BETTER CROPS
WITH PLANT FOOD

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Higher N Use Efficiency Can Lower River Nitrate Concentrations

Special Note to Our Subscribers - Page 27

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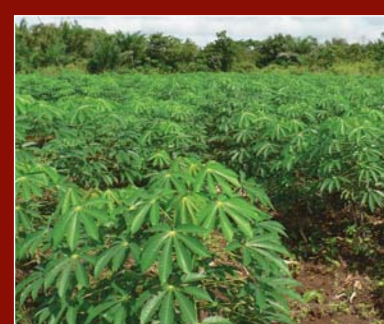

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BETTER CROPS
WITH PLANT FOOD

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Our cover: Aerial photo of the Illinois River and surrounding agricultural landscape.
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C O N T E N T S

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IPNI Program Report - 10 Years of Progress

Available at http://ipni.info/PROGREPORT-2017

2017 marks the 10th Anniversary of the International Plant Nutrition Institute (IPNI). As I look back and consider what we have accomplished over the last ten years, I believe we have achieved much and have made a great difference in nutrient management around the world. We began with 13 founding members; 13 of the global fertilizer industry's leading companies, who had a vision of what IPNI might accomplish. We had 22 scientists covering 7 program areas. Today, we have 30+ scientists covering 13 regional program areas and 3 nutrient focused areas.

IPNI develops and promotes scientific information for the responsible management of plant nutrition. When we were first established we identified 4 strategic goals to guide our activities: leadership on global plant nutrition issues, facilitation of plant nutrient research, enabling education on sustainable use of plant nutrients, and supporting our members. Those goals have served us well and over time have evolved to better recognize and include the central role of the application of 4Rs (right nutrient source, right rate, right time, and right place) in supporting sustainable and responsible nutrient use.

To support our strategic goals, IPNI developed a global tactical plan that identified what we considered as 5 worldwide needs: 4R Nutrient Stewardship, nutrient education, improved fertilizer recommendations, closing yield gaps, and enhancing sustainability. We outlined what we could do to answer those needs and developed program tactical plans that addressed these needs with specific activities at the local level.

This annual report reviews the key issues and needs in each of our programs. It features highlights and priorities from our tactical plan and illustrates accomplishments from implementing our tactical goals, and we provide examples of the impact of IPNI programs.

There are many more achievements and examples that we could show … our intent here is to offer a snapshot or wide-angle view of what IPNI is doing and accomplishing.

We've made a lot of progress in the last 10 years, but we also recognize that agriculture is changing and the needs of the fertilizer industry are changing. Our tactical plans have helped us align our regional programs with global goals and needs, but we need even better alignment to meet the needs of the industry, the farmers, and the stakeholders concerned about nutrient use and management. Going forward IPNI plans to refocus our efforts to position ourselves to be more consistent in our messaging, our educational endeavors, and our nutrient research to better serve our members and clientele.

Dr. Terry Roberts, IPNI President

IPNI Board of Directors Elects New Executive Officers

The IPNI Board of Directors has elected its new executive officers at its annual spring meeting held in Marrakesh, Morocco on May 21, 2017.

Mr. Tony Will, CEO of CF Industries Holdings, Inc. in Deerfield, Illinois, USA, was elected as Chairman of the IPNI Board. Mr. Will replaces Mr. Norbert Steiner, Chairman of the Board of Executive Directors of K+S Aktiengesellschaft. IPNI's new Vice Chair is Mr. Svein Tore Holsether, President and CEO of Yara International ASA in Oslo, Norway. Mr. Joc O'Rourke, President and CEO of The Mosaic Company in Plymouth, Minnesota, USA was elected Chair of the Finance Committee.

"We look forward to the strong leadership from our Board and working committees," said Dr. Terry Roberts, President IPNI.

Mr. Tony Will, Chairman of the IPNI Board

Mr. Svein Tore Holsether, Vice Chair of the IPNI Board

Mr. Joc O'Rourke, Chair of the Finance Committee

Increasing Nitrogen Use Efficiency Correlates with Lower Nitrate Concentrations in the Illinois River

By Clifford S. Snyder, Gregory F. McIsaac, and Mark B. David

This article summarizes watershed N balances that were related by McIsaac et al. (2016) to NO_3-N concentrations and loads in the Illinois River in the U.S. from 1976 to 2014.

The watershed residual N balance was helped by higher crop harvest N removal associated with higher crop yields and relatively modest increases in N inputs in more recent years, and this was correlated with lower flow-weighted NO_3-N concentrations in the river.

Increased crop yields, improved cropping system N use efficiency, and depletion of legacy N stored in the soil over time, may help many farmers and governments reach their N loss reduction goals.

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Aerial view of the Illinois RIver surrounded by a mosaic of farm land.

Loss of NO_3-N via subsurface (tile) drainage in corn-soybean systems in the Midwest U.S. can pose serious eutrophication and related water quality concerns; especially where such water resources are used for drinking water supplies and have concentrations approaching the public health protection standard of 10 mg NO_3-N/L (Ward et al., 2015). Loss of nutrients from soils supporting major cropping and livestock systems within the large Mississippi-Atchafalaya River Basin (MARB) has been estimated to account for up to 60% of the N and 49% of the P entering the Gulf of Mexico (Robertson and Saad, 2013). Those nutrient losses combine with water stratification and coastal currents that favor blooms of algae (or phytoplankton), which die and then contribute to low dissolved oxygen (< 2 ppm) in the relatively shallow waters of the northern Gulf.

In addition to MARB nutrient loss reduction goals reinforced in 2013 by the federal and state agency Hypoxia Task Force, twelve states along the Mississippi River corridor, including Illinois, have developed state-specific nutrient loss reduction strategies aimed at improved local and downstream water quality (EPA, 2015). The Illinois River watershed covers about 40% of Illinois (69,264 km^2 within the 3.2 million km^2 MARB), drains parts of northwestern Indiana and southeastern Wisconsin, includes over 90% of the Illinois population, connects the Mississippi River to Chicago and the Great Lakes, and receives sizeable N and P contributions from nonpoint sources and point sources; including loads from the Chicago metropolitan area wastewater treatment discharges (MWRDGC - Metropolitan Water Reclamation District of Greater Chicago). Illinois is estimated to be the largest N-contributing state to N loads reaching the Gulf (Alexander et al., 2008), averaging > 17 kg N/ha/yr, with subsurface tile-drained corn and soybean systems believed to account for the largest agricultural N losses (i.e., 11% of the NO_3-N load and 3.5% of the water delivered annually to the Gulf from 1980 to 2014).

Previous research in tile-drained watersheds has shown that NO_3-N in streams and rivers may be correlated with stream flow, N input amounts and timing, and crop yields. The work reported here addressed the annual residual agricultural N, which was estimated from USDA crop and livestock production statistics, as well as fertilizer N inputs that were estimated for each county in the Illinois River watershed, using Illinois Commercial Fertilizer Sales reports; assuming the same level of fertilizer N consumption as the rest of the state.

Abbreviations and notes: N = nitrogen; P = phosphorus; NO_3-N = nitrate-nitrogen; ppm = parts per million.

Annual residual agricultural N (RAN) was calculated as:

RAN = [fertilizer N + legume N fixation – harvested N adjusted for manure N applied]

Multiple-year cumulative residual agricultural N (CRAN) balances were also calculated using current year and prior year(s) RANs minus river NO_3-N losses. Annual loads and flow-weighted NO_3-N concentrations in the Illinois River were statistically compared with river flow, RAN lagged one year, and CRAN for two to seven years.

Residual Agricultural Nitrogen

During the 1980s to early 1990s, the RAN averaged 22 kg N/ha, with a peak of 43 kg N/ha in the drought year of 1988. From 1998 to 2010, the RAN was consistently below 20 kg N/ha, and declined to a minimum value of 7.7 kg N/ha in 2008 (**Figure 1**).

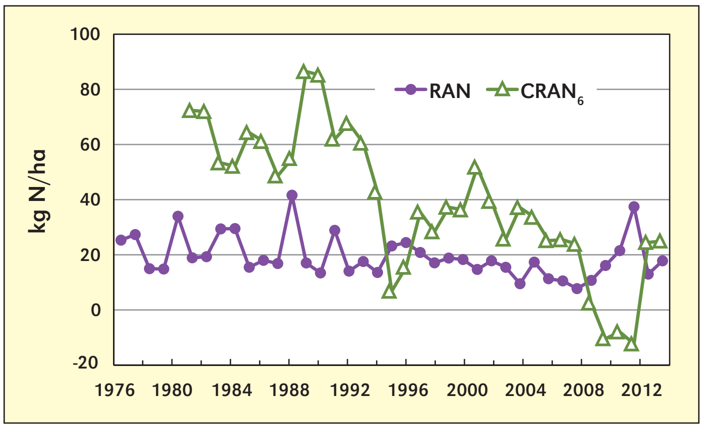

Figure 1. Residual agricultural nitrogen (RAN) and cumulative residual agricultural N over the previous six years ($CRAN_6$) in the Illinois River basin.

River NO_3-N Loads and Concentrations

There was no significant linear trend in Illinois River NO_3-N loads from 1976 to 2014 (**Figure 2**), but declining trends were detected from 1982 to 1989, and from 1993 to 2006, and an increasing trend from 2006 to 2010. The load trends coincide closely with trends in river flow (data not shown). Annual average and November river flow, $CRAN_6$ (previous 6-year cumulative RAN minus 5-year cumulative river N loads), and the MRWRDGC NO_3-N discharge combined to explain 86% of the variation in annual NO_3-N loads.

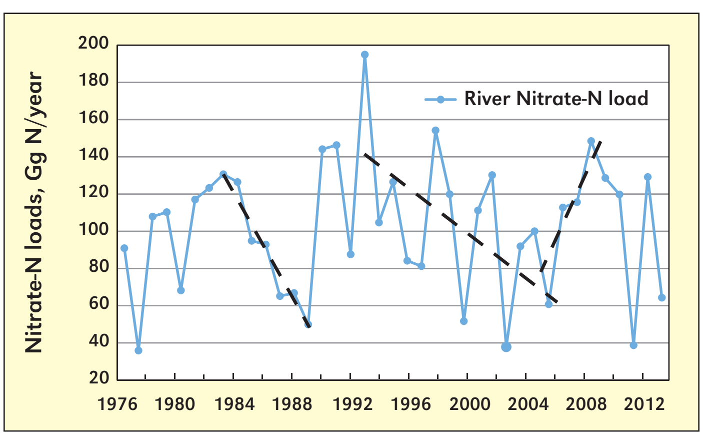

Figure 2. Annual NO_3-N loads in the Illinois River at Valley City, estimated by interpolation. Dashed lines illustrate statistically significant trends for the noted time intervals. Note: 1 Gg = 1,102 short tons.

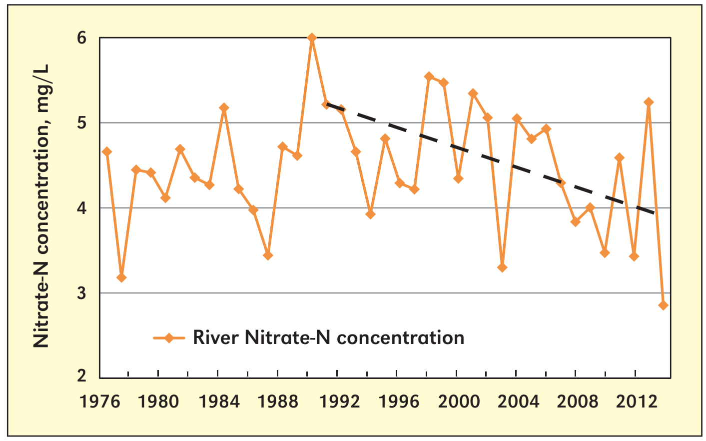

Figure 3. Annual flow-weighted NO_3-N concentrations for the Illinois River at Valley City. Dashed line illustrates statistically significant trend for the noted time interval. Note: 1 mg/L = 1 ppm.

Annual flow-weighted NO_3-N concentrations in the Illinois River varied between 2.9 and 6.0 mg NO_3-N/L, with significant declining concentrations observed from 1990 to 2014 (**Figure 3**). The $CRAN_6$ and MRWRDGC NO_3-N discharge explained 34% of the variation in annual flow-weighted Illinois River NO_3-N concentrations.

These regression results, while not proving cause and effect, suggest that Illinois River NO_3-N loads and concentrations are strongly affected by hydrology, multiple year RAN levels, and NO_3-N discharges from the MWRDGC. Declines in river NO_3-N concentrations after 1990 occurred while fertilizer and manure N use and management in corn production were

Beginning in Chicago, the Illinois River connects the Great Lakes to the Mississippi River.

