedings.

After years of success in the US, the International Plant Nutrition Institute is partnering with New Ag International to take **The InfoAg Conference** to Europe!

This will be a premier event for discussion and advancement of precision agriculture looking at field-centric monitoring with imagery and sensors, seamless connectivity with IoT, data analytics and prediction modeling, variable rate technology, prescription platforms and digitalization.

KEY TOPICS COVERED:

• Sensors • Imagery • Weather Apps • Scouting Apps • Soil Health Monitoring • Data Connectivity
• Data Management and Analysis • Nutrition & Irrigation Management • Robotics & AI • Ensuring ROI

Join us in Dublin to meet with the leaders of the Precision and Digital Agriculture World.

Conference Website: https://lifesciences.knect365.com/infoag-international-conference-exhibition/ **BC**

16th International Symposium on Soil and Plant Analysis

We invite you to attend the 16th International Symposium on Soil and Plant Analysis (ISSPA-16) with focus on ***'Using tools to optimize plant production and quality; exploring the system approach'.*** The biennial conference will be held in Wageningen, The Netherlands June 17 to June 20, 2019.

This international symposium brings together global leaders from industry, government, and academia to share the latest progress in making science-based decisions influencing the stewardship of soil, water, and plants.

Program Themes and Topics

The ISSPA-16 includes several major themes covering soil, plant, products, manure, and system-level coordination. Assessing variations in space (local, region, country, world) and time (short term, long term) will be part of the themes. The ISSPA is an international symposium and presentations of different approaches and from different countries are encouraged to address:

- Chemical Aspects of Soil Fertility
- Physical Aspects of Soil Fertility
- Biological Aspects of Soil Fertility
- Plant Nutrition and Growth
- Agricultural Products
- Using Organics
- System Approaches

The International Symposium on Soil and Plant Analysis (ISSPA) occurs every two years to advance the science of soil and plant analysis. The 2019 meeting is organized by Wageningen University & Research and Eurofins Agro.

For more details on key information, please visit the Symposium's website **www.isspa2019.com**

Annual IPNI Photo Contest Deadline Approaching

Entries for the 2018 edition of our photo contest will be accepted until December 6, 2018. The winners will be announced during the first quarter of 2019.

Our 2018 contest has four categories: (1) **4R Nutrient Stewardship,** (2) **Primary Nutrient Deficiencies,** (3) **Secondary Nutrient Deficiencies,** and (4) **Micronutrient Deficiencies.**

Our 4R category is meant to collect images that demonstrate the best use of crop nutrients with in-the-field examples of 4R Nutrient Stewardship—applying the Right Source at the Right Rate, Right Time, and Right Place.

The three nutrient deficiency categories are meant to collect images of nutrient deficiency in crops. Primary mineral nutrients include: nitrogen (N), phosphorus (P), and potassium (K); secondary mineral nutrients including sulfur (S), calcium (Ca), and magnesium (Mg); and micronutrients including boron (B), copper (Cu), chloride (Cl^-), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

For additional information, see https://www.ipni.net/photocontest/learn **BC**

A. Ibarra

Iron deficiency in coffee grown in Vereda Paltapamba, Narino, Colombia.

R. Atchoglo

Localized placement of urea to maize, Lomé, Southern Togo.

S. Jadhao

Nitrogen deficiency in 30-day-old wheat crop grown in Maharashtra, India.

J. Kaur

Sulfur deficiency in corn grown near Fargo, North Dakota, USA.

Modernization, Yes, but Follow Agronomic Principles

I have often got the impression from many that agriculture has been lagging in terms of its pace of modernization if compared to other industries, but lately I believe these attitudes are changing.

In today's system of globalized food production, it is possible to know a lot about how our foods are produced and processed. For example, consumers can gain a lot of information at the market with a quick scan of a QR or RFID code.

On farms all over the world, many advanced techniques are being incorporated. The mobile phone is now a popular tool to help farmers make decisions, UAVs are increasingly being used to remotely guide decisions, and newer, higher capacity farm equipment is becoming available to make farmer operations easier and more efficient.

We certainly need modern technology to fulfil our mission to conveniently produce more while protecting the environment. However, we can't forget that new technology should always be aligned with proven agronomic principles. Said another way, everything that is used to grow our food should be based on principles developed by science. Farm machinery, for example, should be built and promoted not just with a mindset of doing more in less time, but should respect local agronomy. A clear example of this is in regions where farmers are using machines to increase the use of broadcast P to optimize the completion of an operation without enough consideration for agronomic drawbacks or negative environmental impacts.

History is full of examples of exciting ideas that have led to wrong decisions and a need to step back and rescue old concepts. So, let's avoid any backtracking and start with a respect for proven concepts when endeavoring to build something "new and improved."

Let's always convey the message that science should drive progress. For fertilizers this means, among other things, focusing on the 4R concept. The principles of using the right source at the right rate, right place, and right time are a must for doing things RIGHT!

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