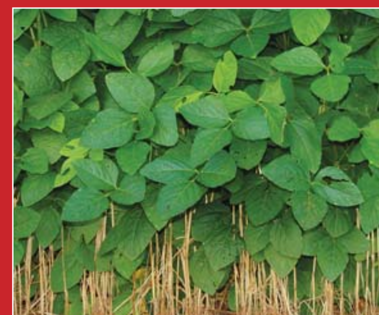
BETTER CROPS WITH PLANT FOOD

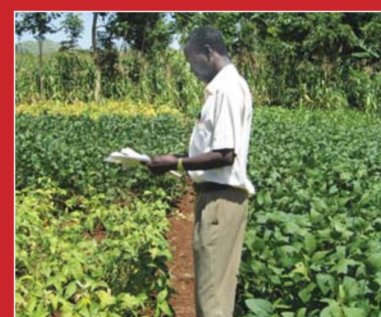
A Publication of the International Plant Nutrition Institute (IPNI)

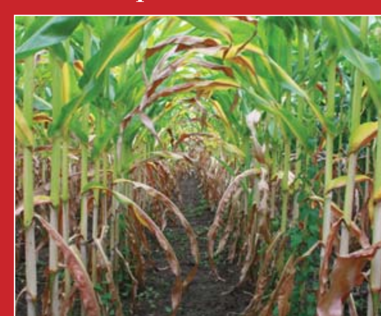
2015 Number 2

A Look at the Nutrient Budget for Brazilian Agriculture

In This Issue...







Also:

...and much more

IPNI

www.ipni.net

BETTER CROPS
WITH PLANT FOOD

Vol. XCIX (99) 2015, No. 2

Our cover: Brazilian soybean field scene. (istockphoto ©alffoto).
Editor: Gavin D. Sulewski
Assistant Editor: Danielle C. Edwards
Circulation Manager: Wendy Hollifield
Design: Rob LeMaster
Back page illustration: Greg Cravens

BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by the International Plant Nutrition Institute (IPNI). Periodicals postage paid at Peachtree Corners, GA, and at additional mailing offices (USPS 012-713). Subscriptions free on request to qualified individuals; others $8.00 per year or $2.00 per issue. Address changes may be e-mailed to: whollifield@ipni.net

POSTMASTER: Send address changes to *Better Crops with Plant Food*, 3500 Parkway Lane, Suite 550, Peachtree Corners, GA 30092-2844. Phone (770) 447-0335; fax (770) 448-0439. Website: www.ipni.net.

Better Crops with Plant Food is registered in Canada Post.
Publications mail agreement No. 40035026
Return undeliverable Canadian addresses to:
PO Box 2600 Mississauga ON L4T 0A9 Canada

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

CONTENTS

Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* can be found at: >**www.ipni.net/bettercrops**<

Zimmcomm New Media

Join Us This Summer at the InfoAg Conference in St. Louis, Missouri – July 28-30, 2015

2015 marks the 20th Anniversary of InfoAg. Since 1995, the InfoAg Conference has been the premier event for the discussion and advancement of precision agriculture. This event has grown to consistently draw interest from around the globe and features a wide range of educational and networking opportunities for professionals interested in learning more about precision agriculture techniques.

In its 20th Anniversary year, the InfoAg Conference continues to put its focus on the application of precision technology and information management for a wide array of crops. The InfoAg Conference is on a streak of record-setting success. Last year, over 1,400 participants shared in presentations on a wide range of topics on technology applications and data management and interpretation. Attendance for 2015 is predicted to set a new record as we settle into a second year in St. Louis.

As with all InfoAg Conferences, the networking among participants is a highlight of the experience. This year, the InfoAg Exhibit Hall will have a new, expanded format. We also encourage you to take advantage of the Pre-Conference Tour to pick up additional first-hand knowledge and interactions.

Details on the program for InfoAg, registration, and conference contacts can be found at the website http://www.infoag.org

Additional links for The InfoAg Conference:

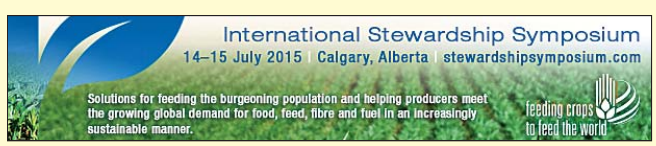
InfoAg Conference Newsletter: http://infoag.org/subscribe

InfoAg on Twitter: @infoag

Details on other conferences and meetings organized by IPNI can be found at: http://www.ipni.net/conferences BC

2015 International Stewardship Symposium - July 14-15

As a partner of the 2015 International Stewardship Symposium, held at the Hyatt Regency Hotel in Calgary, Alberta, IPNI invites you come and discuss the issues and solutions for how we can feed the burgeoning population and help producers meet the growing global demand for food, feed, fiber, and fuel in an increasingly sustainable manner.



Panel discussions include:

- Framework for Increasing Soil Quality
- Better Access to Inputs for Smallholders in Africa
- Climate-Smart Agriculture
- Metrics for Sustainable Agriculture

We invite you to navigate through the conference website to learn more: www.stewardshipsymposium.com. BC

A Look at the Nutrient Budget for Brazilian Agriculture

By Eros Francisco, José Francisco da Cunha, Luís Prochnow, and Valter Casarin

A nutrient budget is an important tool used to evaluate fertilizer use through its presentation of the balance between inputs and outputs in crop production. IPNI has prepared several nutrient budgets for Brazil over the years: Yamada and Lopes (1998), Cunha et al. (2010; 2011; 2014). This article focuses on this most recent study, which examined crop production between 2009 and 2012. Historical trends for fertilizer use (and crop productivity) are also put into perspective.

The authors began with manufactured mineral fertilizer (input) data obtained from annual statistics (ANDA, 2010 to 2013). Crop nutrient removals (output) were calculated using data for 18 crops including: banana, beans, cassava, castor bean, cocoa, coffee, cotton, maize, orange, peanut, potato, rice, sorghum, soybean, sugarcane, tobacco, tomato, and wheat (IBGE, 2010 to 2013) and their respective nutrient concentration in harvested product (Cunha et al., 2014). The 18 crops represent 93% of all nutrient input in Brazil.

Regional Budgets

Average annual nutrient use in Brazil between 2009 and 2012 was 2.84, 3.47 and 3.79 million (M) t of N, P_2O_5 and K_2O, respectively (**Table 1**). The midwest region showed the highest NPK use with 31% of total, followed by the south and southeast, each with 28% of the total. The northeast and north only had 11% and 2% of the total nutrient use, respectively.

The midwest was responsible for 36% and 34% (1.24 and 1.29 M t) of the total P_2O_5 and K_2O use, respectively. This region provides the core of soybean and maize production in Brazil, and plant-available soil P and K in the midwest is inherently low. The southeast accounted for 38% (1.08 M t) of the total N use due to the large areas of sugarcane, orange and coffee production. The amount of N fixed by soybean and common beans was assumed to be 100% and 50% of removal, respectively, and was considered an input.

Crop removal represented an average of 90%, 53% and 80% of N, P_2O_5 and K_2O inputs (**Table 1**). The only region where N and K_2O crop removal exceeded inputs was in the north (+11% for N and +4% for K_2O), which is attributed to low technology adoption and low yields in the region.

For P, the relatively low removal-to-use value of 0.53 reflects the typical dynamics for P in tropical soils, which promote P fixation. But in Brazil, low P removal-to-use is also influenced by recent increases in crop production in newly farmed areas where soil P levels are very low and P application is necessarily high to meet crop demand.

For N, its 0.90 removal-to-use ratio demonstrates the great contribution of biological N fixation in soybeans, which is the most cultivated crop in the country—approximately 28 M ha in 2012.

Potassium, the most commonly applied crop nutrient in

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium. IPNI Project # IPNI-2014-BRA-63

Geographic regions of Brazil.

Table 1. Annual nutrient budgets for regions in Brazil (average of 2009-2012).

Region	Crop removal N	Crop removal P_2O_5	Crop removal K_2O	Legume fixation[1] N	Nutrient applied[2] N	Nutrient applied[2] P_2O5	Nutrient applied[2] K_2O	Balance N	Balance P_2O_5	Balance K_2O	Removal-to-use ratios N	Removal-to-use ratios P_2O_5	Removal-to-use ratios K_2O
	million t												
South	2.21	0.64	0.91	1.53	0.85	1.03	0.96	0.18	0.39	0.05	0.93	0.62	0.95
Midwest	2.57	0.69	1.06	2.06	0.60	1.24	1.29	0.09	0.55	0.23	0.96	0.56	0.82
Southeast	0.99	0.31	0.66	0.29	1.08	0.72	1.02	0.38	0.40	0.35	0.73	0.44	0.65
Northeast	0.56	0.16	0.30	0.35	0.27	0.40	0.43	0.06	0.24	0.13	0.91	0.40	0.70
North	0.18	0.05	0.09	0.12	0.04	0.08	0.09	-0.02	0.04	0.00	1.11	0.58	1.04
Brazil	6.50	1.84	3.03	4.35	2.84	3.47	3.79	0.69	1.62	0.76	0.90	0.53	0.80

[1] Amount of N fixed by soybeans and common beans.
[2] Source: ANDA (2010 to 2013).

Table 2. Annual nutrient budgets for main crops in Brazil (average of 2009-2012).

	Crop removal[1]			Legume fixation[2]	Nutrient applied[3]			Balance			Removal-to-use ratios		
	N	P_2O_5	K_2O	N	N	P_2O_5	K_2O	N	P_2O5	K_2O	N	P_2O_5	K_2O
Crop	----------	----------	----------	----------	million t	----------	----------	----------	----------	----------			
Soybean	4.30	0.92	1.64	4.30	0.10	1.84	1.66	0.10	0.92	0.02	0.98	0.50	0.99
Maize	0.93	0.51	0.34	-	0.84	0.53	0.52	-0.09	0.02	0.18	1.11	0.96	0.65
Sugarcane	0.58	0.18	0.66	-	0.72	0.25	0.78	0.14	0.07	0.12	0.81	0.72	0.85
Coffee	0.05	0.01	0.05	-	0.36	0.10	0.25	0.31	0.09	0.20	0.14	0.10	0.20
Cotton	0.08	0.03	0.08	-	0.17	0.18	0.14	0.09	0.15	0.06	0.47	0.17	0.57
Rice	0.15	0.06	0.06	-	0.14	0.08	0.07	-0.01	0.02	0.01	1.07	0.75	0.86
Beans	0.11	0.03	0.06	0.05	0.08	0.08	0.05	0.02	0.05	-0.01	0.85	0.38	1.20
Orange	0.04	0.01	0.03	-	0.07	0.03	0.05	0.03	0.02	0.02	0.57	0.33	0.60
Wheat	0.106	0.04	0.02	-	0.11	0.08	0.06	0.004	0.04	0.04	0.96	0.50	0.33

[1] For sugarcane, a 20% deduction was considered for K removal considering the regular disposal of vinasse.
[2] Amount of N fixed by soybeans and common beans.
[3] Source: Cunha et al. (2014).

Brazil, presents an adequate budget of 0.80, mainly a reflection of the high level of regard that farmers continue to have for K within their crop production systems.

Crop Budgets

Nutrient budgets for nine crops grown between 2009 and 2012 are presented in **Table 2**. Nutrient use is higher than crop removal in most crops with the exception of N use in maize (1.11), rice (1.07), and for K_2O in beans (1.20)—all due to low nutrient use in these crops.

Potassium use is most balanced in soybean which has a removal-to-use ratio of 0.99, followed by rice (0.86) and sugarcane (0.85). Almost all crops show low P removal-to-use, but maize, rice and sugarcane are exceptions with values of 0.96, 0.75 and 0.72, respectively.

Coffee has the lowest set of removal-to-use values for N (0.14), P_2O_5 (0.10) and K_2O (0.20). Coffee is traditionally grown with a high level of technology and the crop receives large annual applications of nutrients. However, this study does reveal the need to improve agronomic management in coffee through possible use of crop rotation or cover crops that can promote crop nutrient uptake, reduce losses, and increase nutrient use efficiency.

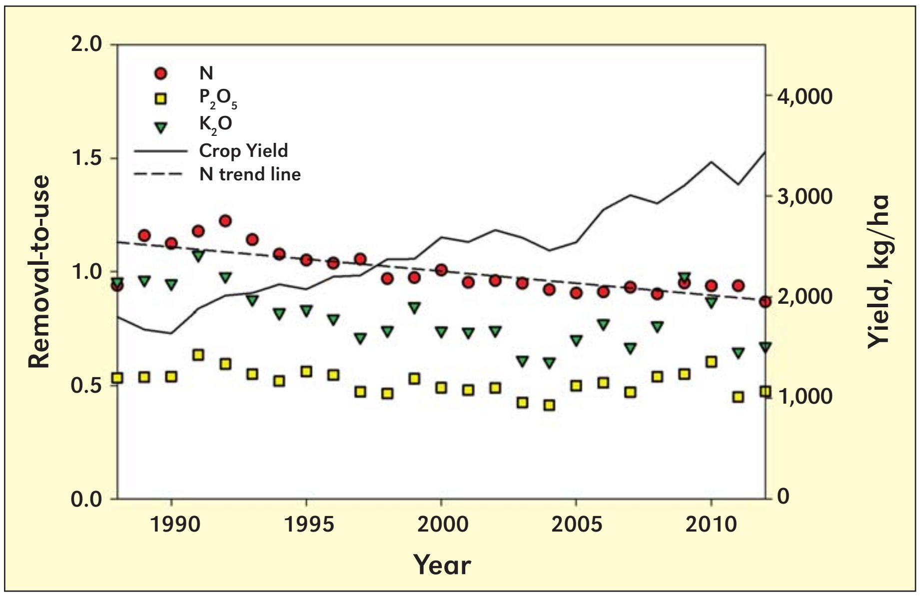


Figure 1. Ratio of N, P_2O_5 and K_2O removal-to-nutrient use by main crops, and average crop yield in Brazil. (Adapted from Cunha et al., 2011).