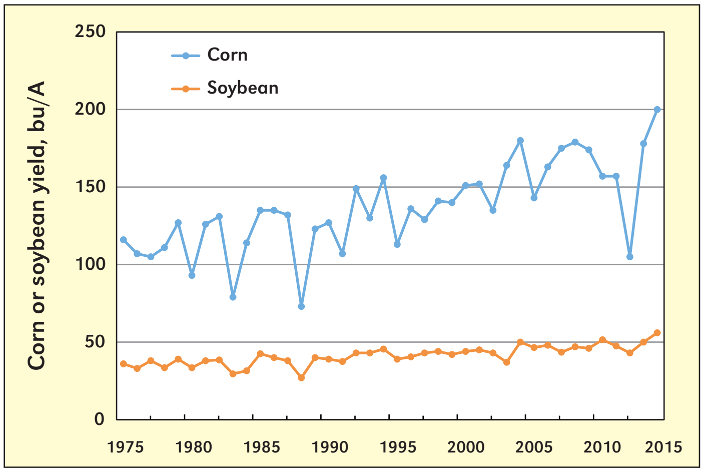

Figure 4. Corn and soybean yields in Illinois, 1975 to 2014. Source: USDA National Agricultural Statistics Service.

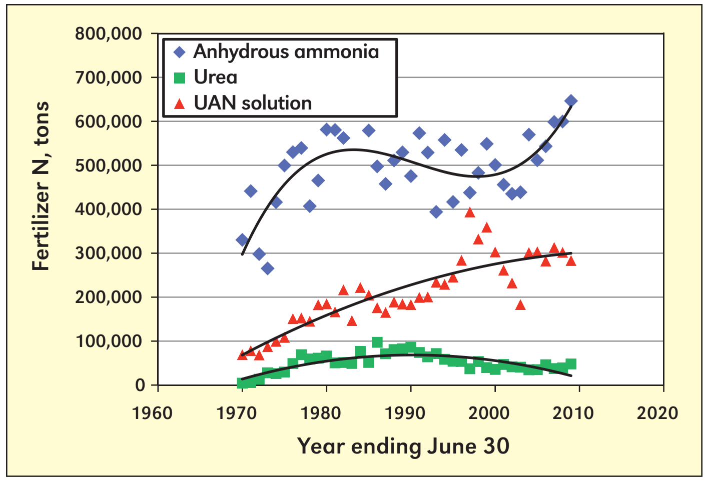

Figure 6. Trends in anhydrous ammonia, urea, and urea ammonium nitrate fertilizer N consumed in Illinois, 1970 to 2009. Note: fertilizer N source data available only through 2009.

becoming more efficient, as indicated by reductions in RAN and $CRAN_6$ since 1990. Higher crop yields (**Figure 4**), and greater crop harvest N removal, in combination with less N application in excess of crop needs, are a plausible explanation for reduced N losses to aquatic resources in the Illinois River watershed.

The improved N use efficiency and reduced NO_3-N concentrations observed in the Illinois River since 1990 occurred even while fertilizer N consumption was trending slightly upward in Illinois after 2001 (**Figure 5**). Beginning in the early 1990s,

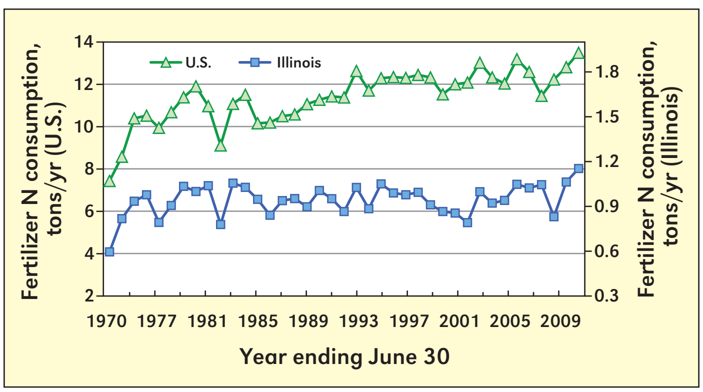

Figure 5. Fertilizer N consumption in Illinois and the U.S., 1970 to 2012.

the consumption of urea ammonium nitrate solutions in Illinois began to grow, compared to the consumption of anhydrous ammonia; then peaked around 2000 and has become more static since. Those fertilizer N consumption changes in Illinois (**Figure 6**) may possibly reflect some shifts in the timing of application; including greater implementation of site-specific tools and technologies (data available only through 2009). In addition, some industry initiatives such as those led by the Illinois Fertilizer and Chemical Association (Payne and Nafziger, 2015) beginning in 2009, may also be having some positive impacts on the more recent declining trends in river NO_3-N concentrations.

Summary

It is difficult to quantify the cropping system, N management, and conservation practices that contributed to lower RAN and $CRAN_6$ values, and improvement in N use efficiency. Straight-forward N budgets used in this study, and other similar studies, can help explain a large proportion of the variations in river NO_3-N loads and concentrations. Meeting nutrient loss reduction goals in the face of more intense precipitation events (that are difficult to predict), drainage, and river flows - associated with a more uncertain climate future - will require greater nutrient stewardship and conservation practice implementation by farmers, their input providers, soil and water conservation professionals, and other watershed stakeholders. Reductions in N and P discharges by municipal point sources should also be given due attention. Such dedicated cooperation and collaboration can help sustain cropping system and environmental improvements in Illinois and elsewhere. BC

Acknowledgement

Fertilizer N source consumption data were provided by Dr. Harry Vroomen with The Fertilizer Institute, Washington, DC.

Dr. Snyder (e-mail: csnyder@ipni.net) was the IPNI Nitrogen Program Director (retired) and also is Adjunct Professor in the Crop, Soil, and Environmental Sciences Department, Division of Agriculture, University of Arkansas. Dr. McIsaac (e-mail: gmcisaac@illinois.edu) and Dr. David (e-mail: mbdavid@illinois.edu) are Professors Emeriti in the Department of Natural Resources and Environmental Sciences at the University of Illinois. Snyder is located in Conway, Arkansas and McIsaac and David are located in Urbana, Illinois

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Impact of Controlled-Release Urea on Upland Maize in Yunnan

By Mei Yin, Fan Su, Gui-bao Wang, Li-bo Fu, Hua Chen, Jian-feng Chen, Zhi-yuan Wang, and Li-fang Hong

Controlled-release urea (CRU) was compared against regular urea (RU) in upland (rain-fed) maize experiments designed to investigate N nutrient source, rate, time, and placement impacts on yield, agronomic traits, and nitrogen use efficiency (NUE). **Yield under CRU was 6 to 20% higher** than that achieved with RU. In turn, NUE was 5 to 17% above that achieved with RU.

Rational application of N fertilizer is one of most important best management practices (BMPs) to maintain optimum crop yields and to ensure environmental stewardship of applied N. Farmers in China have been continually striving for high yields, but cases of irrational fertilization are still common, especially in the case of N as evidenced by low national NUE values that are near 11 to 41% (Zhang et al. 2008). Low NUE not only wastes agriculture resources and increases costs, but it also leads to environmental pollution (Tian et al., 2007; Zhu and Sun, 2008). This issue has brought the worldwide research effort of controlled-release fertilizers into focus for China.

Controlled-Release Urea versus Regular Urea

In upland areas of Yunnan Province, rain-fed maize accounts for the largest cropped area. Common practice of N use has resulted in lower N utilization rates, leading to losses of N and environmental problems. Raising NUE via improved fertilizer sources could reduce these adverse effects and support high productivity of maize in Yunnan.

The district of Yuezhou, Yunnan has a red soil and sloping landscape that is typical for the region. Soil properties listed in **Table 1** suggests a relatively high soil fertility status. The main cropping pattern is early maize (sown in mid April/early May) following late wheat or a legume sown after mid September. Cultivation practices that maintain surface mulch are most common in maize. Maintaining residue on the surface improves crop productivity through better water use during the seasonal drought that is characteristic to this region. However, the use of mulch can limit options for effective placement of fertilizer given the available technology. Controlled-release urea has many potential advantages for this system including ease of broadcast application, better use of time and labor, and higher NUE (Zhao et al., 2010).

Table 1. Nutrient status of upland maize soils, Yunnan.

Field site	pH	Organic matter	Total N	Alkaline hydrolyzed N	Available P	Available K
		----- g/kg -----		----------- mg/kg -----------		
Yuezhou	6.6	31	1.6	162	22	138
Ciying	7.3	31	1.4	119	22	139

This research was conducted for two years to explore the effects of CRU and RU on maize in Qujing, the main maize-producing area in Yunnan. Treatments were selected to test the impact of CRU at the traditional urea-based N rate along with reduced levels of N input (**Table 2**). An additional comparison tested the substitution of RU with CRU as a top-dressed N source. The effects of these different treatments were evaluated according to yield and agronomic traits, accumulation of N in the grain and biomass, and NUE.

NUE (%) = U - Uo / F × 100%;

where U = cumulative N uptake in aboveground biomass with RU or CRU, Uo = cumulative N uptake in aboveground biomass with no RU or CRU, and F = amount of applied N.

Abbreviations and notes: N = nitrogen; NUE = nitrogen use efficiency; CRU = controlled-release urea; RU = regular urea. IPNI Project IPNI-2010-CHN-YN12.

S. Tu/IPNI

Upland maize research site in Yunnan, China.

Results

Traditional N fertilization for these upland maize fields involves a single broadcast application of RU. This research found 6 to 20% increases in maize grain yield by substituting broadcast RU with CRU (**Table 2**), which are results consistent with previous studies (Cao et al., 2009; Sun et al., 2009; Zhu et al., 2007). In the first year, only the 100% CRU treatment produced grain yields that were greater than 100% RU. In year 2, all CRU treatments performed better than 100% RU, but 75% CRU provided the best yield response, followed closely by 100% CRU. The efficiency for N use (NUE) was clearly improved by broadcasting CRU rather than RU.

Based on the grain yield data, the strategy of integrating broadcast RU with top-dressed CRU was effective at providing sufficient nutrient supply throughout the entire growing season. Previous studies (Wang et al., 2007; Zhang et al., 2010) have shown evidence of CRU alone being unable to meet the early demands of crops. Use of 40% RU (broadcast) + 60% CRU (topdressing) produced maize yields that were statistically equal to the highest grain yields produced by 100% CRU (year 1) or 75% CRU (year 2). Nutrient use efficiency in this split RU+CRU application strategy was higher than the split

Table 2. Effect of regular urea (RU) versus controlled-release urea (CRU) treatments on yield of upland maize, Yunnan.

Treatment		First year: N use efficiency, %	First year: Yield, kg/ha	First year: Yield vs. 100% RU, %	Second year: N use efficiency, %	Second year: Yield, kg/ha	Second year: Yield vs. 100% RU, %
- - - - - - - - Check - - - - - - - -		-	8,480 d*	-8	-	8,480 e	-16
Broadcast	Topdressing						
100% RU	-	26 d	9,260 bcd	-	22 c	10,050 d	-
100% CRU	-	38 b	10,710 a	16	33 b	11,690 ab	16
40% RU	60% RU	31 c	9,820 abc	6	30 b	11,300 abc	12
40% RU	60% CRU	36 b	10,400 ab	12	31 b	11,380 ab	13
75% RU	-	26 d	8,970 cd	-3	34 b	11,120 bc	11
75% CRU	-	43 a	10,090 abc	9	45 a	12,000 a	20
50% RU	-	27 d	9,360 bcd	1	34 b	10,570 cd	5
50% CRU	-	37 b	9,800 abc	6	46 a	11,150 bc	11

*Numbers followed by the same letter in columns are not significantly different at $p = 0.05$
Experiments used 20 m^2 plots. Maize variety in the first year was Qidan 2 grown at 63,000 plants/ha; second year - Ludan 12 and 60,000 plants/ha. The full rates were 210-68-63 kg N-P_2O_5-K_2O/ha in the first year and 240-120-75 kg/ha in the second year. The CRU source was from Agrium Advanced Technologies™ containing 43% N. All treatments were provided with balanced rates of P and K using single superphosphate and KCl.

RU treatment (40% broadcast + 60% topdressed) in year 1, but no difference in NUE was observed between these two treatments in year 2. The split application of RU could also be a good fertilizer management strategy to adopt over time since it shows signs of higher yields and NUE compared to a single, early broadcast application of RU. However, the advantages would need to be greater than the costs associated with the extra labor and time demanded by multiple applications.

Conclusion

Application of CRU brought higher maize yields and NUE, reduced nutrient loss, saved labor, and reduced the potential environmental footprint associated with excess N losses. While the rates of N used in this study were far in excess of realistic crop requirements, CRU was confirmed as an effective source and should be a recommended management practice.