Looking Further Back

In order to extend this analysis back to represent removal-to-use prior to 2009, trends in N, P and K budgets between 1988 and 2012 are provided in **Figure 1**. The data shows that N removal was higher than N input up until the late 1990s. After this period, N use has increased due to the adoption of more intensive cropping systems with higher inputs, especially for sugarcane, orange, coffee, and maize. The N removal-to-use ratio reached 0.87 in 2012. Phosphorus removal-to-use has essentially remained constant at 0.60. However, K_2O use has behaved similarly to N, following the same increasing use trend towards the current removal-to-use value of 0.67. Potassium showed a dramatic increase in removal-to-use in 2009 (0.98), which reflects a time of economic crisis and a response by farmers to decrease K input to their cropping systems.

The steady growth in nutrient use within this time frame has been effective at improving crop production in Brazil. The annual average yield of Brazilian agriculture, considering the same list of 18 crops mentioned above, is reflected by a steadily ascending line. In 1990, the yield was around 1,700 kg/ha and after 20 years has increased to 3,440 kg/ha in 2012.

Brazilian agriculture has featured high nutrient consumption in support of significant crop production increases over these recent decades. But crop production in this region is also conducted in a vast area of tropical soils with native properties that do not allow adequate nutrient use efficiency without proper agronomic management. Nutrient budgets have been performed periodically to help identify fertilizer use gaps in crops or regions, as well as to forecast future demands. In this

IPNI Photo/E. Francisco

Soybean harvest in Mato Grosso: its production leads nutrient use in Brazilian agriculture.

context, educational initiatives aimed at educating farmers and agronomists on how to assess the best performance of nutrient inputs are crucial to promote fertilizer use efficiency, minimize nutrient loss, and increase crop production sustainability. BC

Dr. Francisco is Deputy Director (Midwest Region), IPNI Brazil Program; e-mail: efrancisco@ipni.net. Dr. Cunha is an Agronomist and Consultant with Tec-Fértil; e-mail: cunha@agroprecisa.com.br. Dr. Prochnow is Director, IPNI Brazil Program; e-mail: lprochnow@ipni.net. Dr. Casarin is Deputy Director (North and Northeast Region), IPNI Brazil Program; e-mail: vcasarin@ipni.net

References

ANDA. Associação Nacional para Difusão de Adubos. 2010-2013. Anuário estatístico do setor de fertilizantes. São Paulo, SP.

Cunha, J.F., E.A.B. Francisco, V. Casarin, and L.I. Prochnow. 2014. Informações Agronômicas, No. 145, IPNI - Brasil. Piracicaba, SP.

Cunha, J.F., V. Casarin, and L.I. Prochnow. 2011. Informações Agronômicas, No. 135, IPNI - Brasil. Piracicaba, SP.

Cunha, J.F., V. Casarin, and L.I. Prochnow. 2010. Informações Agronômicas, No. 130, IPNI - Brasil. Piracicaba, SP.

IBGE. Instituto Brasileiro de Geografia e Estatística. 2010-2013. Levantamento Sistemático da Produção Agrícola, No. 23-26. Rio de Janeiro, RJ.

Yamada, T., and A.S. Lopes. 1998. Informações Agronômicas, No. 84, IPNI - Brasil. Piracicaba, SP.

Fertilizer Industry Round Table Recognition Award Deadline is August 30

Criteria

1) The award recognizes outstanding achievements in research, extension and/or education that centers on fertilizer technology and associated benefits to agricultural productivity and sustainability.
2) Applicant will be judged based on research originality, quality and practical application as demonstrated by concrete results, letters of recommendation, dissemination of findings, contribution to sustainability, and potential for international application.
3) Applicant must be a resident of Canada or the United States.

Application Procedures

1) Electronic copy of three letters of support. If a student, one should be from the major professor.
2) A description of the focus of the research presented to be evaluated on originality, scope, innovation and potential application.
3) Award recipients are not eligible for more than one award.
4) Priority will be given to those who support FIRT's mission.
5) Questions and application materials should be directed in electronic form to: DMessick@sulphurinstitute.org.

Fertilizer Industry Round Table

Selection Process - A panel of three individuals will select the award winner. The panel will consist of representatives from academia, industry and an environmental-focused entity.

Award - US$2,500 and travel to FIRT's annual conference.

Modern Soybean Varieties' Nutrient Uptake Patterns

By Ross R. Bender, Jason W. Haegele and Fred E. Below

Many soybean fertility recommendations are derived from research conducted during the 1930s to 1970s, and may not be adequate in supporting the nutritional needs of the greater biomass accumulation and seed yield associated with current soybean germplasm and production systems. Furthermore, no recent data exist that document the cumulative effects of improved soybean varieties, fertilizer source and placement technologies, and plant health/plant protection advancements on the rate and duration of nutrient accumulation in soybean. A more comprehensive understanding of soybean's nutritional requirements may be realized through this evaluation of the season-long nutrient uptake, partitioning and remobilization patterns in soybean.

Soybean was originally introduced to United States agriculture as a highly digestible, legume-based forage feedstock. More recently, soybean has been selected for improved seed yield potential, which has increased by four-fold since 1924 (USDA-NASS, 2014). The concentrated nutrient sink of soybean seeds, along with greater yields, creates greater demand for uptake and remobilization during reproductive development, especially compared to benchmark studies conducted during the 1930s to 1970s (Borst and Thatcher, 1931; Hammond et al., 1951; Hanway and Weber, 1971). As a result, the objective of this research was to reassess the mineral nutrition needs of soybean by quantifying season-long nutrient uptake, partitioning and remobilization in modern soybean varieties.

The study was conducted at DeKalb (2012 and 2013) and Champaign, IL (2013) using sites maintained in a corn-soybean crop rotation. A 2.8 relative maturity (RM) and 3.4 RM variety were planted at each site to achieve a final stand of approximately 145,000 plants/A. A fertility treatment included 75 lbs P_2O_5/A as MicroEssentials® SZ™ (12-40-0-10S-1Zn) (The Mosaic Company, Plymouth, MN) banded below the soil surface immediately before planting and 60 lbs K_2O/A as KCl broadcast and incorporated before planting (2013 only), collectively, and was compared to an unfertilized control. Dry matter production and accumulation of N, P, K, S, Mg, Ca, Zn, B, Mn, and Cu were determined at seven incrementally-spaced growth stages: V4 (fourth trifoliate), V7 (seventh trifoliate), R2 (full bloom), R4 (full pod), R5 (beginning seed), R6 (full seed), and R8 (full maturity) (Pedersen, 2009). Biomass collection crates were used to collect senesced leaf and petiole tissues. Each plant was then separated into stem (stems and petioles), leaf (individual leaves), reproductive (flowers and pods), and grain tissue components. All data are reported on a DM basis (0% moisture concentration).

Nutrient Uptake and Removal

Averaged across three site-years and corresponding treatment combinations, mean biomass and grain yield were 8,500 lbs DM/A and approximately 60 bu/A (13% grain moisture concentration), respectively. The fertility treatment resulted in an increase in total DM (+9%) and grain yield (+3%) and therefore greater nutrient accumulation. Because DM allocation and nutrient partitioning to these plant tissues were similar across fertility and varietal differences, nutrient accumulation was averaged across treatments in the data presented.

Table 1. Nutrient accumulation associated with producing, on average, 60 bu/A of soybean grain.

Parameter	Maximum total uptake	Removal with grain	Harvest index	Nutrient removal coefficient†
Macronutrients	lbs/A		%	lbs/bu
N	245	179	73	2.98
P	19	15	81	0.25
P_2O_5	43	35	81	0.58
K	141	57	41	0.95
K_2O	170	70	41	1.17
S	17	10	59	0.17
Mg	45	8	18	0.13
Ca	101	9	9	0.15
Micronutrients	oz/A		%	oz/bu
Zn	4.78	2.00	42	0.033
B	4.64	1.58	34	0.026
Mn	5.30	1.31	25	0.022
Cu	0.90	0.56	62	0.0093

† Multiply grain yield by nutrient removal coefficient to obtain the quantity of nutrient removal. Maximum total nutrient uptake, removal with grain, and harvest index (percentage of total nutrient uptake present in the grain) of macro- and micronutrients were averaged over treatments at DeKalb (2012 and 2013) and Champaign (2013).

Agronomic production practices and soil conditions with a capacity to supply nutrients at the listed quantities in **Table 1** would be expected to meet soybean nutritional needs for an average yield level of approximately 60 bu/A. The potential for nutrient accumulation in soybean has increased by two- to three-fold during the past 80 years as a result of increased DM production and grain yield (Borst and Thatcher, 1931). Mean grain yield values presented in this study are approximately 30 to 40% greater than the current United States average (USDA-NASS, 2014) and the presented nutrient accumulation information may serve as a resource for anticipated improvements in soybean yield.

Grain nutrient HI values are relative indicators of nutrient partitioning to soybean grain tissues, quantified as the ratio of grain nutrient removal to total nutrient accumulation. Nutrients with high requirements for production (e.g., N, K, Ca) or those that have a high HI value (e.g., N, P, S, Cu) may indicate key nutrients for high yield (**Table 1**). On average, over 80% of accumulated P was removed with harvested soybean grain tissues. Similarly, N, S, and Cu each resulted in nutrient harvest indices greater than 50%. Harvest index values for N, P, and S are similar to previously published values; however, K HI has

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cu = copper; Mn = manganese; Zn = zinc; KCl = potassium chloride; DM = dry matter (0% moisture concentration); HI = harvest index, percentage of total nutrient uptake present in the grain; RM = relative maturity.

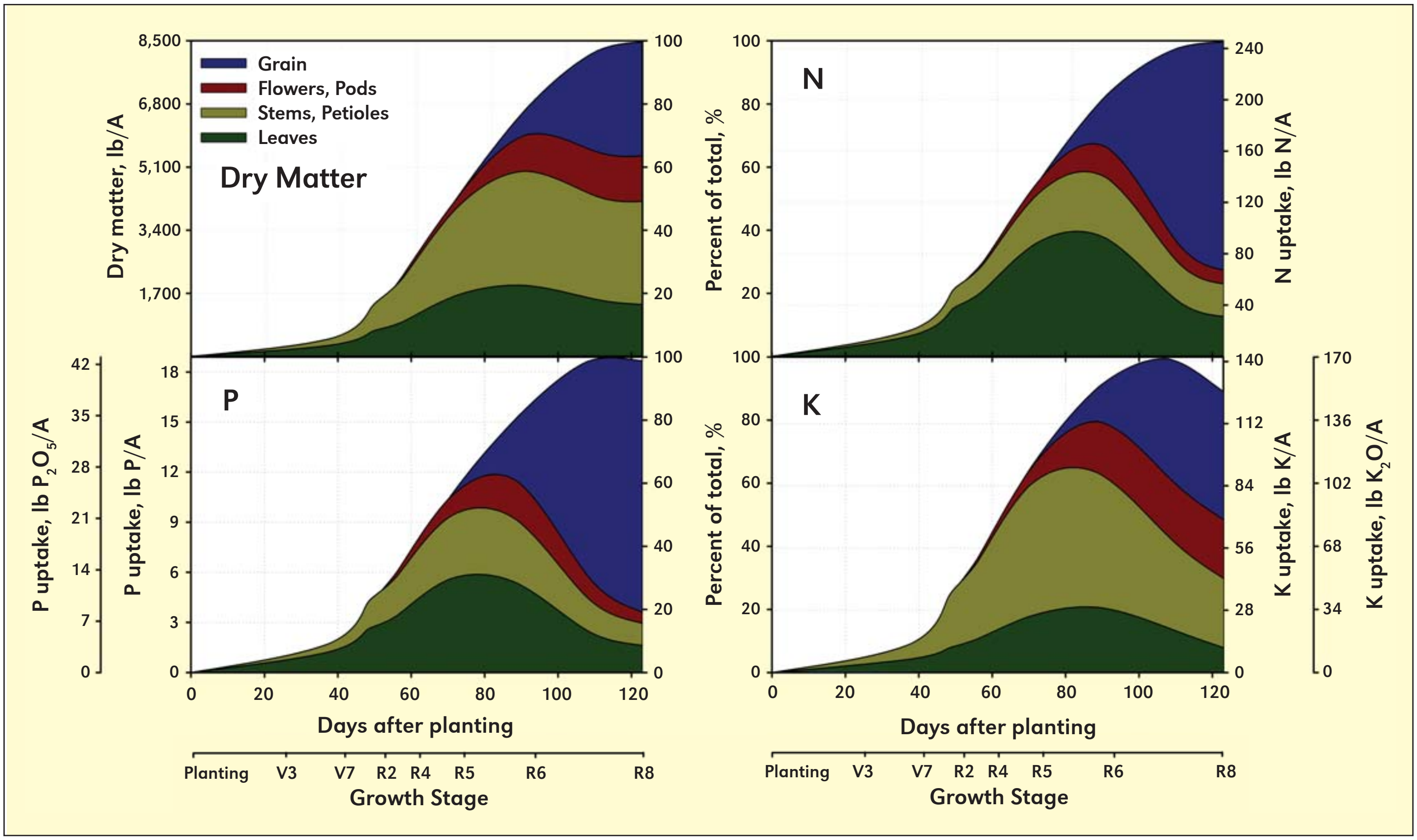


Figure 1. The seasonal accumulation and partitioning of dry matter, nitrogen (N), phosphorus (P, P_2O_5), and potassium (K, K_2O) for an average yield level of 60 bu/A as measured across three site-years during 2012 and 2013.

decreased from nearly 70% (Hammond et al., 1951) to 41% in the current study (**Table 1**). Agronomic production practices that harvest non-grain plant tissues for animal bedding or feed sources, commonplace in key cattle producing regions, may remove, compared to grain harvest, up to an additional 66 lb N, 4 lb P (8 lb P_2O_5), 84 lb K (100 lb K_2O), 7 lb S, 37 lb Mg, 92 lb Ca, 2.78 oz Zn (16 oz = 1 lb), 3.06 oz B, 3.99 oz Mn, and 0.34 oz Cu per acre (**Table 1**).