The optimum application rate for CRU should be a reflection of the soil and growing environment. In this research the optimum RU rate was 50% of the full rate. Controlled-release urea produced higher yields, and the optimum rate varied between 50 to 75% of the full CRU rate or the traditional RU rate. While the study clearly shows that traditional N rates used in the region are far in excess of crop requirements, CRU proved to be an efficient source of fertilizer N, enabling lower N rates without a loss of production. BC

S. Tu/IPNI

CRU significantly increased NUE. NUE under the single broadcast of RU was 26 to 27%, which compares to 36 to 43% for CRU.

TAKE IT TO THE FIELD

CRU can be used in rain-fed maize to reduce labor cost and increase yield and nutrient use efficiency.

Mei Yin, Fan Su, Li-bo Fu, Hua Chen, Jian-feng Chen, Zhi-yuan Wang, Li-fang Hong are with the Agricultural Environment and Resources Institute, Yunnan Academy of Agricultural Sciences, Kunming, Yunnan, China. Gui-bao Wang is with the Fertility Station of Qujing, Yunnan, China.

The mention of any trade name does not necessarily imply any endorsement.

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Adapting Controlled-Release Urea to Sugarcane Production in Southern China

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

Blending controlled-release urea (CRU) with regular urea raised the profitability of cane production over two years compared to urea alone.

Crop N demand at early growth stages was met by urea while CRU ensured sustained N supply at later growth stages.

Sugarcane's single season growing period of 8 to 12 months or more in southwest China produces a huge amount of biomass with millable cane yields up to 150 t/ha. The crop requires a large quantity of nutrients, especially N and K, to achieve the region's high yields. In practice, farmers usually split N fertilizers into three to four timings: at planting, seedling and/or tillering, and grand growth (occurring approximately 120 days after planting) stages. Manual fertilizer application in the sugarcane fields during the humid hot summer is not only a hard job but also time consuming and expensive, especially at the grand growth stage when fertilizer application is very difficult. Controlled-release urea is considered as an ideal alternative N source to crops with long growing periods, like sugarcane. Earlier studies have shown that use of CRU not only increases crop yields, but also reduces the required number of split applications, and improves N use efficiency (Haderlein et al., 2001; Geng et al., 2015).

The objectives of this study were to define optimal rates and blends of CRU used in combination with regular urea (RU) for sugarcane, and to evaluate its influence on cane yield and economic returns. The two-year experiment consisted of nine treatments, including three N rates, three blends of CRU+RU, and two application timings of RU (**Table 1**). Phosphate fertilizer (fused Ca-Mg phosphate, 150 kg P_2O_5/ha) was applied once basally and K fertilizer (potassium chloride, 375 kg K_2O/ha) was split (60:40) between a basal application and during seedling growth. In the planted cane (first crop season), basal fertilizers were applied in the seed furrow and side-dressings were banded between rows. In the ratoon crop (second season), all the fertilizers were banded into soil.

Table 1. Nitrogen application rates and timings for sugarcane field experiments in Guangxi.

Treatment	N rate, kg/ha Total	CRU[1]	RU	N fertilizer timings
No N (CK)	0	0	0	-
RU (2)[2]	330	0	330	Basal, seedling, grand growth
RU (1)	330	0	330	Basal, grand growth
CRU (1)	330	330	0	Basal, grand growth
CRU @ 80% N rate (1)	264	264	0	Basal, grand growth
CRU @ 70% N rate (1)	231	231	0	Basal, grand growth
CRU+RU (60:40) (1)	330	198	132	Basal, grand growth
CRU+RU (80:20) (1)	330	264	66	Basal, grand growth
CRU+RU (60:40) @ 80% N rate (1)	264	211	53	Basal, grand growth

[1]RU = Regular Urea; CRU = Controlled-Release Urea. The CRU source was from Agrium Advanced Technologies™ containing 43% N.
[2]Numbers in the parentheses refer to the number of side-dressings.

Table 2. Sugarcane yields as affected by different treatments in 2013 to 2014.

Treatment	2013 Yield, t/ha	2013 ±% vs RU (2)	2014 Yield, t/ha	2014 ±% vs RU (2)
No N (CK)	62 d[2]	-42	75 d	-45
RU (2)[1]	110 b	2.8	141 ab	3.4
RU (1)	107 b	-	136 b	-
CRU (1)	116 a	8.2	145 a	6.5
CRU @ 80% N rate (1)	104 b	-2.6	138 b	1.2
CRU @ 70% N rate (1)	98 c	-8.1	132 c	-3.1
CRU+RU (60:40) (1)	118 a	10	148 a	8.2
CRU+RU (80:20) (1)	116 a	8.6	146 a	7.1
CRU+RU (60:40) @ 80% N rate (1)	106 b	-0.6	139 ab	2.1

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

Yield and Yield Components

Nitrogen is a vital nutrient in sugarcane production as cane yield was reduced by more than 40% when it was omitted (**Table 2**). In the first year, the 100% N rate treatments using CRU or CRU+RU produced significantly higher cane yields than RU alone. Cane yields were significantly lower with a decrease in CRU rates. The CRU-containing treatments produced similar effects in the second year. The CRU+RU blends (60:40 and 80:20) and 100% CRU treatment achieved the highest (statistically equal) cane yields during the 2-yr period.

The CRU+RU blends might be particularly useful in sugarcane areas where limited soil moisture is available at early growth stages. Earlier studies have highlighted better performance of blends of CRU with RU as compared to CRU alone (You et al., 2008). Any yield advantage in using CRU+RU

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium. IPNI Project CHN-GX14

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Guangxi produces over 60% of China's sugarcane with a planting area of 1.1 million (M) ha and an annual cane production of 78 M t. Sugarcane production is the primary income source for Guangxi's farmers.

blends could be attributed to a combination of immediate N release from RU that meets crop demand at earlier growth stages, and a sustained supply of N from CRU for later growth stages. Data presented in **Table 2** implies that the currently recommended N rate is optimal, and use of CRU alone or in combination with RU is preferred on this medium fertility soil.

Among the agronomic traits investigated such as plant height, cane diameter, number of millable canes and single cane weight, only the latter two were significantly correlated to cane yields. Higher millable canes were generated in the ratoon cane season than in the planted cane season (**Table 3**). No differences in millable canes were observed amongst the highest-yielding treatments. Single cane weight was negatively correlated with millable cane number (i.e., the higher number of millable canes, the lower the single cane weight). Thus, single cane weight was considerably lower in the second year. The two CRU+RU blends produced the highest single cane weight in both years, implying that a blend of CRU+RU in proper proportions can be the best choice for sugarcane production.

Table 3. Millable cane numbers and single cane weight as affected by different treatments in 2013 to 2015.

	--------- 2013 ---------		--------- 2014 ---------	
Treatment	Millable cane, no./ha	Cane weight, kg/cane	Millable cane, no./ha	Cane weight, kg/cane
No N (CK)	45,000 c[2]	1.39 d	64,670 bc	1.19 f
RU (2)[1]	57,560 a	1.91 bc	77,780 a	1.85 d
RU (1)	57,000 a	1.88 c	74,670 b	1.86 d
CRU (1)	57,560 a	2.01 ab	78,670 a	1.91 b
CRU @ 80% N rate (1)	54,670 ab	1.90 c	75,670 b	1.84 e
CRU @ 70% N rate (1)	52,890 b	1.86 c	72,450 c	1.84 e
CRU+RU (60:40) (1)	57,780 a	2.04 a	79,340 a	1.94 a
CRU+RU (80:20) (1)	57,670 a	2.01 ab	77,890 a	1.97 a
CRU+RU (60:40) @ 80% N rate (1)	55,560 ab	1.91 bc	76,340 ab	1.89 c

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

Economic Returns

Economic returns corresponded well with cane yields (**Table 4**). The CRU+RU blends (60:40 and 80:20) and the 100% CRU treatment produced net incomes that were US$644, $521, and $467/ha higher than the RU (1) treat-

TAKE IT TO THE FIELD

Mix CRU and RU in the right proportion for sustained nutrition of sugarcane to generate high yield and profitability.

ment in year 1, and $587, $471, and $400/ha higher in year 2, respectively. This further confirms that application of CRU to sugarcane is cost effective, and use of CRU blends with RU may be more profitable than applying CRU alone.

Summary

Applications of CRU can reduce the frequency of N fertilizer applications when compared to RU management, and can significantly increase sugarcane yields in both the planted and the ratoon cane seasons. The blended treatments of CRU+RU (60:40 and 80:20) and 100% CRU produced the highest cane yields over the 2-yr period. This yield advantage is attributed to the increased number of millable canes and single cane weight. The three CRU treatments produced higher net incomes than the RU (1), suggesting that CRU would be a preferred source of N for sugarcane, and blends of CRU+RU in appropriate proportions might be more effective than CRU alone when used in similar growing conditions.

Acknowledgement

The authors would like to acknowledge the support from Agrium Inc. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the International Plant Nutrition Institute (IPNI). BC

Table 4. Economic returns of different treatments.

	Net income[2], US$/ha	
Treatment	2013	2014
No N (CK)	2,028	2,667
RU (2)[1]	4,568	5,836
RU (1)	4,597	5,787
CRU (1)	5,064	6,187
CRU @ 80% N rate (1)	4,352	5,833
CRU @ 70% N rate (1)	3,988	5,523
CRU+RU (60:40) (1)	5,241	6,374
CRU+RU (80:20) (1)	5,118	6,258
CRU+RU (60:40) @ 80% N rate (1)	4,512	5,918

[1]Numbers in the parentheses refer to the number of side-dressings.
[2]Net income refers to the values after deducting the total cost including fertilizers (CRU prices have exceeded RU by US$154 to US$200/t), pesticides, labors for fertilizer and pesticide applications, irrigation, and harvest.

Prof. Zhou (e-mail: lqzhou@gxaas.net), Mr. Huang, Ms. Zeng, and Ms. Zhu work at the Institute of Agricultural Resources and Environment, Guangxi Academy of Agricultural Sciences, and Prof. Tan is with the Sugarcane Institute, Guangxi Academy of Agricultural Sciences, Guangxi, China. Dr. Tu is Deputy Director, IPNI China Program, Chengdu, Sichuan, China

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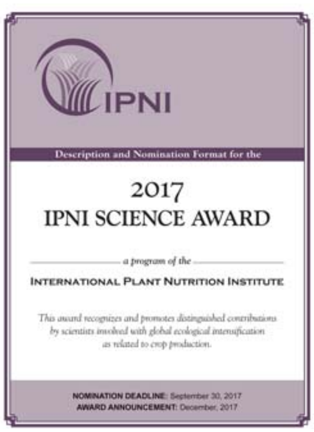
IPNI Science Award – Nominations Are Due September 30, 2017

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.



The IPNI Science Award requires that a nomination form (no self-nominations) and supporting letters be received at IPNI Headquarters by September 30, 2017. Announcement of Award recipient will be in December, 2017. 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.

Dr. Ismail Cakmak (right) receives 2016 IPNI Science Award from Dr. Terry Roberts, President IPNI.

All details and nomination forms for the 2017 IPNI Science Award are available from the IPNI Awards website http://www.ipni.net/awards.

Ammonia Loss and Fertilizer Nitrogen Recovery from Surface-Applied Urea during the Overwinter Months

By Richard Engel, Carlos Romero, Clain Jones, and Tom Jensen

Montana's semiarid climate contributes to greater susceptibility of surface applied urea to ammonia (NH_3) loss overwinter.

Instead of late-fall or winter applications, a spring application of urea after soils have thawed provides the greatest agronomic and environmental benefits.

Broadcast applications of urea during the overwinter period is a common management practice for dryland winter wheat production in semi-arid Montana. The popularity of this practice is based on the need to spread workloads. Farms in this region commonly have > 1,000 ha under no-till or minimal tillage systems and this places considerable pressure on farmers to complete planting operations over a short-time span (e.g., < 2 weeks in mid-September).

Surface applications of urea are widely recognized as being susceptible to NH_3 loss. However, the long-held belief by farmers and their fertilizer suppliers is that NH_3 loss can be mitigated, or prevented, by applying urea to cold soils during the overwinter period. Our research has shown that is not necessarily the case (Engel et al., 2012), and that considerable loss of N as NH_3 (i.e., > 20% of the applied amount) can occur following urea application to cold soils with temperatures < 5°C, including soils covered with a modest snowpack. The most important finding of this research is that the worst-case conditions for NH_3 loss were after urea applications were made to moist soil surfaces with high moisture content, followed by slow drying with little or no precipitation. In Montana and other neighboring areas of the Northern Great Plains, these conditions are more likely to occur during the overwinter period compared with the spring. Soil surfaces are usually frozen during the winter, but still can be moist due to intermittent periods of shallow surface thawing. The distribution of precipitation is such that winters are typically dry with only 14 to 15% of the total annual precipitation (310 to 420 mm) occurring over a 4-month period (Dec 1 to Mar 31; MCO-UM, 2015). As a result, precipitation events will typically be low in volume, and broadcast urea applied to the soils is likely to remain near the surface where it is susceptible to volatilization. Conversely, in the spring following thaw, temperatures are warmer and drying of the soil surface is more rapid. Spring precipitation events that occur tend to be larger in volume and surface-applied urea will more likely be dissolved and infiltrate further into the soil where it is less susceptible to volatile losses.

The apparent difference in susceptibility of urea to volatilization between overwinter and early-spring applications timings prompted us to examine more closely the cumulative NH_3 losses during these periods. Also, treating urea with urease inhibitor (NBPT) is a recognized method to reduce NH_3 losses from surface-applied urea applications (Engel et al., 2011; Grant et al., 1996; Sanz-Cobena et al., 2008; Turner et al., 2010). Hence, we compared NH_3 losses from urea with and without this fertilizer additive.

Abbreviations and notes: N = nitrogen; NH_3 = ammonia; NBPT = N-(n-butyl) thiophosphoric triamide. IPNI Project USA-MT17

Ammonia measurements were quantified by a micrometeorological approach that utilized circular plots (40 m dia), and a center mast equipped with samplers for collecting NH_3. These measurements were coupled with a companion study run at the same field site, where fertilizer N recovery by winter wheat was quantified using ^{15}N-enriched urea applied to micro-plots within a replicated small-plot experiment design. We hypothesized that: i) cumulative NH_3 loss from urea would be greater for late-fall and winter applications, or overwinter applications, relative to the spring application timings, ii) addition of NBPT would reduce NH_3 loss from urea, and iii) cumulative fertilizer NH_3 loss would ultimately affect fertilizer N recovery by winter wheat.

Field Experiments

Field trials were conducted at private farms in central Montana during the 2011/12, 2012/13, and 2013/14 seasons. The experiments were located in large fields (> 60 ha) that were under a no-till, crop-fallow management system with winter wheat being the dominant crop. The micrometeorological experiments and replicated small-plot experiments with ^{15}N-labelled urea were conducted at the same time but at physically separated locations within the farm fields. The trials consisted of three fertilization application timings (late-fall, winter, and spring) and two N sources (urea and urea+NBPT). The first application event or timing (late-fall) was made in late-November to early-December at approximate soil freeze-up. The second event (winter) was applied in February to frozen soil. The third event (spring) was applied in April following ground thaw and crop green-up. Urea and urea+NBPT were applied at a rate of 100 kg N/ha. The urea was coated with NPBT (1 g/kg) as a liquid formulation sold under the trade name, Agrotain Ultra™ (Koch Agronomic Services, LLC, Wichita, KS, USA).

NH_3 Flux vs. Time Relationships

Ammonia flux measurements revealed very different patterns of NH_3 loss following urea applications in the overwinter period (late-fall and winter) compared to the spring (**Figure 1**). In all years, NH_3 flux following the late-fall and winter applications rose over 14 to 58 d to peaks that were higher than for the spring application timings. Thereafter, NH_3 emission activity was prolonged and did not fall to nominal levels (≤ 3 g N/ha/h) until 87 to 103 d and 49 to 62 d post-fertilization for these respective application timings. The prolonged emission activity was in part a result of the cold temperatures and dry conditions that slowed or limited urease activity. Also, the soil below the surface was largely frozen and any precipitation and melting of snow that occurred did not allow for urea infiltration

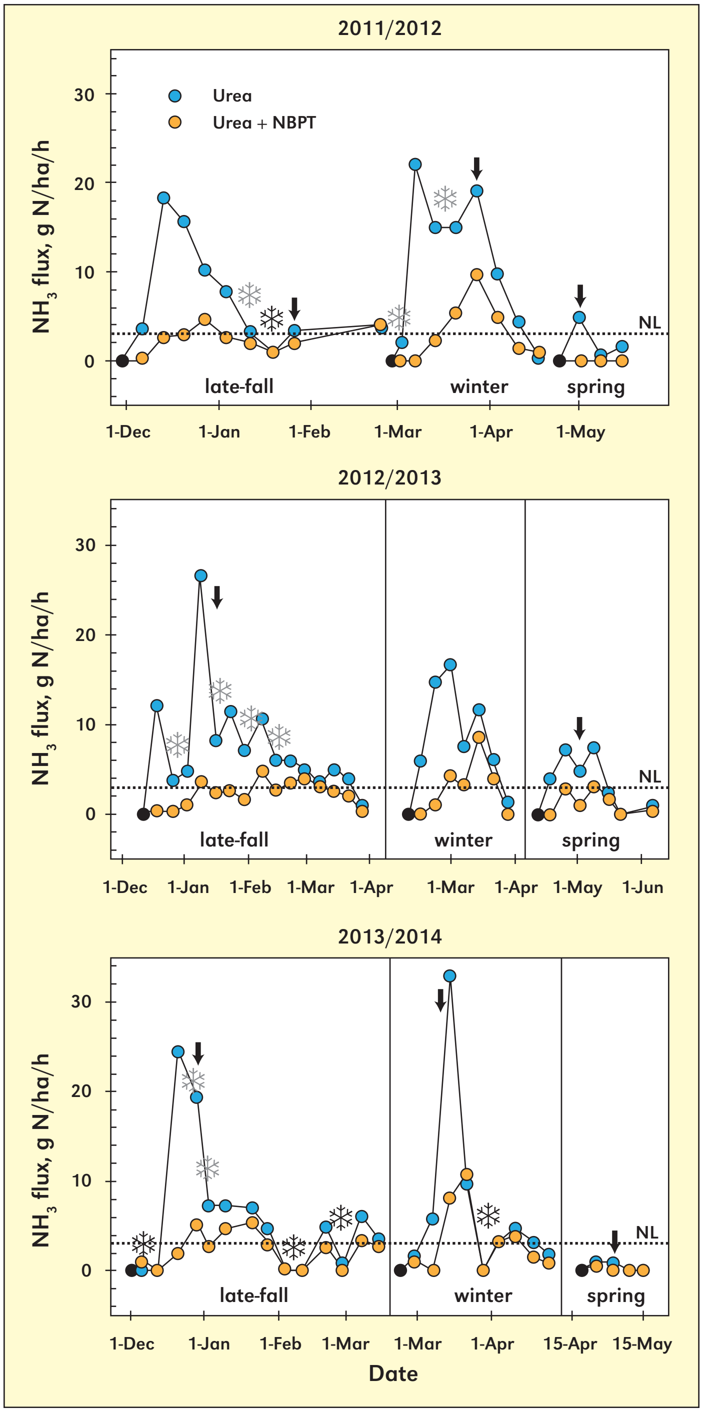


Figure 1. Ammonia from urea and urea coated with *N*-(*n*-butyl) thiophosphoric triamide (NBPT) following three application timings (late-fall, winter, spring) during 2011/2012, 2012/2013 and 2013/2014. Dark circles indicate the fertilizer application dates (NH_3 flux is assumed = 0). Arrows indicate proximate time when 95% of applied urea (without NBPT) had hydrolyzed. NL = nominal level (3 g N/ha/hr). ❄, ❄ Indicate partial and full snow cover, respectively.

into the soil to a depth where it was protected against volatilization to the atmosphere. The pattern of NH_3 emission activity following the late-fall and winter urea applications sometimes exhibited a deep saw-tooth, or up and down, pattern as a result of intermittent snow cover and wet-dry cycles (**Figure 2**). For example, the drop-off in NH_3 flux at the second (Dec 26) and third (Jan 2) sampling events of the late-fall 2012/13 trial was a result of two light snowfall events (5 and 2.5-cm depth) that occurred 10 d (Dec 22) and 21 d (Jan 2) postfertilization. These snowfall events effectively blocked NH_3 release to the atmosphere.

Figure 2. Time sequence photographs of field site. NH_3 emission activity was effectively blocked by the snow cover on received on Dec 22 (top), then resumed following the melting of the snow cover over 2-week period (**see Figure 1**)

The accumulated snow then melted and NH_3 emission flux resumed as evident by the peak on Jan 9 (**Figure 2**). In all years, NH_3 flux following the spring applications were lower in

Table 1. Cumulative NH_3 loss (% applied N) from urea and urea+NBPT for late-fall, winter, and spring applications. Average over three years (2011/12, 2012/13, 2013/14).

	N fertilizer source	
	Urea	Urea + NBPT
Application timing	% applied	
late-fall	16.4 a†	6.0 c
winter	11.4 b	4.2 c
spring	2.0 cd	0.6 d

† timing x N source significant (p = 0.003) and means followed by the same letter are not significantly different (p = 0.05).

TAKE IT TO THE FIELD

Delay urea application until after the spring thaw when larger precipitation events can move N down into the soil where it is more protected from volatilization.

Use of NBPT will reduce NH_3 loss from surface applied urea—by up to two-thirds compared to untreated urea.

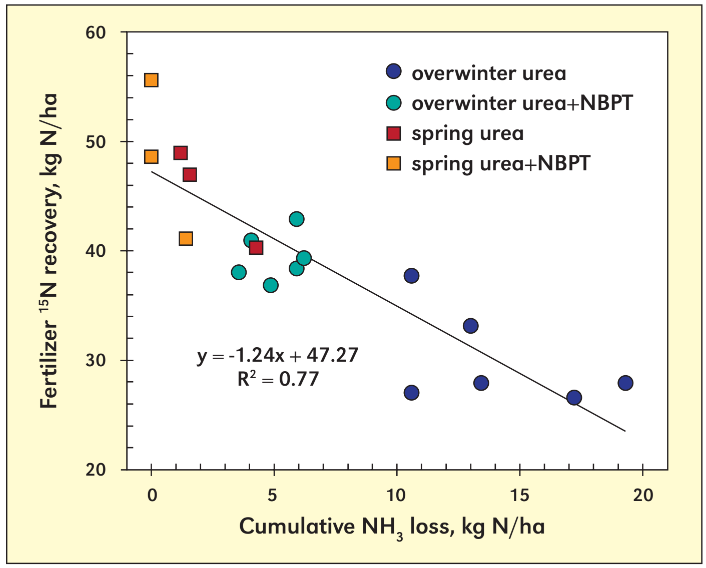


Figure 3. Fertilizer-^{15}N recovery in grain plus straw of winter wheat and cumulative NH_3 loss relationships among the N management strategies that included urea and urea+NBPT (100 kg N/ha) applied during the overwinter period (late-fall, winter) and spring following thaw. Three-year summary (2011/12, 2012/13, 2013/14) from central Montana.

intensity and shorter in duration than the late-fall and winter applications. Spring applications were made after the soils had thawed and precipitation events that occurred allowed for the greater depth infiltration of urea. Also, the precipitation events were larger during the spring compared to the overwinter period. For example, precipitation events during the spring often exceeded 12 mm, while during the late-fall and winter trial events were typically limited to snowfall with less than 6 mm water equivalent.

Ammonia flux versus time profiles for urea+NBPT indicate the urease inhibitor was effective in reducing NH_3 emissions, and the peak NH_3 flux observed for the three application timings. The mitigation effects were most clearly evident in the profiles for the late-fall and winter trials. Initially, NH_3 flux was reduced by 90 to 95% by NBPT over the first week following the dissolution of the fertilizer granules. Thereafter, the efficacy of NBPT diminished such that the NH_3 flux vs. time curves for urea and urea+NBPT converge at 50 to 75 d and 28 to 48 d post-fertilization for the late-fall and winter applications, respectively (**Figure 1**).

Cumulative NH_3 Loss and Fertilizer N Recovery

A three-year summary of our results found cumulative NH_3 loss (% applied N) was significantly affected by timing and the interaction of timing and NBPT (**Table 1**). The interaction resulted because the mitigation of cumulative NH_3 loss by NBPT was greater for the overwinter urea applications relative to the spring urea applications. Multiple comparison tests show the largest cumulative NH_3 loss was observed for urea applications in the late-fall followed by the winter applications. Cumulative NH_3 was similar between the urea+NBPT late-fall and urea+NBPT winter applications. The addition of NBPT reduced cumulative NH_3 loss from urea by 63.4, 63.2, and 70.0% for the late-fall, winter, and spring applications, respectively.

Our measurements of fertilizer ^{15}N recovery of urea in the grain plus straw at maturity were directly related to cumulative NH_3 loss at the field sites (**Figure 3**). The high correlation (R^2=0.77) indicates that volatilization represents an important pathway for N loss in semiarid climates when urea is surface-applied during the overwinter period. This was further validated by our finding that the addition of NBPT improved wheat fertilizer ^{15}N recovery of urea, in particular for the late-fall and winter application timings.