Time and Rate of Nutrient Uptake

The rate and time of acquisition varied among nutrients and were associated with specific vegetative or reproductive growth periods. Nearly 75% of K uptake occurred before the onset of seed filling (**Figure 1**) compared to the uptake of N, P, S, Mg, Ca, Zn, B, Mn, and Cu, which were more evenly distributed during vegetative and seed-filling growth phases (**Figures 1, 2** and **3**). With the exception of K, maximum rates of nutrient uptake were consistent across macro- and micronutrients and tended to occur during a brief period that bracketed R4. Unlike the rapid uptake of mineral nutrients before tassel emergence in maize (Bender et al., 2013a), nutrient uptake in soybean more closely coincided with DM accumulation, producing a steady, season-long pattern of nutrient assimilation. Soybean nutrient uptake patterns closely resemble those published during the last 80 years (Borst and Thatcher, 1931; Hammond et al., 1951; Hanway and Weber, 1971), although in modern cultivars, the proportion of total nutrient accumulation acquired during seed-filling has increased over time. The differences are especially apparent for N, P, Mg, and Ca, which have increased by as much as 18% during this part of the reproductive period. Collectively, these findings suggest that the improved yield of soybean has concomitantly increased the potential for nutrient accumulation.

Nutrient Use

Grain acquired nutrients from a combination of 1) direct partitioning to developing grain tissues, and 2) nutrient remobilization from leaf, stem, or flower and pod tissues. Nutrients with relatively high (greater than 50%) HI values included P, N, Cu, and S (**Table 1**). Nutrient remobilization from other tissues complemented nutrient acquisition during seed filling to meet grain nutrient demands.

Consistent with earlier studies, the amount of grain N and P obtained from remobilization was as much as 4-fold greater from leaf versus stem tissues. The opposite was discovered with K where approximately twice the amount of K was remobilized from stem compared to leaf tissues. Although the magnitude of K remobilization from existing stem tissues had not been previously documented, these data reinforce the importance of season-long nutrient availability and the utility of existing plant tissues as reservoirs to accommodate intra-seasonal periods of elevated nutrient demand.

Implications for Soybean Production

Intensified agronomic production practices and improved varieties have contributed to greater soybean yields than ever before and provide the driving force for greater nutrient accumulation. From a historical perspective, routine fertilizer applications of K were potentially used to maximize total biomass, especially during the introduction and populariza-

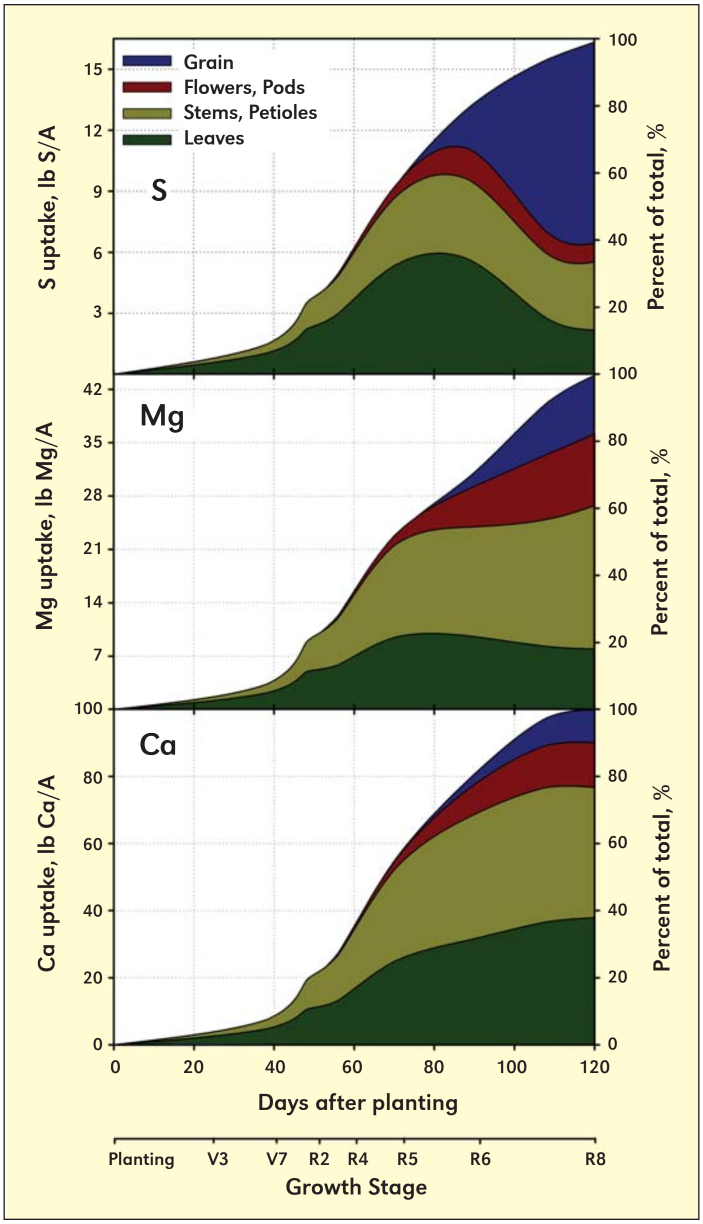


Figure 2. The seasonal accumulation and partitioning of sulfur (S), magnesium (Mg), and calcium (Ca) for an average yield level of 60 bu/A as measured across three site-years during 2012 and 2013.

tion of soybean as a forage legume in the United States. After comparing current data to initial soybean nutrient uptake research (Borst and Thatcher, 1931), newer soybean varieties selected for high seed yield have increased HI values for DM (+11%) and P (+13%) with a simultaneous reduction in K HI (-17%). Altered DM and nutrient harvest indices with substantial increases in the percentage of total nutrient accumulation during seed-fill necessitate precise nutrient management for current production systems. Although total P accumulation measured approximately half that of a maize crop yielding 230 bu/A (Bender et al., 2013a and 2013b), similar P HI values of nearly 80% suggest that P removal in corn/soybean systems is significant and needs to be monitored closely to ensure adequate nutrient replacement rates. The partitioning of K in soybean has different agronomic implications. The low K HI places emphasis on the cycling of K from various depths in the soil to the plant and eventually to the soil surface as K leaches from plant tissues, beginning after R6 (**Figure 1**). This process may promote the stratification of K in soil, particularly under reduced tillage systems.

Soybean assimilates a substantial amount of N during its growth due to the high protein concentration of the grain. Although the current study did not distinguish between N acquired from the soil versus N acquired through symbiotic N_2 fixation, past literature suggests that, on average, the soybean plant obtains approximately 50% of its N from N_2 fixation when supplied 22.5 lb N/A as in this study (Salvagiotti et al., 2008). Also, roots and nodules comprise approximately 4.8% of the total plant N (Schweiger et al., 2014), so would contribute 12 lb N/A to the total. Given the total accumulation of 245 lb N/A (grain + vegetative) and 12 lb N/A in the roots, we can assume that approximately half, or 129 lb N/A, was obtained from N_2 fixation. Harvesting the soybean grain removed 179 lb N/A and would thus result in soil depletion and a negative N balance of nearly 50 lb N/A.

Conclusions

The primary objective of this research was to quantify nutrient uptake, partitioning and remobilization using current soybean varieties in modern soybean production systems. Biomass production, grain yield, and, for some nutrients, harvest indices have risen during the last 80 years, resulting in concurrent increases in nutrient accumulation. Patterns of biomass production and nutrient accumulation are presented for an average yield of approximately 60 bu/A and are most suitable for producers targeting this yield level. Although nutrient acquisition was most rapid between R3 to R4 for measured nutrients, patterns of nutrient accumulation revealed intra-seasonal differences in the timing of nutrient acquisition. Uptake of K primarily occurred during late vegetative and early reproductive growth in contrast to uptake patterns of N, P, S, Mg, Ca, Zn, B, Mn, and Cu, which were more evenly distributed throughout the entire growing season. Consequently, soil conditions and agronomic practices that also ensure nutrient availability through late-season reproductive growth would be expected to meet soybean fertility needs for these nutrients.

During seed-filling, grain tissues acquired nutrients through remobilization and season-long nutrient accumulation. Four nutrients had HI values greater than 50%: P (81%), N (73%), Cu (62%), and S (59%), reinforcing the need for adequate nutrient availability during reproductive growth.

The findings in this study provide insight into the dynamics of nutrient accumulation in modern varieties of soybean and are expected to contribute to improvements in agronomic recommendations. In particular, this study indicates that proper soybean nutrition requires adequate nutrient availability throughout the growing season, including late-season reproductive growth. BC

Acknowledgment

The authors wish to thank The Mosaic Company for their financial support of this research. The article is an excerpt from a research paper appearing in Agron. J. 2015:107:563-573.

Dr. Bender is a Graduate Research Assistant, University of Illinois at Urbana-Champaign, located in Urbana, Illinois; e-mail: bender14@illinois.edu. Dr. Haegele is a Research Scientist, DuPont Pioneer, located in Ivesdale, IL; e-mail: jason.haegele@pioneer.com. Dr. Below

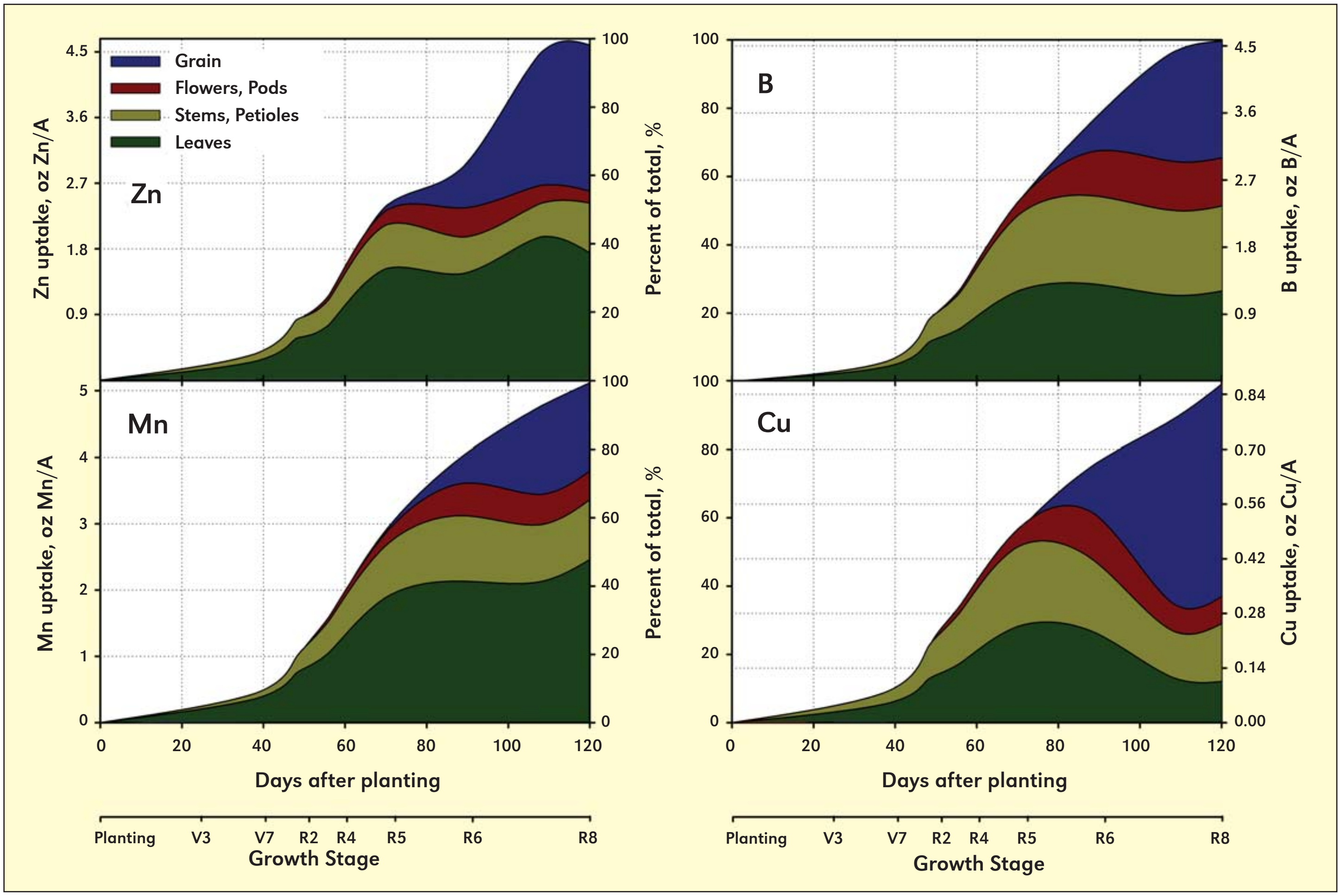


Figure 3. The seasonal accumulation and partitioning of zinc (Zn), boron (B), manganese (Mn), and copper (Cu) for an average yield level of 60 bu/A as measured across three site-years during 2012 and 2013.

is a Professor of Crop Sciences, University of Illinois at Urbana-Champaign, located in Urbana, Illinois; e-mail: fbelow@illinois.edu.