Summary

This three-year study supported our hypothesis that cumulative NH_3 loss following overwinter (Dec to Mar) applications of urea would be larger than spring applications following thaw. There are a number of environmental factors in Montana's semiarid climate that likely contribute to the greater susceptibility of urea to NH_3 loss during the overwinter period. Precipitation events following the late-fall and winter applications of urea were typically small in size (≤ 6 mm) and most often occurred as light snowfall events, hence urea likely remained at, or near, the surface for a prolonged time. Also, frost layers in the soil prevented the downward movement of water and dissolved urea. In contrast, precipitation following the spring applications often consisted of larger events (≥ 12 mm) that reduced NH_3 emission activity. In general, the pattern of low intensity and small precipitation events during the late-fall and winter versus larger precipitation events during the spring is consistent with long-term records of climate in the semiarid northern Great Plains. Finally, the management implications of this study are that late-fall and winter urea applications should be avoided to provide the greatest benefit to soil N fertility, and to minimize NH_3 emissions into the atmosphere. Addition of NBPT (1 g/kg) will reduce cumulative NH_3 loss from urea by approximately two-thirds over untreated urea. However, the best management strategy is to delay urea applications until the spring after soils have thawed, and when larger precipitation events are more likely to occur that allow for urea-N infiltration into the soil where it is protected against volatilization to the atmosphere. BC

The mention of any trade name does not necessarily imply any endorsement.

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Dr. Tai McClellan Maaz Named IPNI Nitrogen Program Director

Dr. Tai McClellan Maaz has been hired as Nitrogen Program Director with the International Plant Nutrition Institute (IPNI) effective September 1, 2017. Dr. Maaz will be based from IPNI Headquarters in Peachtree Corners, Georgia, USA.

Prior to Dr. Maaz's appointment to IPNI, she held a United States Department of Agriculture (USDA) Agriculture and Food Research Initiative (AFRI) Post-doctoral Fellowship at Washington State University in Pullman, Washington. Dr. Maaz's recent post-doctoral fellowship and concurrent research has been focused on the management of nitrogen to minimize losses and improve use within cereal-based agronomic systems including the dryland winter wheat grown in the Palouse region of the northwestern U.S. Dr. Maaz's Ph.D. research led to recommended economic optimal nitrogen rates for canola in Eastern Washington. She also examined the impact of nitrogen supply, available water, and rotational effects on nitrogen use efficiency. Dr. Maaz succeeds Dr. Clifford Snyder who retired from the position of Nitrogen Program Director since 2007.

"We express our gratitude to Dr. Snyder for the significant impact he has had over his 22-year career with IPNI. The skills and experience that Dr. Maaz brings to the Institute will position her well as she takes over the role and we look forward to her Directorship," said Dr. Terry Roberts, President of IPNI.

Dr. Tai McClellan Maaz
IPNI Nitrogen Program Director

Tai received her Ph.D. from Washington State University (Soil Science) in 2014, her M.Sc. from the University of Hawaii in 2010, and her B.Sc. from the University of Hawaii in 2007. As a Ph.D. student, she received training in the National Science Foundation (NSF) Integrated Graduate Education Research Training (IGERT)'s Nitrogen Systems: Policy-oriented Integrated Research and Education (NSPIRE) program. She presently belongs to the Soil Science Society of America, the American Society of Agronomy, as well as the Center for Environmental Research, Education and Outreach at Washington State University.

Dr. Tom Bruulsema Named IPNI Vice President, Americas & Research

Dr. Tom Bruulsema of Guelph, Ontario, Canada has been promoted to Vice President, Americas & Research, with the International Plant Nutrition Institute (IPNI) effective June 26, 2017.

Prior to Dr. Bruulsema's appointment to IPNI Vice President, he has served as IPNI Phosphorus Program Director since 2015. Dr. Bruulsema has also served as Northeast Regional Director for the IPNI North America Program since the Institute's establishment in 2007, which is a position he also held for PPI since 1994. Dr. Bruulsema succeeds Dr. Paul Fixen who retired from IPNI after an impactful 28-year career.

"Paul will be missed, but the knowledge and experience Dr. Bruulsema brings to his new role will ensure a smooth transition for our Institute," said Dr. Terry Roberts, President of IPNI.

A native of Guelph, Ontario, Dr. Bruulsema received his B.Sc. (Agriculture) at the University of Guelph, Ontario, his M.Sc. (Crop Science) at the University of Guelph, and his Ph.D. (Soil Science) at Cornell University, New York. Prior to his work with the Institute, Dr. Bruulsema worked as a research associate at the University of Minnesota (1994) and an agronomist with the Mennonite Central Committee in Bangladesh (1986-1990).

Dr. Tom Bruulsema
IPNI Vice President, Americas & Research

Throughout his 23-year career with the Institute, Dr. Bruulsema has been a respected leader for agronomic research and education programs in North America and beyond. Dr. Bruulsema has been recognized as a Fellow of the American Society of Agronomy (ASA), the Soil Science Society of America (SSSA), and the Canadian Society of Agronomy, and is a Certified Crop Adviser.

Closing the Yield Gap for Wheat and Canola through an Adjusted Nitrogen Nutrition Index

By Andreas Neuhaus, Marianne Hoogmoed, and Victor Sadras

A new wheat and canola nitrogen nutrition index (NNI) has been developed as an interpretation method for more profitable and sustainable in-season N applications in dry climates with unfertile soils.

Crop advisers and growers can use the N Nutrition Index (NNI) to improve risk management or certainty around in-season N applications in wheat and canola. Once shoot N concentration and shoot biomass are measured or estimated using relevant tools in the field, a NNI can be calculated.

The theoretical concept of a NNI was introduced in a previous issue of *Better Crops* (Neuhaus et al., 2016). In brief, the NNI is a measure of crop N status. It is calculated as the ratio of actual N concentration (as measured in the crop) to critical N concentration. Critical N concentration is the minimum concentration of N that a crop requires to achieve maximum growth and can be determined experimentally. This concentration reduces with biomass growth, and this is captured in a so-called N dilution curve, which related critical N concentration with biomass. It was argued by Justes et al. (1994) that maximum crop growth would lead to reaching full yield potential, hence a NNI ≥ 1 is desirable.

This approach uses crop growth as a relatively easy-to-obtain, sensitive, and flexible indicator for benchmarking N deficiency throughout all crop stages (without the need of a skilled agronomist to identify crop stages correctly). However, doubts remained whether maximum crop growth would also lead to maximum yield in water-limiting environments. This article provides an update on NNI research through a comparison of wheat and canola, and proposes an adjustment which accounts for the water x N interaction.

Wheat and canola are two major crops grown in western and south eastern Australia. Nitrogen dilution curves required to calculate NNI for these crops have been determined in temperate climates with high yield potentials (Ulrich, 1952; Greenwood et al., 1990; Justes et al., 1994; Lemaire et al., 2008; Colnenne et al., 1998). By transferring the concept and applying the same equations for NNI to wheat and canola in the climate of Western Australia (WA) we observed an over-estimation of N deficiency (**Figure 1**). Hence there is a need to adjust the critical N dilution curves for water-limiting environments.

Abbreviations and notes: N = nitrogen; NNI = nitrogen nutrition index.

In order to transfer the NNI concept to water-limited and lower-yielding growing areas in WA we investigated the impact of rainfall and also addressed the often-seen N deficiency at early plant stages (shoot biomass < 1 t/ha in wheat and < 1.4 t/ha in canola) where the fraction of nitrates in wheat are considered to be an equally important indicator of N status apart from total N (%). NNI and plant water relations are linked (Sadras and Lemaire, 2014) and hence a lower N dilution curve under certain rainfall conditions may provide better correlations with yield data.

We found that by applying the methodology of Greenwood et al. (1990) on our dataset to derive a new N dilution curve (3.91 x biomass$^{-0.32}$) for winter wheat and then adjusting the NNI to rainfall (and nitrates for wheat < 1 t/ha biomass), we obtained a better NNI-yield correlation (**Figure 2**). For canola, the N dilution curve by Colnenne et al. (1998) was adequate for annual rainfall over 400mm, but was adjusted by a factor 0.5 for crops grown with less than 400mm of annual rainfall.

Interestingly, when comparing both crops in the same graph and plotting NNI versus absolute yield (**Figure 3**), the pattern of the yield ratio between the two crops (i.e., canola:wheat = 0.5) and the slope towards maximum yield (i.e., 2.85:5.7 = 0.5) are matching.

The calibrated, local trial data above integrates different

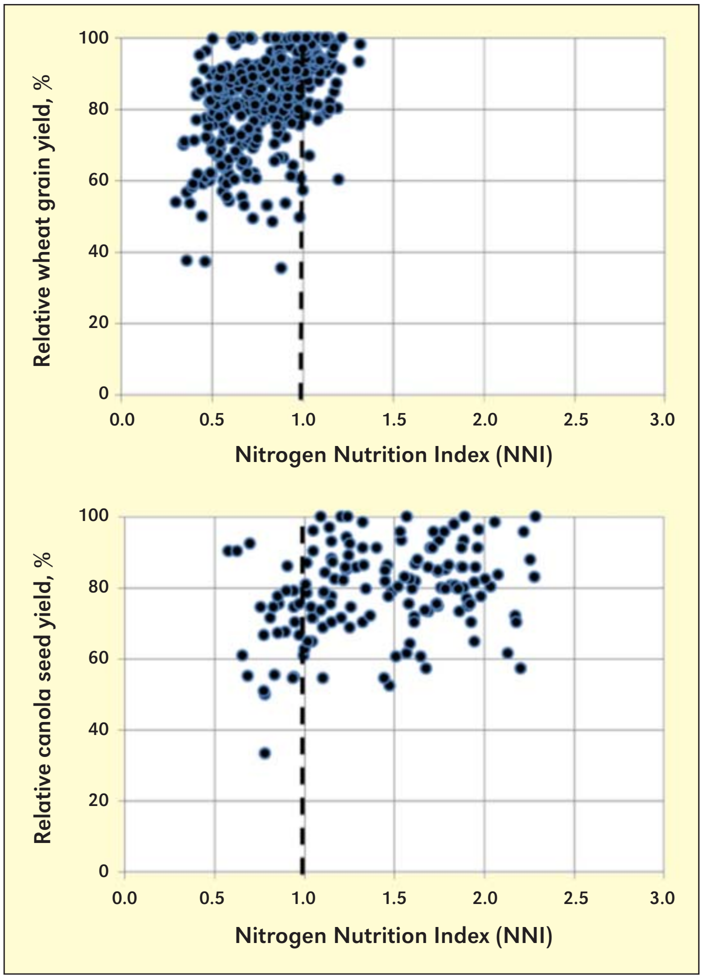

Figure 1. Application of the NNI from high-yielding, temperate climates shows sufficient N for wheat growth in particular, even if the NNI is < 1.0, which theoretically should indicate N deficiency and yield responsiveness to N applications. Graphs for wheat (top) and canola (bottom) were produced using CSBP Ltd. research trial data from WA. To calculate NNI, the critical N dilution curve for wheat with biomass > 1 t/ha (N = 5.3 x biomass^ - 0.44) was taken from Justes et al. (1994) and the curve for canola with biomass > 1.4 t/ha (N = 4.48 x biomass^ - 0.25) was taken from Colnenne et al. (1998).

TAKE IT TO THE FIELD

A NNI ≥ 1 likely means little yield response to an in-season N fertilizer application, but a later plant sampling might be considered in order to use the NNI as a monitoring tool for whenever in-season N applications are planned.

varieties, management, soil, and climate-specific conditions. The initial hypothesis that dilution curves from high-yielding environments will "shift" downwards under conditions of water deficit can be confirmed with this WA-CSBP Ltd. dataset. The research on NNI is ongoing and alternative approaches using growth stage instead of biomass to relate to critical N concentrations will be be explored.

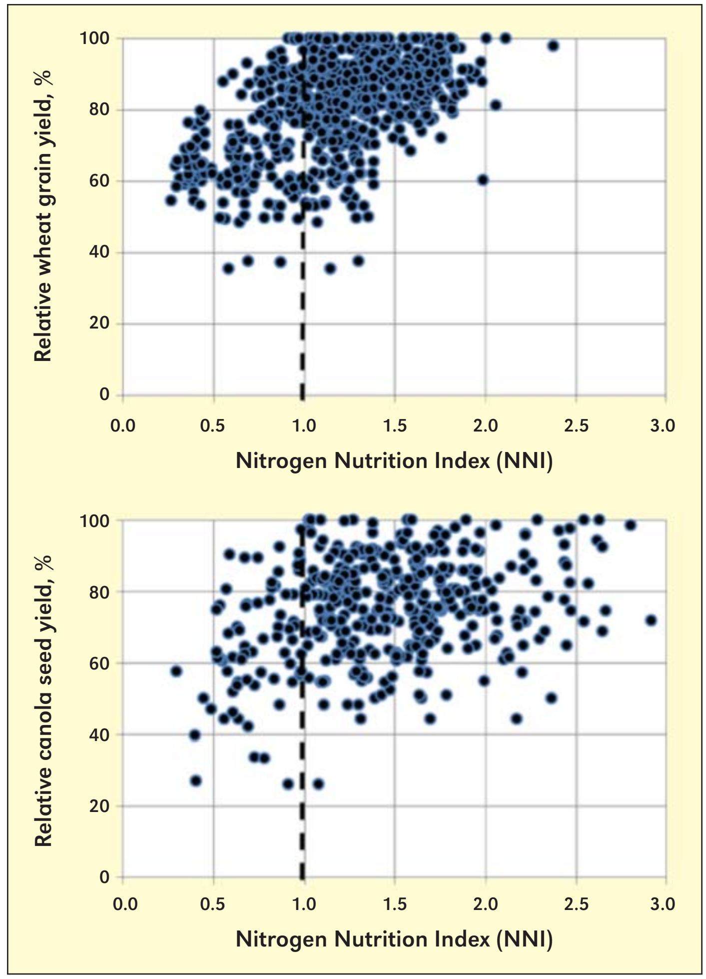

Figure 2. Adjusting the NNI by lowering the N dilution curve depending on rainfall (and nitrates in case of young wheat plants) shows N deficiencies in wheat (top) and canola (bottom) when the NNI < 1.0.

NNI EQUATIONS USED IN FIGURE 2

WHEAT (top graph)

NNI (SR† + GSR > 400mm and Biomass < 1 t/ha) = [(% N / (3.91 x $biomass^{-0.32}$)) + (mg/kg NO_3 / (610 x $biomass^{-0.91}$)) / 2]

NNI (Biomass > 1 t/ha) = % N / (3.91 x $biomass^{-0.32}$)

NNI (SR + GSR < 400mm) = % N / [(3.91 x $biomass^{-0.32}$) x 0.7]

CANOLA (bottom graph)

NNI (SR + GSR > 400mm and Biomass > 0.88 t/ha) = % N / (4.48 x $biomass^{-0.25}$)

NNI (SR + GSR < 400mm) = % N / [(4.48 x $biomass^{-0.25}$) x 0.5]

†SR = Summer Rain; GSR = Growing Season Rain.

Summary

This research can applied by crop advisors to offer improved risk management or certainty around in-season N applications. Once shoot N concentration and shoot biomass are measured from field samples or estimated using relevant tools in the field, a NNI can be calculated. Thereafter, fertilizer decisions could be based on closing the yield gap between

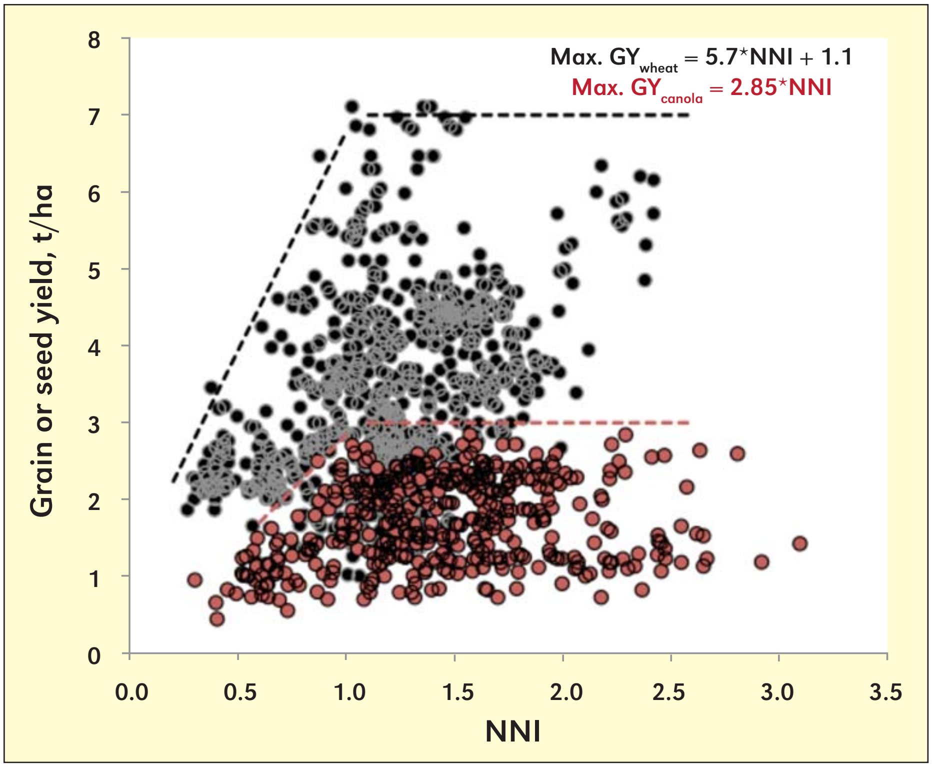

Figure 3. A rainfall-adjusted NNI < 1.0 corresponds to decreasing yield in wheat and canola.

yield potential at the calculated NNI and the water-limited yield potential that could be achieved in that season depending on rainfall. BC

Acknowledgement

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Dr. Heidi Peterson Named IPNI Phosphorus Program Director

Dr. Heidi M. Peterson has been hired as Phosphorus Program Director with the International Plant Nutrition Institute (IPNI) effective September 5, 2017. Dr. Peterson is filling the directorship previously held by Dr. Tom Bruulsema, who was appointed as IPNI Vice President, Americas and Research, earlier this year.

"Dr. Peterson comes to IPNI with significant leadership, teaching, and research experience surrounding phosphorus stewardship issues," said Dr. Terry Roberts, IPNI President. "We look forward to the impacts Heidi will have on the Institute's research and educational missions," Roberts added.

Dr. Peterson completed her Ph.D. in Biosystems and Agricultural Engineering (2011) at the University of Minnesota in St. Paul. Her Dissertation was titled "Estimating Renewable Water Flux from Landscape Features." She has a M.Sc. in Agronomy (2003) from Purdue University in West Lafayette, Indiana. She completed her B.Sc. (2000) in Natural Resources and Environmental Science, at Purdue University.

Most recently and since 2013, Dr. Peterson worked as a Research Scientist for the Minnesota Department of Agriculture. She was the lead technical expert on agricultural best management practices (BMPs) needed to address impaired waters issues within the state's agricultural landscapes. The position gave her oversight over research focusing on cover crop establishment and nutrient crediting, precision conservation, nutrient management, and innovative sub-surface drainage treatment.

Dr. Heidi Peterson
IPNI Phosphorus Program Director

Dr. Peterson has also been actively collaborating (since 2013) with phosphorus research scientists participating within tasked working groups of the Phosphorus Sustainability Research Coordination Network (P RCN), centered at Arizona State University. Dr. Peterson has been Adjunct Assistant Professor for the Department of Bioproducts & Biosystems Engineering at the University of Minnesota (U of M) since 2014. Previous to these positions, Heidi worked as a Post-Doctoral Research Fellow with the U of M Department of Bioproducts & Biosystems Engineering.

Heidi belongs to the American Society of Agronomy, American Society of Agricultural and Biological Engineers, the Soil and Water Conservation Society, and the International Network of Research on Coupled Human and Natural Systems. She will be based in Stillwater, Minnesota, U.S.A.

Cassava Productivity Linked to Potassium's Influence on Water Use Efficiency

By Kodjovi S. Ezui, Angelinus C. Franke, Peter A. Leffelaar, and Ken E. Giller

Adequate K supply is requisite for increasing cassava productivity and enhancing resilience to water stress.

Zingore/IPNI

Sustainable intensification of cassava production depends largely on maintaining proper soil K fertility.

Low soil fertility is recognized as an underlying factor to poor crop productivity in sub-Saharan Africa. This is associated with sub-optimal agricultural practices including low and unbalanced fertilizer application. Continuous cultivation of cassava without fertilizer application causes severe nutrient depletion, especially for K (Howeler, 2002). This situation of poor crop production is worsened by erratic rainfall patterns under rain-fed conditions with up to 60% yield losses experienced due to drought (Alves, 2002).

Potassium plays key roles in stimulating the photosynthetic activity of leaves, increasing the translocation of photosynthates to the roots, and regulating stomatal aperture and closure (Chérel et al. 2014). However, the influence of K on water use efficiency (WUE) and water transpiration is poorly documented. The focus of this study was to assess the effect of K on cassava yield, WUE, and water transpiration as affected by N and P availability under rain-fed conditions in West Africa.

On-farm experiments were conducted at two sites with contrasting soil K concentrations in southern Togo for two consecutive seasons (**Table 1**). At each experimental site, 15 nutrient combinations of N, P, and K at the rates of 0, 50, and 100 kg N and K/ha, and at 0, 20, and 40 kg P/ha were laid out in a randomized complete block design with three replicates (Ezui et al., 2017). Plot sizes were 5.6 m x 8 m (44.8 m^2) and cassava was planted at the recommended density of 0.8 m x 0.8 m (15,625 plants/ha). Mineral N fertilizer was applied as urea, P fertilizer as triple superphosphate, and K fertilizer as potassium chloride. Sequential harvests were carried out at 4, 8, and 11 months after planting (MAP) on both sites, except in year 1 in Djakakope where the trial was only harvested at 11 MAP.

Table 1. Soil physical and chemical characteristics (0 to 20 cm depth) before crop establishment on the fields in Sevekpota and Djakakope, Togo.

	Sevekpota		Djakakope	
Soil property	Field 1 (2012)	Field 2 (2013)	Field 1 (2012)	Field 2 (2013)
Org. Carbon, g/kg	11.5	12.2	6.2	4.7
Org. Nitrogen, g/kg	0.9	0.8	0.4	0.3
Sodium, mmol/kg	1.2	0.4	0.1	0.1
Potassium, mmol/kg	3.5	1.4	0.4	0.7
Calcium, mmol/kg	18.1	13.6	18.2	17.3
Magnesium, mmol/kg	5.3	4.5	7.1	7.0
Sand, g/kg	536	680	835	858
Silt, g/kg	163	150	52	45
Clay, g/kg	301	170	113	97
pH (H_2O), 1:2.5	6.5	6.5	6.5	6.5
Bray-P1, mg/kg	1.9	3.2	4.5	10.4
Total Phosphorus, mg/kg	189	202	155	194

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Water use efficiency [g dry matter (DM)/kg water] was estimated for each treatment as the weight of the biomass produced over the cumulative amount of water potentially transpired from planting to harvest. Potential transpiration (PTRAN) was based on the Penman equation (Penman, 1948). Cumulative PTRAN was obtained by integrating PTRAN over time, between planting and the different crop harvests. The cumulative PTRAN at each harvest was plotted against the amount of biomass produced at that harvest. The slope of the regression line of this graph is taken as the overall WUE for cassava.

Gross margin for different fertilizer treatments were calculated by subtracting the cost of fertilizers from the value of the cassava produced. We used national average values (± standard deviation) of fertilizer prices in Togo: US$1.72 ± 0.10 per kg N, $3.48 ± 0.37 per kg P, and $1.82 ± 0.19 per kg K (http://africafertilizer.org); and fresh cassava root prices at the farm gate of $0.118 ± 0.040 per kg (CountrySTAT, 2015).

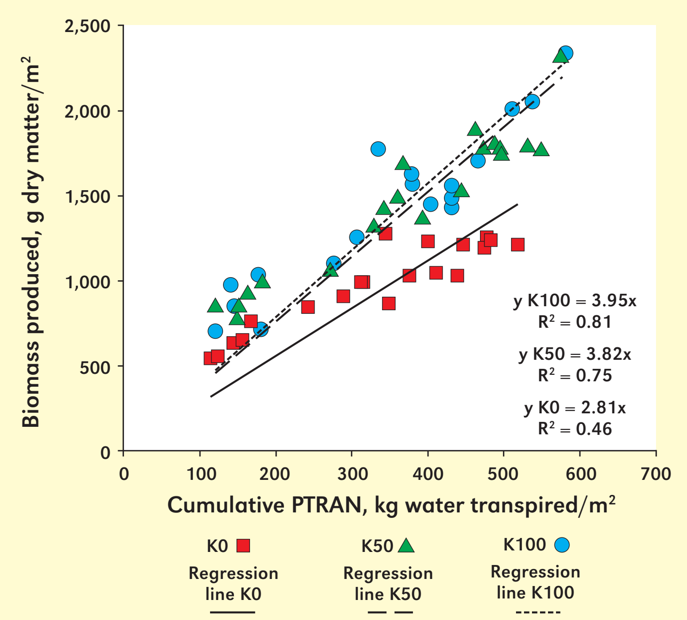

Figure 1. Response of cassava biomass production to PTRAN as affected by K rates in Djakakope, and the related WUE as indicated by the slopes of the regression lines. Each point corresponds to the average of a fertilizer treatment at a given harvest, time, and year.

Table 2. Yield (t root DM/ha) and WUE (g biomass DM/kg water transpired) as affected by N, P, and K fertilizer applications and their significant interactions with harvest time in Djakakope and Sevekpota. For each fertilizer rate of a given nutrient, all rates of the two other nutrients are included.