References

Bender, R.R, J.W. Haegele, M.L. Ruffo, and F.E. Below. 2013a. Agron. J. 105:161-170.

Bender, R.R, J.W. Haegele, M.L. Ruffo, and F.E. Below. 2013b. Better Crops with Plant Food 97:7-10.

Borst, H.L., and L.E. Thatcher. 1931. Ohio Agr. Exp. Sta. Bul. 494:51-96.

Hammond, L.C., C.A. Black, and A.G. Norman. 1951. Iowa Agr. Exp. Sta. Res. Bul. 384:463-512.

Hanway, J.J., and C.R. Weber. 1971. Agron. J. 63:406-408.

Pedersen, P. 2009. Spec. Publ. PM1945. Iowa State Univ. Coop. Ext. Serv., Ames.

Salvagiotti, F., K.G. Cassman, J.E. Specht, D.T. Walters, A. Weiss, and A. Dobermann. 2008. Field Crops Res. 108:1-13.

Schweiger, P., M. Hofer, J. Vollmann, and W. Wanek. 2014. Physiol. Plant. 152:546-557.

USDA-NASS. 2014. National statistics for soybean: soybean, grain – yield, measured in bu/acre. Statistics by Subject. USDA National Agricultural Statistics Service.

Role of Soil Productivity in Nutrient and Water Use in Zimbabwe

By Natasha Kurwakumire, Regis Chikowo, Adrian Johnston, and Shamie Zingore

Addressing soil variability is a critical part of making site-specific fertilizer recommendations. Research in Zimbabwe evaluated crop yield responses on soils varying in organic carbon content. The research confirms balanced nutrient management had an overriding effect on maize grain yield and water productivity, but only when soil organic carbon (SOC) was >4 g/kg soil.

Dr. Regis Chikowo, University of Zimbabwe addresses local farmers at a field experiment site.

The challenges of inherently poor soil fertility, prohibitive costs and limited access to crop production inputs, and recurrent droughts have plagued smallholder farmers in Zimbabwe for generations. Rainfed agriculture is the most common practice, and as little as 20 to 40% of seasonal rainfall is used in crop production due to high runoff and evaporation. Poor nutrient and soil water availability has resulted in maize grain yields rarely exceeding 1.5 t/ha on these farms for the past 5 to 6 decades.

Historic management of farms, including fertilizer and manure management, straw return and erosion, have led to significant spatial variation between and within farms. While soil types impact some of this variation, resource endowment and preferential application of fertilizer and manure close to the homestead have accentuated these productivity gradients (Zingore et al., 2007). Given the impact of these gradients on nutrient use efficiency and yields across farms, targeting nutrient application tactfully becomes an important management practice for resource-constrained farmers (Vanlauwe et al., 2006, 2011).

It is important to point out that a number of soils in sub-Saharan Africa have been classified as "poorly or non-responsive" due to complex chemical imbalance and poor physical structure which inhibit crop response to fertilizers (Vanlauwe et al., 2002, 2011; Zingore et al., 2007). Unfortunately, fertilizer recommendations in Zimbabwe are based on the assumption of resource (soil and water) homogeneity and differentiated only by agro-ecological zone. This study was carried out to assess the response of maize to fertilizer inputs across a gradient of soil quality, and evaluate how nutrient management impacted both grain yield and water productivity.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; AN = ammonium nitrate; KCl = potassium chloride; SSP = single superphosphate.

The study was carried out in Dendenyore Ward, Wedza District of Eastern Zimbabwe. This region has annual precipitation of >800 mm and a mean temperature of 24°C during the November to April production season. The soils are sandy Lixisols with low SOC and poor nutrient supply potential. The trials were conducted on three farms, all within a 1 km radius, and varying in SOC. Type 1 soils had ≤4 g SOC/kg soil, Type 2 with >4 to 6 g SOC/kg soil, and Type 3 with >6 g SOC/kg soil. Productivity, historic input management, and clay content increased from Type 1 to Type 3 soils.

Fertilizers were applied using five treatments, including: 1) control; 2) N and K (AN + KCl); 3) NPS (SSP + AN); 4) PKS (SSP + KCl) and 5) NPKS (compound fertilizer 7-14-7-8 + AN + KCl). Target nutrient rates were 120-40-60-22 kg N-P_2O_5-K_2O-S/ha, with 20 N and all P, K and S applied at planting and 50 N at two advanced growth stages. In year 2 of the study, the target rate was changed to 120-20-30-11 kg/ha. However, in both years of this project, drought conditions prevented the second N split, so only 70N was applied.

Maize grain yields were significantly increased by the addition of fertilizers on all soils of the study area in both years

Dr. Chikowo demonstrates the yield gap using plots that received NPKS fertilizer versus the zero fertilizer check.

Table 1. Maize grain yields response to fertilizer additions on three soils differing in soil organic carbon (SOC), 2011/12 and 2012/13.

Soil Type		Check	NK	NPS	PKS	NPKS	$LSD_{0.05}$
		- - - - - - - - - - -	Grain yield, kg/ha	- - - - - - - - - - -			
Type 1	Year 1	280	400	1,400	310	1,465	198
≤4 g SOC	Year 2	200	730	1,360	240	1,440	210
Type 2	Year 1	1,000	1,720	2,900	1,300	3,190	200
>4 to 6 g SOC	Year 2	810	2,373	3,653	1,200	3,400	200
Type 3	Year 1	1,100	2,400	3,700	1,690	3,750	250
>6 g SOC	Year 2	1,200	1,378	3,200	1,100	3,560	190

(**Table 1**). The low SOC Type 1 field did not show a grain yield response to NK or PKS in year 1; however, the site did respond to the NPS and NPKS treatments. This indicates that these Type 1 soils are nutrient responsive and would not be categorized as non-responsive soils. In almost all cases, no difference was observed between the NPS and NPKS treatments, suggesting that indigenous soil K supply was sufficient to meet yields approaching 5 t/ha. The abundance of feldspar minerals in these granite-derived sandy soils in Zimbabwe provided an adequate K reserve at these yield levels (Nyamapfene, 1991).

The check yield for Type 1 soils was only one-quarter to one-sixth the yield of the check for Type 2 and 3 soils, indicating the significant impact of higher SOC on crop productivity. Similarly, compared to the check, the grain yield response for the NPKS treatments was 5 to 7 times for Type 1 soils, and 3 to 4 times for Type 2 and 3 soils. The NPKS yield for Type 1 soils was only marginally greater than the check yields of Type 3 soils, indicating a large yield gap that is associated with low soil organic matter, soil acidity, and possible deficiency of secondary and micronutrients. These maize yield responses clearly illustrate that fertilizer recommendations must be made on a site and soil specific basis in order to take into account these vast differences in production potential.

In this study, field Types 2 and 3 had comparable yields, supporting the existence of a critical SOC threshold of about 4.6 g/kg soil (Mtambanengwe and Mapfumo, 2005). Confirmation of this helps farmers in the allocation of scarce organic resources to those low SOC fields where the greatest improvement in productivity can be achieved. The responses from this range of soils also illustrate that for a modest application of fertilizer nutrients, very large yield increases can be captured, illustrating the productive potential of these soils in meeting future food security needs in Zimbabwe.

Similar to the grain yield responses, water productivity showed a significant positive increase with fertilizer additions on all soil types (**Table 2**). The positive role that balanced nutrition plays in improving the grain production per unit of rainwater is clearly illustrated in this study. Having a flexible system of fertilizer N application, where the second top dress application could be applied only with sufficient soil moisture, provided the farmers with the opportunity to reduce losses from unnecessary input additions. This type of flexibility becomes critical as part of any crop productivity enhancement program in rainfed regions.

Table 2. Water productivity as influenced by nutrient management across three experimental sites, 2011/12 and 2012/13.

Soil Type		Check	NK	NPS	PKS	NPKS	$LSD_{0.05}$
		- - - - - - - - - - -	kg grain/mm rain	- - - - - - - - - - -			
Type 1	Year 1	0.33	0.37	1.68	0.48	1.76	0.16
≤4 g SOC*	Year 2	0.22	0.82	1.53	0.27	1.62	0.20
Type 2	Year 1	1.20	1.83	3.49	1.82	3.84	0.18
>4 to 6 g SOC	Year 2	0.91	2.66	4.10	1.35	3.82	0.15
Type 3	Year 1	1.19	3.54	4.09	2.03	4.42	0.17
>6 g SOC	Year 2	1.35	1.55	3.59	1.23	4.00	0.23

*SOC = soil organic carbon.

The results of this study clearly show that balanced nutrient management had an overriding impact on maize grain yields and water productivity, but this effect only occurred when SOC was greater than 4 g/kg soil. These results highlight the importance of management of limited organic resources in smallholder farming systems, and support the targeting of these resources on low SOC fields where the potential for greatest improvement in productivity can be achieved. BC

This paper is a summary for Better Crops from the manuscript published in Field Crops Research 164 (2014) 136-147.

Ms. Kurwakumire is an M.Phil. graduate and Dr. Chikowo is a Professor of Agronomy, University of Zimbabwe, Harare, Zimbabwe. Dr. Johnston is Vice President IPNI Asia, Africa & Middle East Group. Dr. Zingore is Director, IPNI sub-Saharan Africa Program.

References

Mtambanengwe, F. and P. Mapfumo. 2005. Nutr. Cycl. Agroecosyst. 73:227-233.
Nyamapfene, K. 1991. Soils of Zimbabwe. Nehandra Publishers, Harare, Zimbabwe.
Vanlauwe, B., J. Diels, O. Lyasse, K. Aihou, E.N. Iwuafor, N. Sanginga, and J. Deckers. 2002. Nutr. Cycl. Ecosyst. 62:139-150.
Vanlauwe, B., J. Kihara, P. Chivenge, P. Pypers, R. Coe, and J. Six. 2011. Plant Soil 339:35-50.
Vanlauwe, B., P. Tittonell, and J. Mukalawa. 2006. Nutr. Cycl. Agroecosyst. 76:171-182.
Zingore, S., H.K. Murwire, R.J. Delve, and K.E. Giller. 2007. Agric. Ecosyst. Environ. 119:112-126.

Changes in Soil Quality Indicators under Oil Palm Plantations Receiving Best Management Practices

By N. Pauli, C. Donough, T. Oberthür, J. Cock, R. Verdooren, Rahmadsyah, G. Abdurrohim, K. Indrasura, A. Lubis, T. Dolong, J.M. Pasuquin, and M. Fisher

The effect of best management practices (BMPs) to intensify oil palm production and improve yield were evaluated in Indonesia and Malaysia. While no clear, consistent differences were found in the soil properties between BMP and reference (REF) treatments over four years, improvements in soil pH and % soil organic carbon (SOC) were recorded for both treatments. The study found no significant deterioration in the measured soil properties over the four years, suggesting that appropriate management practices for oil palm can improve several aspects of soil quality.

Adoption of IPNI BMPs over four years led to an extra 3.5 to 6.5 t C/ha/yr in soils under oil palm.

Indonesia and Malaysia produce 87% of the world's palm oil of 53 million t/yr, which is around 30% of the world's production of vegetable oil. Demand for vegetable oil has increased linearly since the 1970s, while demand for palm oil has grown exponentially because of its lower cost. Production has increased through area expansion, with planted area to oil palm in Kalimantan, Borneo of 903 km^2 in 1990, 8,360 km^2 in 2000, and 31,640 km^2 in 2010. This expansion was into tropical forest, both intact and logged, old rubber plantations, and peat lands. Forest accounted for 55 to 90% of the area expansion in Malaysia and Indonesia, with negative impacts on biodiversity, C accumulation, and food security.

Abbreviations and notes: N = nitrogen; P = phosphorus; C= carbon. IPNI Project # IPNI-2005-SEAP-3

Instead of increasing the area of palm oil plantations, further demand could be met by increasing current yields, which historically have grown by only 1% per yr for the past 30 years up to 2005. Better management can increase yields of palm oil from the average 4 t/ha to 5 to 6 t/ha, or as much as 8 t/ha in good years. Breeding for better yields is also feasible, but is a longer-term objective, while better management offers the possibility of better plantation performance in the short term.

Better management covers many aspects of crop and plantation operations, ranging from crop hygiene, site-specific rates and methods of fertilizer application, harvest frequency, and so on. IPNI has developed a set of BMPs best described as those agronomic practices that reduce the gap between current site yield and potential yield.