	Djakakope		Sevekpota	
Factors	Yield	WUE	Yield	WUE
N effects				
0 N	5.59	3.73	6.70	3.99
50 N	7.45	4.11	8.23	3.70
100 N	7.28	3.81	8.39	3.44
p value	*0.006*	*0.051*	*<0.001*	*0.021*
P effects				
0 P	6.30	3.73	7.63	3.68
20 P	7.34	4.13	7.65	3.49
40 P	6.68	3.83	8.03	3.85
p value	*0.089*	*0.296*	*0.094*	*0.277*
K effects				
0 K	4.87	3.14	7.71	3.74
50 K	7.74	4.22	8.56	3.77
100 K	7.71	4.26	7.05	3.51
p value	*<0.001*	*<0.001*	*0.048*	*0.162*
Harvest x N				*0.092*
Harvest x K	*<0.001*			
Harvest x N x K		*0.024*		
P x K				*0.062*

TAKE IT TO THE FIELD

The effects of K on water use efficiency (WUE), root yield, and profitability in cassava are heavily influenced by its balance with N.

Effect of K on WUE and Yield

Overall response of cassava WUE and storage root production to fertilizer applications was higher at Djakakope (**Table 2**) due to the lower soil N and K concentrations compared to Sevekpota (**Table 1**). Potassium application increased WUE over the cropping season in Djakakope (**Figure 1; Table 2**). The application of K also improved root DM at both locations. The positive effect of K on WUE could be ascribed to the ability of K to regulate stomatal aperture and closure (Chérel et al., 2014), given the high sensitivity of cassava to a leaf-to-air vapor pressure deficit. This mechanism allows the crop to transpire the limited amount of available water slowly during the dry season, resulting in greater DM gain and larger WUE over the cropping season. In our study, however, the effects of K on WUE can be attributed to enhanced biomass production. At Sevekpota, K fertilizer did not show significant effects on WUE nor on PTRAN and PET due to the high soil K status of this site. A critical soil K range of 0.08 to 1.8 mmol/kg is generally associated with cassava response to K applications (Howeler, 2002).

Effects of N on WUE and Yield

Nitrogen application decreased WUE in Sevekpota, but increased PTRAN (**Table 2**). Nitrogen additions did increase root DM in Sevekpota and Djakakope. The increase in PTRAN by N application goes along with a rise in plant photosynthetic activity (El-Sharkawy and Cock, 1986) due to the positive effect N has on leaf area development. This results in larger soil coverage by the plant canopy, leading to reduced evaporation from the soil.

The results in **Table 2** reveal that N and K play complementary roles in determining cassava productivity. While N is more active in enhancing water transpiration through larger cassava leaf area development, K plays a role in improving the efficiency of water use by cassava.

Effects of P Application on WUE and Yield

Phosphate fertilizer did not have any significant effect on WUE, or root DM at either site. This weak response of cassava to P fertilizer can be attributed to the crop's strong mycorrhizal associations, which improves cassava's efficiency to extract P from the soil (Sieverding and Leihner, 1984).

Effect of Harvest Time on WUE

Estimated WUE ranged from 1.54 to 7.12 g DM per kg water transpired, with an overall value of 3.22 g biomass DM produced per kg water transpired over the cropping season, and a coefficient of determination (R^2) of 0.64. Water use efficiency was 3.58 and 2.99 g DM per kg water in Djakakope (R^2 = 0.64) and Sevekpota (R^2 = 0.68), respectively. These values are comparable to the 2.9 g total biomass DM per kg of water transpired for cassava reported by El-Sharkawy and Cock (1986).

The variability in WUE within sites can be credited not

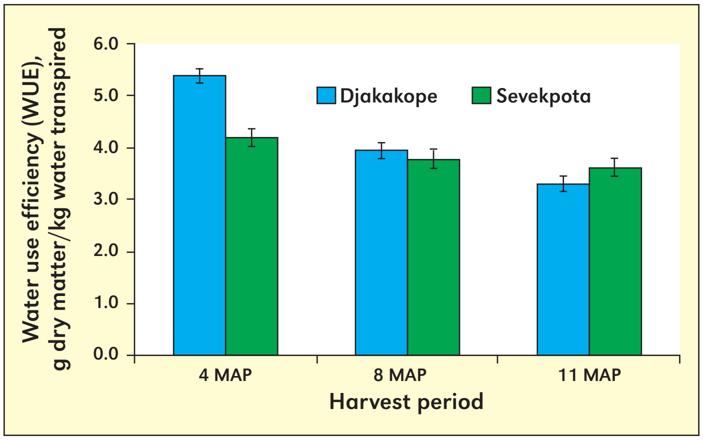

Figure 2. WUE as affected by harvest times in Djakakope and Sevekpota. Error bars indicate the standard error of the mean.

only to response to N and K applications, but also to the effect of harvest time (**Figure 2**). Greater WUE was obtained at 4 MAP harvest, compared to 8 and 11 MAP harvests ($p < 0.001$). Demands for water and light energy are high during the first 6 MAP, which comprises a period of strong vegetative growth, generally from 3 to 6 MAP (Alves, 2002). Fertilizer application should be well timed to ensure nutrient availability at the critical growth period to ensure higher use efficiency. Beyond this phase, the rate of shoot growth is reduced in favor of carbohydrate translocation to the roots.

Economic Benefits of K Application

The economic analysis revealed that gross margin of fertilizer use increases as WUE of cassava rises, particularly in Djakakope (**Figure 3**). The largest gross margins were achieved with the application of 50 and 100 kg K/ha in Djakakope, and with 50 kg K/ha in Sevekpota. These results stress the importance of supplying balanced amounts of K on a site-specific basis in order to achieve an optimal return from investment in fertilizer. BC

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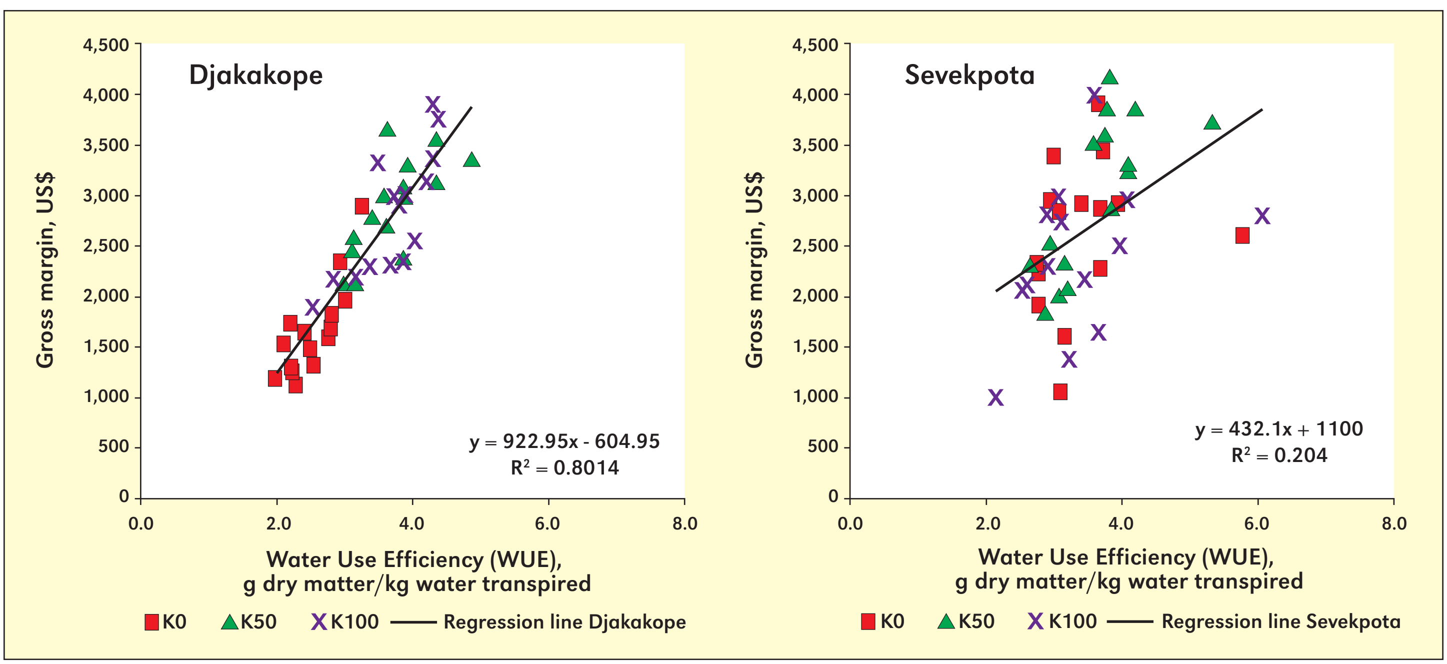


Figure 3. Gross margin of fertilizer use as a function of WUE at different K rates at Djakakope and Sevekpota.

Managing Sulfur for Enhanced Productivity in the Irrigated Oil Palm Plantations of Southern India

By Teki Nagendra Rao and Nasim Ali

Information on response to S application in oil palm is limited, and there is a need to understand the importance of S nutrition in oil palm based on the crop's high removal rate plus the large potential for the loss of applied S.

Sulfur is recognized as one of the most limiting nutrients after N, P, and K in Indian agriculture. Low soil S concentrations and corresponding crop responses to S fertilization are commonly reported in India (Tandon, 2011). However, S nutrition in oil palm is less explored even though S uptake by oil palm and S removal through fresh fruit bunch (FFB) harvest are both considerable (Gerendás et al., 2015). Additionally, nutrient loss caused by high rainfall/irrigation events typical of the growing environment in southern India promotes significant leaching of S in sulfate form, especially in coarse-textured soils.

India's commercial oil palm production began in the 1960s and today the southern state of Andhra Pradesh is the largest center for oil palm cultivation in the country. Farmers in the state have achieved sustained success with oil palm under public-private partnerships involving government and commercial agencies. A survey was organized during 2013-14 to determine the nutritional status of this region's oil palm plantations. Leaf samples were collected from 177 mature oil palm plantations at Chintalapudi, Kamavarapukota, Dwaraka Tirumala, and Unguturu mandals of West Godavari district in Andhra Pradesh.

Composite samples were collected from each oil palm garden using the central point of the rachis of frond #17, and analysed for leaf N and S. The analyses revealed that N concentration ranged from 1.61 to 3.92% (average of 2.60%), and the average N concentration in all four mandals was within the published optimum range of 2.4 to 2.8% (**Table 1**). Similarly, the leaf S concentration ranged from 0.04 to 0.18% (average of 0.10%), indicating that values across all the surveyed plantations were below the published critical level of 0.20% (**Figure 1**).

Gerendás et al. (2015) reported a N:S ratio of 15:1 as optimum for oil palm grown in Indonesia. However, leaf analyses data in the current study showed N:S ratios ranging from 15 to 80 with a mean of 29, suggesting significant imbalance between these two nutrients (**Figure 2**). Leaf N:S ratio and leaf S concentration were significantly and inversely related to each other (**Figure 3**), highlighting the importance of S fertilization for narrowing down the prevailing N:S ratio.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; KCl = potassium chloride; 1 US$ = 64 Indian Rupees (Rs.).

Marking the palms for sulfur experiment.

Table 1. Leaf nitrogen concentration (%) of oil palm plantations in four mandals of West Godavari district, Andhra Pradesh.

Leaf N concentration	Chintalapudi	Kamavarapukota	Dwaraka Tirumala	Unguturu
Mean	2.58	2.76	2.57	2.50
Std. Dev.	0.39	0.50	0.28	0.25

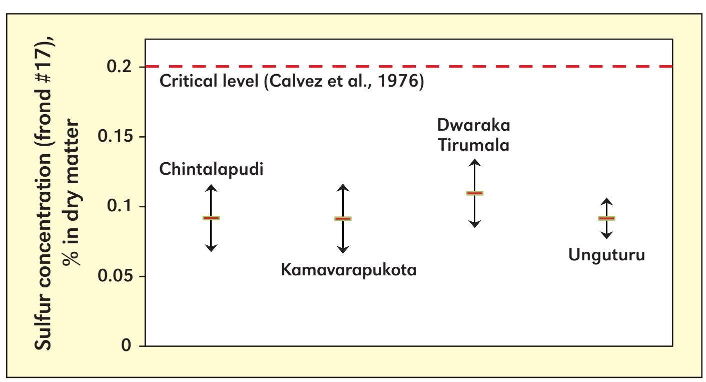


Figure 1. Average S concentration for samples of frond #17 (dry weight basis) in four mandals of West Godavari district, Andhra Pradesh (arrows indicate standard deviation).