Over four years, the BMP treatment improved the harvest

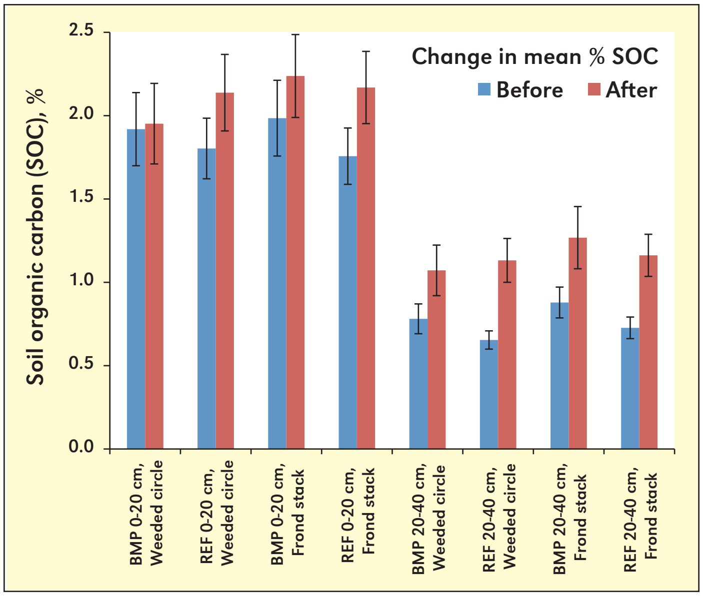


Figure 1. Change in mean soil organic carbon for each unique comparison of management, soil depth and soil sample location. n = 30 for each data point. Error bars represent the range. 'Before' refers to measurements taken at the commencement of the field trial. 'After' measurements were taken four years later at the conclusion of the trial.

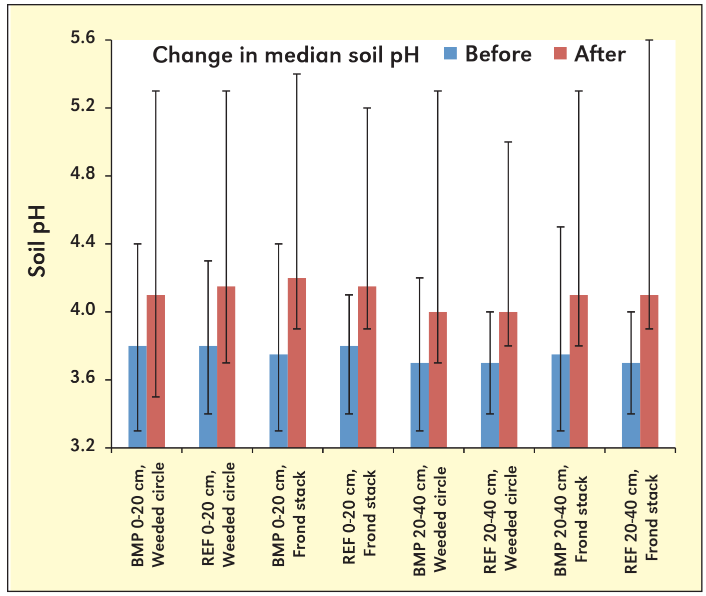


Figure 2. Change in median soil pH for each unique comparison of management, soil depth and soil sample location. n = 30 for each data point. Error bars represent standard error. 'Before' refers to measurements taken at the commencement of the field trial. 'After' measurements were taken four years later at the conclusion of the trial.

by increased crop recovery and also by increased crop productivity. Yield improvements at the six sites ranged from 1.5 to 5.4 t of fresh fruit bunches per ha (Pasuquin et al., 2014). It is not known, however, what impact BMP might have on soil properties compared with standard plantation management. The objective of the experiment was to compare the effect of BMP compared with standard management on a range of soil properties across representative sites in Indonesia.

Six sites were chosen in Indonesia on the islands of Sumatra and East Kalimantan, located over 3.5° of latitude and almost 17° of longitude. The climate for all sites was humid equatorial with rainfall varying from 1,900 to 3,100 mm. Four sites experience no water stress during the year; one has water deficits in some years, while the sixth has severe water deficits in many years. Mean annual temperatures of the six sites were similar, 26.6 to 27.1°C. Most sites were flat, with some undulating to hilly areas in places. Soil texture varied from clay to loamy sand.

A palm plantation consists of several estates (2,000 to 5,000 ha) within which the smallest management unit is a block (25 to 30 ha). We identified one commercial partner plantation at each of the six study sites. Within each selected plantation, five pairs of blocks were distributed over 1 to 5 estates. Estates within a selected plantation were no more than 30 km apart.

Each pair consisted of two adjacent blocks with similar terrain and soils, using soil surveys if they were available or on-site selection if not. The blocks within each pair were as similar as possible, sown in the same year with seed from the same source, had the same management history, especially fertilizer, and similar yields.

One block of each pair was allocated to estate management (REF), the second received IPNI's BMPs. BMP varied between sites but in general, blocks were harvested more frequently (at intervals no more than 7 to 8 days compared to 10 to 13 days). There was little difference in fertilizer applications except increased P from 80 to 180 kg/ha at site 1 in North Sumatra.

In some blocks close to the oil mills, empty fruit bunches (EFB) were applied to the inter-row area in the BMP treatment aiming for 40 t/ha/yr. BMP included removing senescent fronds and surplus fronds to achieve a leaf area index of 5 to 6. Removed fronds were stacked between the rows of palms. On some but not all blocks, BMP included additional drainage, culling unproductive and diseased palms, removing woody weeds and epiphytes, and control of insect pests.

Each block was sampled on a fixed grid, 30 to 36 points depending on the area of the block, 1 m from the trunk (within the weeded circle), and also under the stack of fronds in the inter-row space. Soils were sampled 0 to 20 cm and 20 to 40 cm at the start and end of the experiment. Samples within a block were bulked and sub-sampled (500 g) for analysis of texture, pH, SOC, total N, available P and exchangeable cations.

BMP vs. REF Blocks

Soil properties did not differ significantly between the BMP and REF blocks after the four years of the trial. This was unexpected, especially as the BMP blocks yielded more than the REF blocks. Certainly, the variability between paired blocks in commercial plantations makes it difficult to show statistical significance in a period as short as four years. Moreover, estate managers may have incorporated some of the aspects of BMP into REF management.

While soil analysis was not a useful indicator of oil palm yield, soil pH and SOC both increased in the BMP and the REF treatments during the four years of the experiment (**Figure 1 and 2**). The increase in median pH varied between 0.3 to 0.45 units in both the BMP and REF blocks and at both soil depths. The differences were greater under the frond stacks than under the weeded circle.

Differences in SOC were almost statistically significant.

The most important feature was that SOC percentage increased by about the same amount in the 20 to 40 cm depth as in the surface soil, with a range 0.03 to 0.48%. If we ignore the lowest figure, the range is 0.25 to 0.48%. At a bulk density of 1.4 g/cm^3, common in plantation soils, the increase in SOC is 14 to 26 t/ha over the four years of the experiment (to 40 cm depth), or 3.5 to almost 6.5 t C/ha/yr.

These are very high figures, but show considerable opportunity to contribute as potential sinks for atmospheric CO_2. Fisher et al. (1994, 1997) showed that an introduced African oil palm-type on the eastern plains of Colombia accumulated C as deep as 80 to 100 cm. It would be worthwhile in future work to sample the soil to at least 1 m. As might be expected, the increases were greater under the frond stacks than in the weeded circles around each palm. This contrasts with the observation of increasing soil acidification and decreased carbon stocks under oil palm plantations reported elsewhere. The question clearly requires further work.

Summary

The results show that with reasonable management, soil quality under oil palm can improve. It may be that in the longer term, BMP may be shown statistically better than standard plantation management. It would be useful to revisit these sites in 10 years' time.

There was no significant deterioration in the soil properties measured over the four years of study. However, in both management treatments soil pH and SOC increased, indicating that appropriate oil palm management techniques can help improve soil quality. Further research on the mechanisms by which BMPs can improve soil quality, and monitoring over longer periods of time is recommended to give plantation managers a clearer picture of the potential 'co-benefits' that can be obtained with adoption of BMPs designed to increase oil palm yield. BC

This paper is a summary for Better Crops from the paper published in Agriculture, Ecosystems and Environment 195 (2014) 98-111.

Dr. Pauli is with the School of Earth and Environment, University of Western Australia, Crawley, WA, Australia. Mr. Donough (Consultant), Dr. Oberthür (Director), Dr. Cock (Consultant), Dr. Verdooren (Consultant) are with the International Plant Nutrition Institute, Southeast Asia Program, Penang, Malaysia (e-mail: toberthur@ipni.net). Rahmadsyah is with Wilmar International, Indonesia. Dr. Abdurrohim is with PT Sampoerna Agro Tbk, Indonesia. K. Indrasuara is with Bakrie Agriculture Research Institute (BARI), PT Bakrie Sumatera Plantations Tbk, Indonesia. A. Lubis is with Permata Hijau Group, Indonesia. T. Dolong is with PT REA Kaltim Plantations, Indonesia. Dr. Pasuquin is with the International Rice Research Institute, Los Baños, Philippines. Dr. Fisher is with the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

References

Fisher, M.J., I.M. Rao, M.A. Ayarza, C.E. Lascano, J.I. Sanz, R.J. Thomas, and R.R. Vera. 1994. Nature (London) 371:236-238.

Fisher, M.J., R.J. Thomas, and I.M. Rao. 1997. *In* R. Lal, J. Kimble, R. Follett, and B.A. Stewart (eds.), Management of carbon sequestration in soil. Adv. Soil Sci. Series. Boca Raton, Florida: Lewis Publishers, 405-420.

Pasuquin, J.M., J. Cock, C.R. Donough, T. Oberthür, Rahmadsyah, G. Abdurrohim, K. Indrasuara, T. Dolong, and S. Cook. 2014. Better Crops with Plant Food 98:13-16.

IPNI Science Award – Nominations Are Due September 30, 2015

Each year, the International Plant Nutrition Institute (IPNI) offers its IPNI Science Award to recognize and promote distinguished contributions by scientists. The Award is intended to recognize outstanding achievements in research, extension or education; with focus on efficient management of plant nutrients and their positive interaction in fully integrated crop production that enhances yield potential. Such systems improve net returns, lower unit costs of production, and maintain or improve environmental quality.

Past Winners

2014: Dr. A. Halvorson, from USDA-ARS.
2013: Minimum requirements for the award were not met.
2012: Mr. A.E. Johnston of Rothamsted Research.
2011: Dr. M.J. McLaughlin of the CSIRO.
2010: Dr. A.N. Sharpley of the University of Arkansas.
2009: Dr. J.K. Ladha of the International Rice Research Institute (IRRI).
2008: Dr. J. Ryan of the International Center for Agricultural Research in Dry Areas (ICARDA).
2007: Dr. M. Singh Aulakh of Punjab Agricultural University (PAU), India.

The IPNI Science Award requires that a nomination form (no self-nominations) and supporting letters be received at IPNI Headquarters by September 30, 2015. Announcement of Award recipient will be on December 15, 2015.

An individual Award nomination package will be retained and considered for two additional years (for a total of three years). There is no need to resubmit a nomination during that three-year period unless a significant change has occurred.

All details and nomination forms for the 2014 IPNI Science Award are available from the IPNI Awards website http://ww.ipni.net/awards.

Optimal Rates for Corn Nitrogen Depend More on Weather than Price

By Bill Deen, Ken Janovicek, John Lauzon, and Tom Bruulsema

Corn yield response to N fertilizer varies from year-to-year owing to weather. Optimal N rates depend on the yield response, and also vary with the price ratio between fertilizer and corn. In a trial in Elora, Ontario, optimal N rates over six years varied more than three times as much due to differences in weather as compared to differences in price ratio. While small profit gains can be achieved by adjusting N rates for price ratio, there is much more potential profitability and environmental benefit to be gained in better adapting N management to weather.

Over the past decade, the price of corn has fluctuated considerably. From 2011 to 2013 Ontario farmers received some of the highest prices ever, while market forces during 2014 and 2015 eroded prices to their lowest levels in five years. This decline has led many producers to reconsider N application rates. The economically optimal N rate (EONR) depends on the ratio between N and corn prices. A falling corn price reduces optimal rates of N, but the producer often lacks information to answer the question, "by how much?" In this study, we used data from two sources, the Ontario Corn N Database, and a long-term N trial, to quantify relationships of EONR to prices, and to compare to weather effects on EONR.

The Ontario Corn N Database includes data on grain yield response to fertilizer N from field experiments conducted from 1962 to 2013. An earlier version was described by Janovicek and Stewart (2004). The database was queried to generate a subset of 213 trials conducted between 1990 and 2013—with previous crops of soybean, dry edible bean, forage grasses (no legumes) and small grains (mostly winter wheat), not following cover crops (including red clover)—a minimum of four N rates, and non-N limited grain yield of at least 110 bu/A. To characterize yield response to N rate, data from the Ontario Corn N Database was fitted with a quadratic plateau response model.

A long-term N trial with continuous corn was established at Elora, ON in 2009. The soil at the experimental site is a Guelph loam with pH 7.7, silt 48%, clay 20%, and soil organic matter 4.5%. Over the six years of the trial, agronomic management factors were held constant, except that fall chisel plowing was re-

Abbreviations and notes: N = nitrogen; \$ = Canadian dollar. IPNI Project # IPNI-2008-CAN-ON29


IPNI2015TBR04-1217

Excellent growing conditions in 2013 led to high yields and high optimal N rates.

Table 1. Average farm-level prices paid and received in Ontario, Canada.

	2009	2010	2011	2012	2013	2014
Fertilizer N price, $/lb	0.79	0.51	0.60	0.74	0.67	0.62
Corn price, $/bu	4.14	5.26	6.16	6.61	5.89	4.67
Price ratio, lb corn/lb N	10.7	5.5	5.4	6.3	6.3	7.4

Source: McEwan (2015) and Kumuduni (2015).

Table 2. Economically optimal N rate decreases as price ratios increase. The changes are small except when fertilizers become extremely expensive relative to corn.

	Low-yielding trials[2] 110-160 bu/A		High-yielding trials[2] > 160 bu/A	
Price ratio[1], lb corn per lb of N	Optimal rate, b/A	Yield, bu/A	Optimal rate, lb/A	Yield, bu/A
4.5	120	138	149	185
5.4	116	137	144	185
6.7	110	136	137	184
10.7	91	134	119	182
13.7	79	131	108	179

[1] Mean price ratio in Ontario from 2009-2014 was 6.7; annual means varied from 5.4 to 10.7.
[2] n = 113 and 100 response trials for low and high yield groups, respectively, in the Ontario Corn N Database.

Table 3. Profit gain comparing scenarios for N rates.

Rate scenario comparison	2009	2010	2011	2012	2013	2014
	-------- Profit gain, $/A --------					
Actual versus average price ratio[1]	1.94	0.27	0.25	0.03	0.02	0.08
Actual EONR versus 150 lb N/A[2]	6.70	8.94	8.82	8.71	59.29	26.90

[1] Actual ratio for each year from Table 1 as compared to the average ratio of 6.7 for the period.
[2] 150 lb N/A is the rate recommended by the Ontario Corn N Calculator for the average yield attained.

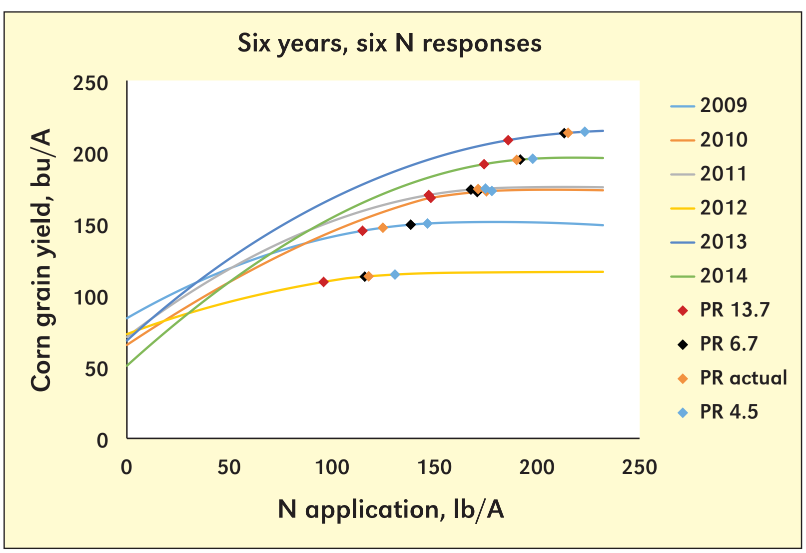


Figure 1. Curves indicate fitted corn grain yield response to applied N at Elora, Ontario. Points indicate the economically optimal N rates for price ratios (PR) varying from 4.5 to 13.7 lb corn per lb of N.

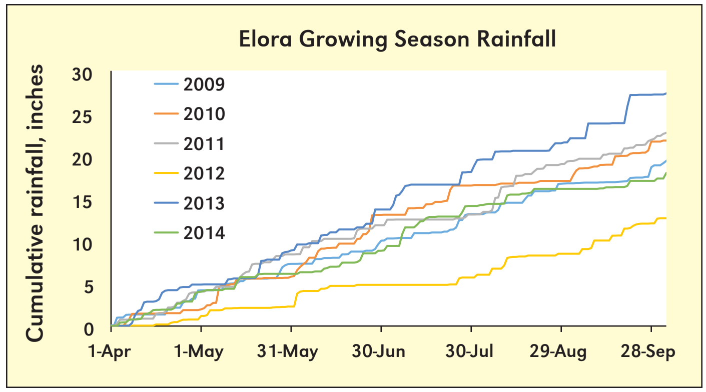


Figure 2. Rainfall accumulation differences during the growing season explained much of the variation in yield and optimal N rate.

placed by fall moldboard plowing from the fall of 2010. The hybrid for the first five years was Pioneer 38B14, and was changed to Dekalb DKC39-97 in 2014. Weather was the major factor that varied among years. At planting, all plots received 27 lb N/A as a starter. Each year, additional rate treatments were applied for total annual N rates of 27, 52, 78, 129, 195, and 232 lb/A. These rates were applied across four treatments involving preplant and sidedress timings, and histories of different N rates applied to the previous corn crop. Responses were averaged over timing and history. With four replications, each year's response curve was supported by a total of 160 data points. Curves were fit using the Crop Nutrient Response Tool V4.5 (Bruulsema, 2015), which uses an R^2-weighted mean of five response functions, providing precision for detailed comparisons of scenarios for profitability.

Price ratio (PR) was defined as the cost of fertilizer divided by the cost of grain. Economically optimal N rates were defined as the rate at which the last increment of added N generated a yield response equal in value to that of the added N.

Results

Price ratios varied considerably among years (**Table 1**), even when based on annual average prices. The average N price divided by the average corn price for 2009 to 2014 produced a price ratio of 6.7 lb of corn per lb of N. Considering that within each year, some producers may pay more for fertilizer and receive less for their corn than others, the scenarios shown in **Table 2** were extended to include a wider range of price ratios, based on half the reported variation in fertilizer prices, and assuming ±10% variation in corn prices. The changes in optimal N rates, relative to a price ratio of 6.7, were largest when price ratios increased to the high end of the range (levels which occurred only in 2009). Changes were similar for both the low and high yielding subgroups of trials. A reduction in EONR corresponds with a reduction in corn yield. Producers reducing rates in response to high fertilizer prices and low corn prices may see yield reductions of 3 to 5%, across the range of price ratios shown in **Table 2**.

In the Elora field trial, yield responses to N varied widely among years (**Figure 1**). Yield varied by 100 bu/A in response to water availability each year (**Figure 2**). The driest year, 2012, produced the lowest yields and showed the lowest optimal N rates. The highest yielding year, 2013, had unusually high rainfall in late June and early July. Even though it followed the drought year, it also showed the highest optimal N rates.

Optimal N rates varied from 118 to 215 lb N/A over the six years (**Figure 1**). This year-to-year variation was more than three times greater than the average range of rates arising from adjusting for the extremes of price ratio within a year. Since these year-to-year differences depend on weather, they are difficult to predict. Nevertheless, some of the yield variation could have been predicted by mid-June each year by simply looking at rainfall data as in **Figure 2**. Modeling tools could also make predictions of N mineralization and losses by that time. Producers are able to apply N at growth stages even beyond mid-June. These data point to a large potential opportunity to improve optimal rate prediction by using tools to incorporate measured and forecast weather data into mid-season N application decisions.

The economic value of a scenario in which actual EONR is implemented, as compared to a recommendation of 150 lb N/A derived from the Ontario Corn N Calculator, is shown in **Table 3**. These values for potential profit were calculated from the response functions shown in **Figure 1** and the prices shown in **Table 1**. The potential profit gain from addressing year-to-year variability greatly exceeds the profit that can be expected by making adjustments each year for actual price ratios.

The benefits of addressing weather-related variability in N response increase further when environmental impacts are also considered. Measurements of soil nitrate and long-term effects on soil organic N will be reported in future articles. Nitrous oxide emissions have been monitored for two years and are reported in Roy et al. (2014). Matching the N applied to year-specific crop N demand has large potential to reduce surplus N available for losses. BC

Dr. Deen (e-mail: bdeen@uoguelph.ca) and Dr. Janovicek are with the Department of Plant Agriculture, University of Guelph, Guelph, ON, Canada. Dr. Lauzon is with the School of Environmental Science, University of Guelph.

References

Bruulsema, T.W. 2015. Crop Nutrient Response Tool, http://nane.ipni.net/article/NANE-3068, Accessed 30 March 201 IPNI, Guelph, ON, Canada.

Janovicek, K.J. and G.A. Stewart. 2004. *In* Proceedings of the 34th North Central Extension-Industry Soil Fertility Conference. Des Moines, IA, USA. pp. 12-19.

Kumuduni, 2015. Historical Provincial Estimates by Crop, Ontario Ministry of Agriculture, Food, and Rural Affairs, http://www.omafra.gov.on.ca/english/stats/crops/estimate_hist_metric.htm#Grain Corn, Accessed October 20, 2014.

McEwan, K. 2015. Ontario Farm Input Monitoring Project, University of Guelph, Ridgetown, ON, Canada. http://www.ridgetownc.uoguelph.ca/research/research_reports_profile.cfm?profile=mcewan&name= Ken McEwan Accessed 30 March 2015.

Roy, A.K., C. Wagner-Riddle, et al. 2014. Can. J. Soil Sci. 94:563-573.

IPNI Crop Nutrient Deficiency Photo Contest—The Rules for 2015

The International Plant Nutrition Institute (IPNI) is continuing its sponsorship of its plant nutrient deficiency photo contest during 2015 to encourage field observation and increase understanding of crop nutrient deficiencies. To get up-to-date, here is our list of rules for this year's contest:

1. In addition to the four nutrient categories (N, P, K and Other Nutrients - secondary and micronutrients), our **Feature Crop** category for 2015 is focused on **Root and Tuber Crops** (e.g., Potato, Sweet Potato, Cassava, Carrot, Beets, etc.)

2. Our list of prizes is as follows:

- US$300 First Prize and US$200 Second Prize for Best Feature Crop Photo.
- US$150 First Prize Awards and US$100 Second Prize Awards within each of the N, P, K and Other Nutrient categories
- In addition, all winners will receive the most recent copy of our USB Image Collection. For details on the collection please see http://ipni.info/nutrientimagecollection

3. Specific supporting information is required for all entries, including:

- The entrant's name, affiliation and contact information.
- The crop and growth stage, location and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors and additional details that may be related to the deficiency.

4. Photos and supporting information can be submitted until **Wednesday, December 9, 2015 5pm EST** and winners will be announced in early 2016. Winners will be notified and results will be posted at www.ipni.net.

Nutrient Requirement for Natural Rubber

By Debasis Mandal, Bhaskar Datta, Mrinal Chaudhury, and Sushil Kr Dey

The need to improve fertilizer application within the mature rubber plantations of Tripura, India is apparent given the importance of the crop and the poor fertility soils upon which it is grown. Field study suggests an application of 60 kg N and 60 kg P_2O_5/ha along with an insurance application of K increased rubber yield significantly. Fertilizer response curves and soil test-based fertilizer application rates suggest a general fertilizer recommendation of 45 kg N, 45 kg P_2O_5 and 40 kg K_2O/ha for mature rubber plantations.

Rubber is a crop of primary importance for Tripura, which has about 67,700 ha under cultivation. It is the second largest rubber-producing state after Kerala. Rubber yield is higher in Kerala, but quality is comparable between the two state's plantations. Tripura's production is challenged in the face of poor soil fertility status. The rubber-growing soils of these northeastern (NE) states of India are highly weathered, and the essential cations have been leached out of the soil profile due to high rainfall. A highly acidic soil environment with poor plant-available nutrient status prevails (Mandal et al., 2013). A majority of the plantations in Tripura are affected from past shifting cultivation practices where slash and burn techniques removed much of the organic residue and thus created low organic matter soil.

Studies highlight that rubber trees respond well to fertilizer, particularly in challenging scenarios where soils are nutrient poor (Singh et al., 2005). Balanced fertilizer recommendations during immature and mature periods of rubber tree production have been considered an important management option for optimal plantation growth and yield. Such recommendations were formulated by the Rubber Research Institute of India (RRII) based on various field experiments carried out in Kerala and other traditional rubber-growing tracts. However, there is a need to modify these recommendations for northeastern India, as the nutrient requirement for rubber is likely to be higher due to poorer soil fertility.

This article describes the fertility status of rubber soils of Tripura and common fertilizer recommendations prescribed to growers. Data on crop response to NPK combinations has led to a proposed revision to fertilizer use in mature rubber plantations of the region.

Table 1. Soil fertility status (0 to 30 cm depth) in rubber fields (n = 2,102) of Tripura.

Soil status	Content	No of samples	% Samples	Fertilizer recommendation	Common application
Organic C (OC)					
Soil status	OC content in soil, %	No of samples	% Samples	Fertilizer N recommendation	Common application, kg N/ha
Low	0.5 to 0.75	726	35	Raise by 15 to 20%	42 to 45
Medium	0.75 to 1.5	1,284	61	Raise by 0 to 5%	35 to 38
High	>1.5	92	4	Lower by 5 to 10%	30 to 32
Available P (Bray-P2 extractable)					
Soil status	Avail. P, mg/100g	No of samples	% Samples	Fertilizer P recommendation	Common application, kg P_2O_5/ha
Low	<1	2,040	97	Raise by 15 to 20%	42 to 45
Medium	1 to 2.5	44	2.2	Raise by 0 to 5%	35 to 38
High	>2.5	18	0.8	Lower by 5 to 10%	30 to 32
Available K (Sodium acetate extractable)					
Soil status	Avail. K, mg/100g	No of samples	% Samples	Fertilizer K recommendation	Common application, kg K_2O/ha
Low	<5	1,150	55	Raise by 15 to 20%	40 to 45
Medium	5 to 12.5	876	42	Raise by 0 to 5%	35 to 38
High	>12.5	76	3	Lower by 5 to 10%	30 to 32

Soil Fertility Status

Historical soil sampling by RRII Tripura between 2003 and 2010 has collected about 2,100 samples from grower's fields across the state. Data from samples collected at 0 to 30-cm depth are provided in (**Table 1**).

Soil pH is predominantly acidic with values commonly varying from 3.9 to 5.9. About 35% of sampled soils had organic carbon (OC) values below critical values (<0.75%) and 61% of soils have medium status (0.75 to 1.5%). Soil organic carbon is a significant determinant for N recommendations and critical low OC values stress a need of maintaining N application rates at adequate levels.

In case of available P, 97% of soils are well below critical values. Available P varied from 0.01 to 5.2 mg/100 g, and the majority of soils fall under the very low-to-low category.

Available K concentrations range from 1.5 to 60 mg/100g. About 55% of the soils are low in available K and 42% show medium values. The soils of northeast India also contain relatively high amounts of exchangeable Mg, which can compete with plant K uptake (Singh et al., 2005). Moreover, K plays a significant role in rubber latex flow from the tree. Given this, optimum K application is especially important to consider.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; g/t/t = grams/tree/tapping; LSD = least significant difference.

Rubber Responses to Fertilizer

Two long-term field studies are used to illustrate the response of Tripura's rubber plantations to fertilization. The first study is an RRII experimental farm in Taranagar, with RRIM 600 clone trees established in 1980. Three levels of N (0, 30, 60 kg/ha), three levels of P_2O_5 (0, 30, 60 kg/ha), and three levels of K_2O (0, 20, 40 kg/ha) were used within 6 m x 6 m plots (**Table 2**). The plants were opened for tapping in 1988 when 70% of plants attained a mean trunk girth of 50 cm at 150-cm height. Yield of individual trees from the sixteen inner plants/plot were recorded, and the annual mean yield (gram/tree/tap) was calculated between 1991 and 2002. Fertilizer and yield response curves for N and P are provided in **Figures 1 and 2**.

The economic product of rubber is latex. Latex is collected by controlled wounding (tapping) of bark of the trees. The tree trunk shown, was divided into two panels and one part of the tree was tapped once in three days for five years, and then switch over to other panel. This type of tapping system is termed as the half spiral once in three days (notation is 1/2Sd/3). The mean annual tapping days is 70.

The second study was started in 1986 at Tulakona, Agartala with the RRIM 600 clone and six treatments (**Table 3**). The plants were opened for tapping during 1994 using a 1/2Sd/3 tapping system. Mean annual tapping days obtained from this trial was 68 and tree stand per ha was 400. Yield was recorded from individual trees between 1995 and 2000.

At Taranagar, a significant yield increase was attributable to N and P, but not to K (**Table 2**). Application of 60 kg N resulted in a significant increase to 41.2 g/t/t. Similarly, application of 60 kg P_2O_5 produced a significant increase to 38.7 g/t/t. Fertilizer response curves suggest a maximum of 47 kg N/ha and 53 kg P_2O_5/ha (**Figures 1 and 2**). A mean annual yield of 46.7 to 47.2 g/t/t, or 1,307 to 1,321 kg/ha (400 trees/ha x 70 tapping days), was obtained between 1991 and 2002. In comparison, average rubber yields in Tripura are 10 to 11% less (Anon, 2013).

At Tulakona, trees also responded to higher rates of fertilizer application (**Table 3**). Application of 30-30-30 kg N-P_2O_5-K_2O/ha produced a yield of 36.7 g/t/t; while 60-60-60 and 90-90-90 produced equally as high yields near 45 g/t/t. Rubber is a deciduous tree that can add 6 to 8 t/ha of leaf material annually to the soil floor, which upon decomposition releases about 94 to 120 kg N, 5 to 7 kg P, and 20 to 25 kg K for plant uptake (Varghese et al., 2001). This recycled source of nutrients remains an important factor to consider in the overall nutrient management plan of rubber plantations.

Table 2. Effect of NPK on latex yield, Taranagar, Tripura (1991-2002).

Treatment[1], kg/ha	Yield, grams/tree/tap
0 N	32.6
30 N	35.8
60 N	41.2
0 P_2O_5	31.6
30 P_2O_5	35.3
60 P_2O_5	38.7
0 K_2O	34.6
20 K_2O	36.2
40 K_2O	36.9
LSD (p = 0.05)	2.98

[1]Grand mean of the nine possible combinations.

Table 3. Effect of NPK on latex yield, Tulakona, Tripura (1995-2000).

Treatment, kg N-P_2O_5-K_2O/ha	Yield, grams/tree/tap
30-30-30	36.7
60-60-60	44.8
90-90-90	45.3
LSD (p = 0.05)	4.7

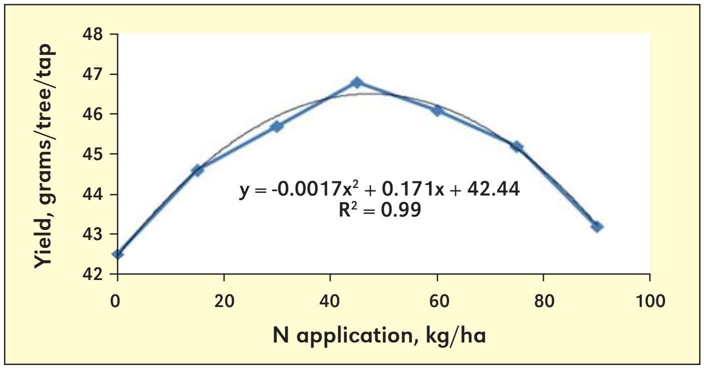


Figure 1. Fertilizer N response curve for rubber, Tripura.

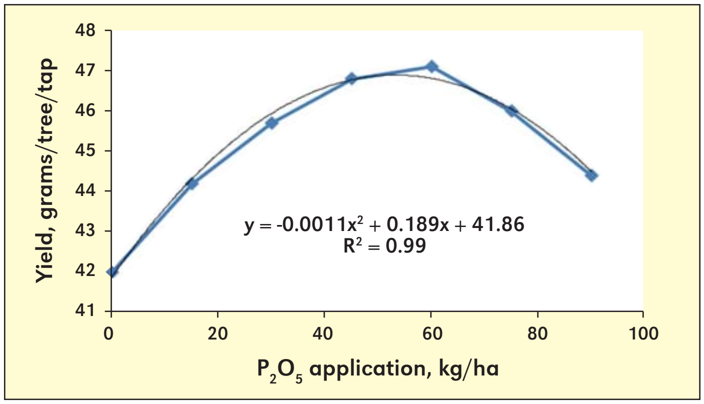


Figure 2. Fertilizer P response curve for rubber, Tripura.

Summary

Evidence suggests a need to modify the present recommendations of N, P and K for the mature rubber plantations of Tripura. The majority of soils fall within the low-to-medium fertility range for N, P and K. It is recognized that recommendations for these responsive soils should be raised by 15 to 20% for low testing soils and by 5% for medium testing soils. Considering the poor nutrient status of soils in this region, fertilizer-yield response studies, and common fertilizer recommendations, a generalized balanced fertilizer application of 45-45-40 kg N-P_2O_5-K_2O/ha would create significant benefit to Tripura's rubber growers. BC

Dr. Mandal is Sr. Scientist (e-mail: dmandal@rubberboard.org.in), Mr. Datta is Scientist and Dr. Dey is Joint Director attached with the Regional Research Station, Rubber Research Institute of India in Agartala, India; Dr. Chaudhury was Sr. Scientist (e-mail: mrinalrrii@yahoo.com) with the Regional Research Station, Rubber Research Institute of India in Guwahati, India.

References

Anon. 2013. Rubber in Tripura. Zonal Office, Rubber Board, Agartala, India (unpublished).

Mandal, D., T.K. Pal, M. Joseph, and S.K. Dey. 2013. Rubber Board Bulletin 31:4-9.

Singh, R.P., D. Mandal, J. Mercykutty, A.C. Sarma, C.K. Gupta, and A.K. Krishnakumar. 2005. Natural Rubber Res. 18:161-171

Varghese, M., A.C. Sharma, and J. Pothen. 2001. Indian J. Natural Rubber Res. 14:116-124.

Singh, R.P., D. Mandal, J. Mercykutty, and A.C. Sarma. 2010. Natural Rubber Res. 23:28-36.

4R Potassium Management Practices for Cotton in Northern China

By Shutian Li, Yan Zhang, Rongzong Cui, and Suli Xing

Potassium fertilization is important for higher lint yield and better quality of cotton in northern China, but its application remains inadequate within the region. Research demonstrates a benefit to combined applications of preplant K used along with an in-season K topdressing. Fertilizer K source had little consistent impact on the agronomic response, but economics often governs source selection for the farmer. Banding at depth and drip fertigation can significantly improve K use efficiency where these placement options are available.

Cotton is the major fiber crop that is grown in 25 provinces of China, covering a total area of 5 million (M) ha and producing 6.5 M t of lint. In northern China, cotton is mainly planted in Xinjiang, Henan, Hebei, and Shandong and accounts for over 67% of the total area and production in China. Many farmers in northern China rely on cotton as their main cash crop.

Cotton requires more K than most other field crops. Potassium can improve plant photosynthesis, metabolism and resistance to diseases like anthocyanosis or "bronze-wilt" disease. Therefore, K fertilization plays an important role in improving lint yield and quality. Many studies (Pettigrew et al., 1996; Oosterhuis et al., 2014) have reported reduced fiber length, maturity and micronaire in cotton crops not adequately supplied with K. Despite this, fertilizer K is used in insufficient amounts in cotton production in northern China. Also, K is generally applied once before planting using compound fertilizer sources, and is rarely applied again during the growing season. This has led to lower cotton yields and poor fiber quality, which in turn, impacts farmer income. This review details how application of the 4R principles of nutrient stewardship for K application (i.e., applying fertilizer K using the right source at the right rate, right time, and right place) can often boost yields and improve cotton quality in northern China.

Right Source

There are many K fertilizer sources, but KCl and K_2SO_4 are widely used in northern China's cotton production. The source of K can often have little effect on the allocation of dry matter throughout the cotton plant, but economic differences between products commonly dictate source preferences. Sulfur containing sources such as K_2SO_4 is the preferred K fertilizer in S-deficient soils, and has a low salt index and non-hygroscopic characteristics.

Physical properties of K sources may also affect cotton yield and quality. For example, Wang et al. (2011) indicated that granular KCl could slowly release K to soil, which was better for cotton at later growth stages as it helped to reduce K leaching. Mid-season development of K deficiency in cotton often appears in northern China due to the high K demand during flowering, or following periods of high rainfall, particularly on sandy soils.

Table 1. Total plant K uptake by cotton plant to produce 1 t of cotton lint at various application rates of K in three provinces of northern China.

----- Hebei -----		---- Shandong ----		----- Xinjiang -----	
K applied, kg K_2O/ha	Total plant K uptake, kg K_2O/t	K applied, kg K_2O/ha	Total plant K uptake, kg K_2O/t	K applied, kg K_2O/ha	Total plant K uptake, kg K_2O/t
0	68	0	89	0	145
38	80	30	93	20	145
75	77	60	99	38	149
150	89	120	99	75	150
225	85	180	104	112	148
300	89	240	106	150	150

Regions with low rainfall or little irrigation have risks associated with possible over accumulation of Cl^- in the soil profile when using KCl. In these areas, excess Cl^- is not readily leached out of the surface soil and can contribute to soil salinity (Kafkafi et al., 2001). It is important to understand the Cl^- balance for a soil-crop system to determine the appropriate amount of KCl or ratio of KCl to K_2SO_4 when used together.

Right Rate

The total plant K uptake by cotton generally exceeds that of N and P. IPNI experiments in northern China show that cotton requires a total uptake of 68 to 150 kg K_2O/ha to produce 1 t of lint (**Table 1**). Cotton yield and the corresponding K uptake are commonly higher in Xinjiang than in Hebei or Shandong.

The K fertilizer requirement depends on the yield potential

Table 2. Effect of K application timings on cotton lint yield (kg/ha) in three provinces of China.

	---- Hebei ----		--- Shandong ---		---- Xinjiang ----	
Treatment	2012	2013	2012	2013	2012	2013
No K	1,430a	1,370c	1,490b*	1,190c	1,270c	1,530b
100% at planting	1,520a	1,430abc	1,610ab	1,280ab	1,440ab	1,810a
50% at planting, 50% at first flower	1,510a	1,440abc	1,670a	1,340a	1,500a	1,770a
50% at budding, 50% at boll forming	1,540a	1,550a	1,630a	1,230bc	1,520a	1,910a
50% at budding, 50% at boll opening	1,540a	1,510ab	1,620a	1,220bc	1,420b	1,770a
50% at first flower, 50% at boll opening	1,500a	1,400bc	1,570ab	1,210bc	1,380b	1,790a

*Different letters following numbers within columns indicate significant difference ($p < 0.05$)

Abbreviations and notes: N = nitrogen; K = potassium; S = sulfur; Cl^- = chloride; KCl = potassium chloride; K_2SO_4 = potassium sulfate; KH_2PO_4 = potassium phosphate.

Plots comparing K application timings in cotton grown in northern China.

and the soil K status. In soils containing moderate amount of K, maintenance of existing K supplies may be a suitable goal. For example, for a target yield of 1,500 kg/ha on a medium-K soil, the recommended K application rate would range from 104 to 225 kg K_2O/ha, which is about equal to the total plant K uptake when no crop residue is returned to the field. In some areas, the K application rate can be greatly reduced if the residues are returned since only 29 to 45 kg K_2O/ha is commonly removed through harvested lint and seed. In soils with low amounts of K, a common recommendation is to apply enough K to meet the immediate cotton crop need, while adding an additional amount to build soil K concentrations. In the high-K soils of Xinjiang, the K application rate can be somewhat reduced from the recommended maintenance rate, depending on fertilizer cost.

The yield response of cotton to KCl fertilizer varies according to local conditions (**Figure 1**). The optimum economic rates of KCl were calculated as 150, 212 and 136 kg K_2O/ha for cotton in Hebei, Shandong and Xinjiang with soil exchangeable K values of 89, 82 and 177 mg K/kg, respectively.

Right Time

IPNI research has indicated that maximum K uptake occurs between the flowering to boll-forming stages, which accounts for 50 to 60% of the total plant K uptake (**Figure 2**). While not significantly different from applying all K at planting, maximum cotton lint yield was obtained when 50% of the recommended K was applied at planting, and the remaining K topdressed at flowering or boll-forming stage (**Table 2**). Therefore, maintaining a sufficient supply of K during the later cotton growth stage is quite important for yield. This has been attributed to the rooting system of cotton, which is less dense than some other crops, and cotton root growth slows during the boll development period (Pearson and Lund, 1968).

Foliar application of KH_2PO_4 at later growth stages can increased boll number, boll weight, seed yield, lint yield, lint percentage, and promote normal growth and maturity (Wang et al., 2007). Split application of K_2SO_4 between planting and topdressing at early flowering is effective at increasing cotton yield, quality and K use efficiency (Li et al., 2012). Fu et al.

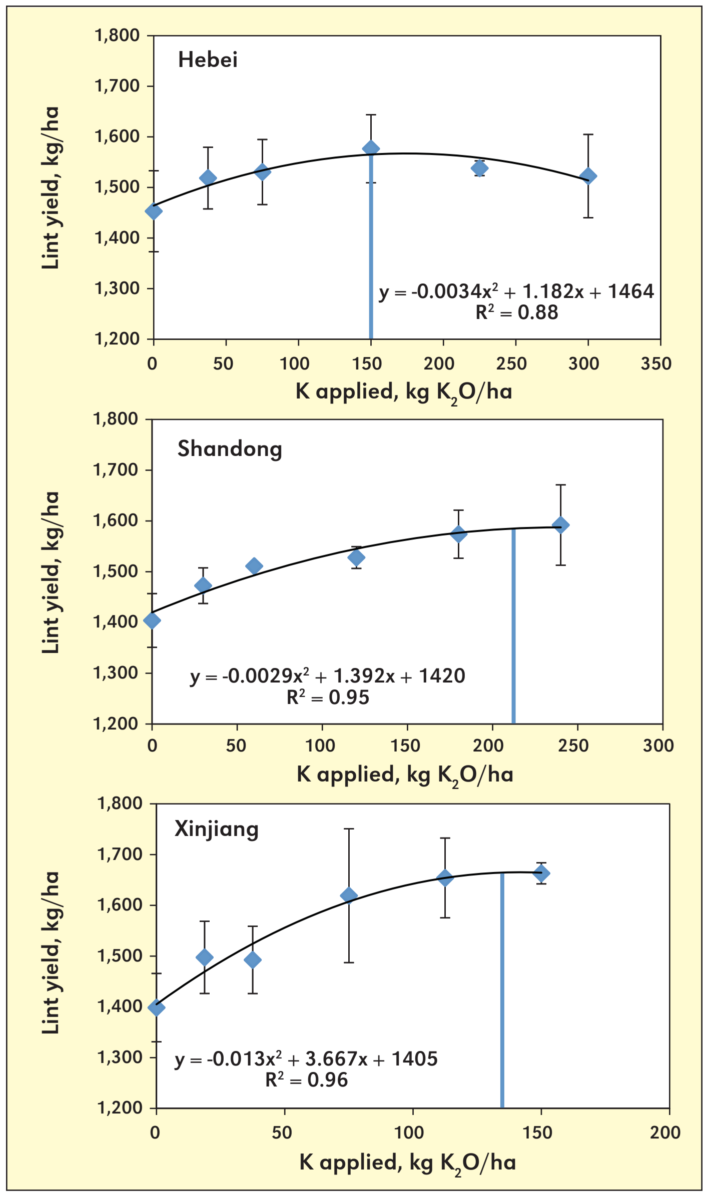


Figure 1. Relationships between fertilizer K rates and cotton lint yield in three provinces of North China.

(2013) and Xu (2013) found maximum seed cotton yield with 120 kg K_2O/ha in two similar split applications.

Right Place

Since cotton is a deep-rooted crop, K fertilizer is best placed at close proximity to this root mass for maximum benefit. Pre-plant application of K fertilizer should be incorporated 20 to 30 cm deep, while fertilizer K applied in-season can be banded 5 to 10 cm away from cotton plants. Cotton seedlings are very sensitive to Cl^- at concentrations of 100 to 200 mg Cl^-/kg of soil, so avoidance of placing KCl in the seed row is often recommended (Kafkafi et al., 2001).

In northern China's drip-irrigated cotton under plastic mulching, fertilizer K is applied with water. Other application methods like deep banding also improve K use efficiency and increase cotton yield. Adeli and Varco (2002) indicated that a combination of band and broadcast application of K fertilizer was more effective in increasing cotton lint yield than either method alone. Specifically, they reported a maximum lint yield with the application of 34 kg K/ha banded plus 136 kg K/ha broadcast.

Summary

This research review provides strong evidence that cotton requires an abundant supply of K, with fertilizer additions balanced between preplant application and an in-season topdress application. While fertilizer K source had little consistent impact on the agronomic response, more economic sources can increase returns to the farmer. Where fertilizer placement is an option, band application or drip fertigation can significantly improve K use efficiency. Careful consideration of K management based on 4R principles can support higher yield and quality in cotton. BC

Dr. Li is Deputy Director, IPNI China Program, Beijing, China; e-mail: sli@ipni.net. Ms. Zhang is Professor, Plant Nutrition and Water Saving Institute, Xinjiang Academy of Agricultural Sciences, China. Mr. Cui is Professor, Institute of Agricultural Resources and Environment, Shandong Academy of Agricultural Sciences, China. Ms. Xing is Professor, Institute of Agricultural Resources and Environment, Hebei Academy of Agricultural and Forestry Sciences.

References

Adeli, A., and J.J. Varco. 2002. J. Plant Nutr. 25:2229-2242.
Fu, X., B. Yuan, Y. Liu, X. Zhang, and Y. Nie. 2013. J. Agri. 3:6-11. (In Chinese).
Kafkafi, U., G. Xu, P. Imas, H. Magen, and J. Tarchitzky. 2001. Int. Potash Inst., Basel, Switzerland; IPI Res. Topics No. 22, pp. 11-15.
Li, Z., E. Chen, M. Zhang, Q. Zhao, X. Xu, H. Ji, X. Song, and X. Sun. 2012. Acta Agronomica Sinica, 38: 487-494. (in Chinese).
Oosterhuis, D.M., D.A. Loka, E.M. Kawakami, and W.T. Pettigrew. 2014. Adv. Agron. 126:203-233.
Pearson, R.W., Z.F. Lund. 1968. Agron. J. 60:442-443.
Pettigrew, W.T., J.J. Heitholt, and W.R. Jr. Meredith. 1996. Agron. J. 88:89-93.
Wang, D., G. Yang, J. Tong, H. Tang, X. Zhou, and Q. Wang. 2011. China Cotton 38(10):2-5. (In Chinese).
Wang, S., B. Zhu, H. Li, C. Zhang, and W. Xiong. 2007. China Cotton, 34(10):16. (In Chinese)
Xu, X. 2013. M.S. Thesis. Shandong. Agri. Univ. (In Chinese).

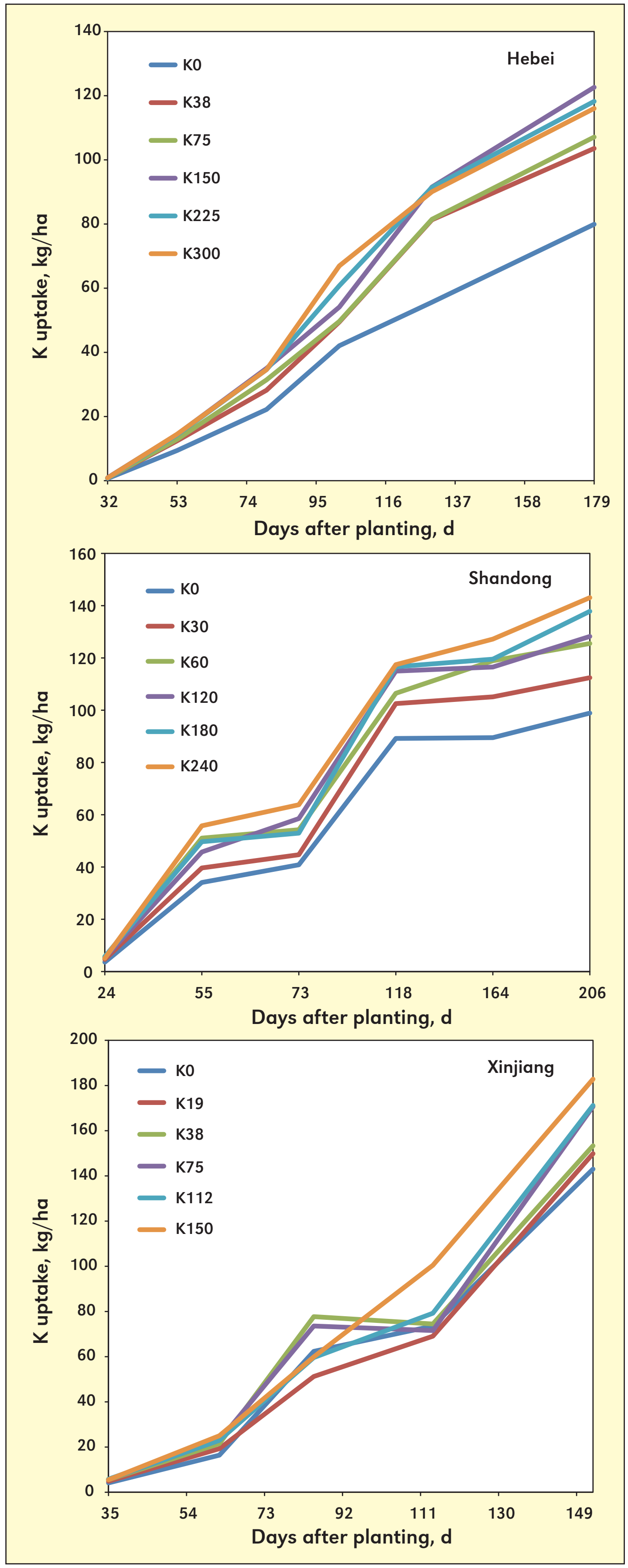


Figure 2. Seasonal K uptake by cotton under different fertilizer K rates (kg/ha) in three provinces of China.

The Next "Big" Thing

In visiting growers and advisers to discuss nutrition within farming systems, the question often comes up about the next great stride in the science around plant nutrition. Is there something obvious we are missing with our current practices?

The list of essential nutrients is still led by large amounts of nitrogen, phosphorus and potassium, moderate amounts of sulfur, calcium and magnesium, and small amounts of boron, chloride, copper, iron, manganese, molybdenum, and zinc. Nickel was the most recent addition to the list, and plants also can benefit from supplies of aluminium, cobalt, selenium, silicon, and sodium.

It seems unlikely this list will extend to the whole periodic table, and so these are what we need to deal with in a healthy soil—which is probably enough to keep most farmers and agronomists scratching their heads.

As farming systems evolve, new angles on the old issues come up. For example, no-till farming can lead to nutrient stratification, different seasons can move nutrients around, high production systems can draw down micronutrients, and changing crops can make some nutrients more or less limited that in previous rotations.

While these are all important to keep in mind, the real next "big" thing is making reasoned and verifiable decisions about how to manage the nutrients we have and those we need to add. 4R Nutrient Stewardship places that process at the center of sustainable farming systems—matching the right source, applied at the right rate, at the right time, and in the right place.

Applying the 4R principles is the next big thing—smart management of those principles we think we understand. There are no "silver bullets"—and anyway silver is not one of the essential nutrients.

BETTER CROPS
International Plant Nutrition Institute
3500 Parkway Lane, Suite 550
Peachtree Corners, Georgia 30092-2844
www.ipni.net

Dr. Robert Norton
Director, IPNI Australia and New Zealand Program