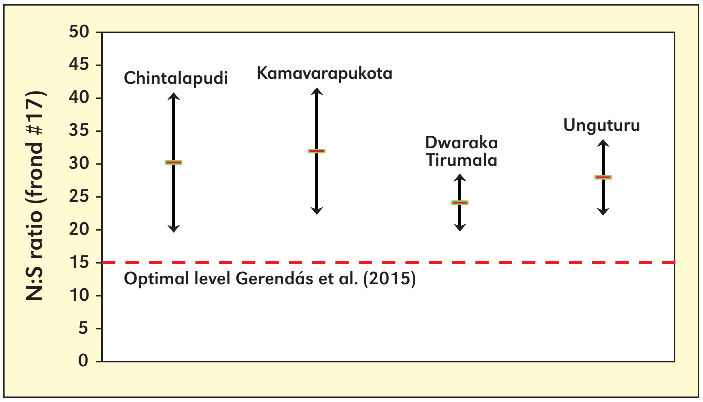


Figure 2. Average N:S ratio for samples of frond #17 (dry weight basis) collected across four mandals of West Godavari, Andhra Pradesh (arrows indicate standard deviation).

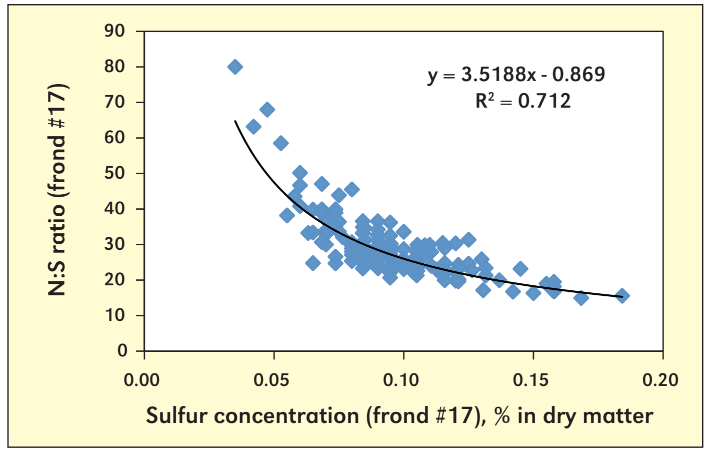


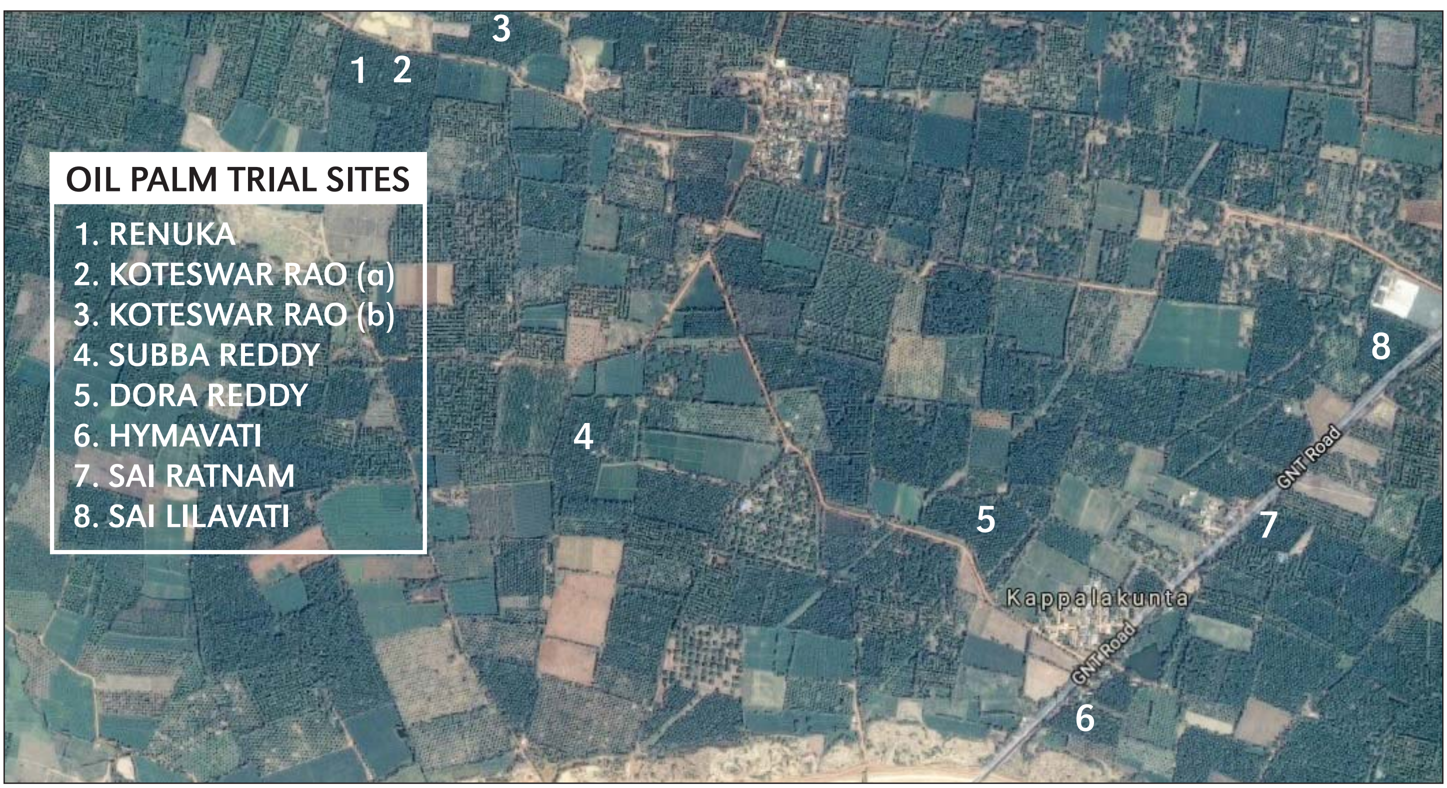
Figure 3. Relationship between N:S ratio and S concentration in samples collected across four mandals of Andhra Pradesh.

Farmers growing oil palm generally apply single superphosphate (SSP) as a source of P, which contains S in gypsum ($CaSO_4 \cdot 2H_2O$) form. However, it is not known whether such a sparingly soluble form of S is an appropriate source for oil palm grown in nearly neutral, coarse-textured soils. It is generally assumed that SSP indirectly supplies adequate S for the crop. However, our assessment of S status of oil palm plantations showed values below the critical level across the region. Either palms are low in S because of inadequate application rates or a lack of S availability due to an inappropriate source. A field study was organized during 2014 and 2015 to further investigate the response of oil palm to S fertilization in the region.

Sulfur Response Study

Mature oil palm plantations of 6 to 8 years in age were chosen at eight locations in the Kappalakunta area of Dwaraka Tirumala Mandal. The sites represented the sandy to loamy soil texture common to the region. Initial leaf and soil samples had S concentrations below critical values (averages across sites: 0.13% for leaves and 6.1 mg/kg for soil). Palms were irrigated through micro-sprinkler systems, a common practice followed in most plantations of the region.

The study consisted of three treatments: 1) farmer practice (FP), 2) FP + Gypsum, and 3) FP + elemental S (ES). Farmer practice was considered a control, blanket management practice that included $N\text{-}P_2O_5\text{-}K_2O$ application of 1,200-600-1,200 g/palm/yr using urea, SSP, and KCl. This combination is a general recommendation for the region (Narasimha Rao et al., 2014). SSP contributed 400 g S/palm/yr. The FP + Gypsum treatment applied an additional 400 g S/palm/yr through the gypsum source (without increasing P dose). Since gypsum is also a S source being used by some farmers, this treatment was incorporated in the study. The FP + ES treatment added 400



Map showing multi location trial sites (farmer plantations) at Kappalakunta (Dwaraka Tirumal Mandal) where the experiment was organized during 2014 and 2015.

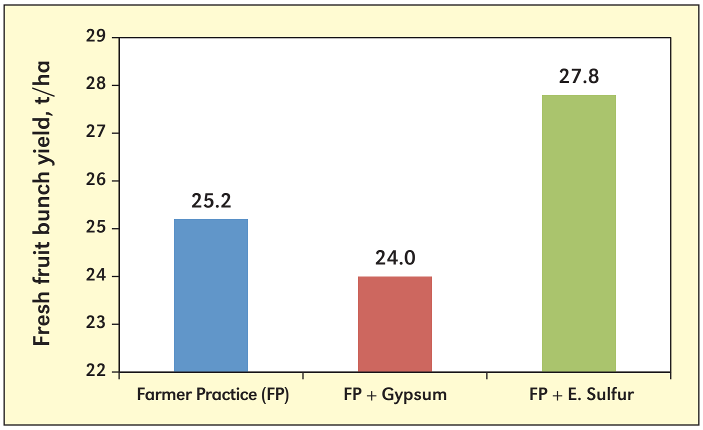


Figure 4. Average oil palm FFB yield response to additional S application over farmer practice at eight locations. Critical Difference = 2.03 (p = 0.05).

g S/palm/yr through a granular bentonite clay-based form of elemental S. Sulfur uptake and removal of S by oil palm were taken into consideration while deciding the rates of applied S.

Thus, the study considered increasing the dose of S application either through the gypsum source or the new bentonite S source. Of the two S sources, gypsum is a sparingly soluble S source with Ca as an associating cation whereas bentonite S is slow release in nature with no associating cation and sulfate is released only after oxidation. The entire S dose was divided into two equal splits (200 g S/palm at each application) and applied at an interval of three months from the beginning of each year to ensure better solubilization and absorption by the oil palm. Applied S was placed at the basin encircling the trunk at a distance of nearly one meter.

In each plantation, 30 palms distributed in three rows were selected for each treatment, and nutrients as per FP, FP + Gypsum, and FP + ES were applied to the three treatments. The middle row of 10 palms were tagged and observations were recorded only from the tagged palms to avoid a border affect. Thus at each location, 90 palms were chosen for the study (0.63 ha) and response to right source of S application was determined. FFBs were collected from each site at 10 day harvest intervals, weighed, and yields were recorded for two consecutive years (2014 and 2015).

The average yield of FFB, averaged over sites and years, across the oil palm plantations of the study region was 25.2, 24.0, and 27.8 t/ha/yr under FP, FP + gypsum, and FP + ES, respectively (**Figure 4**). The FFB yield in FP + ES was significantly higher compared to FP and FP + Gypsum. The results suggested that application of bentonite S along with FP improved the yield of FFB significantly by 2.6 t/ha/yr over FP. Application of FP, with additional application of 400 g S/palm sourced through gypsum had no profound effect on oil palm productivity as far as S nutrient source is concerned. The study also indicated that additional application of S at 400 g/palm through bentonite S resulted in an additional net return of Rs. 13,946/ha (US$218) with an improved incremental benefit:cost ratio of 4.7, respectively (data not shown). Hence, in order to obtain yield response to S application, oil palm growing farmers may choose bentonite S instead of gypsum as an appropriate S source applied at 400 g S/palm/yr.

Sulfur fertilizer application in a circle around the palm trunk (right place) as per prescribed method, each hectare is planted with 143 palms at nine meter distance triangular planting.

Summary

Leaf S concentrations in the oil palm plantations across four mandals of West Godavari district in Andhra Pradesh were below the referenced critical level of 0.20% S and had N:S ratios beyond 20:1, indicating the need for improved S nutrition. A multi-location field study conducted during 2014 and 2015 showed oil palm response to S fertilization. Application of 400 g S/palm/yr (in addition to FP) through bentonite S (bentonite clay based elemental S pastilles) was considered as an appropriate source of S to improve the FFB yield of oil palm. This may be applied in two splits at an interval of three months during early months of each year placed at the basin encircling the trunk at a distance of approximately one meter. Thus, practicing principles of 4R Nutrient Stewardship coupled with the inferences drawn from leaf tissue analyses shall form the basis of S nutrition for improved productivity of oil palm plantations in Andhra Pradesh. BC

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TAKE IT TO THE FIELD

Applications of a bentonite clay-based elemental S can provide an effective S supply for improving FFB yields of irrigated oil palm plantations grown on coarse-textured, S-limited soils.

Dr. Rao is Chief Agronomist, Oil Palm Plantations R&D (e-mail: Nagendra.rao@godrejagrovet.com) and Mr. Ali is Business Head of Oil Palm Plantations (e-mail: Nasim.ali@godrejagrovet.com) at Godrej Agrovet Ltd., India.

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Annual IPNI Photo Contest: Now a Forum to Share Crop Diagnostics and 4R Accomplishments

Starting this year, the International Plant Nutrition Institute's annual photo contest expanded its format to include (1) our regular competition for finding the clearest examples of crop nutrient deficiency and (2) a new 4R Nutrient Stewardship category designed 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 entries have been coming in steadily but we'd like to see more!

Submit your best photos in any of these four categories until December 5, 2017. Our winners will be announced early in 2018.

For additional information, please contact Gavin Sulewski, IPNI Editor, at gsulewski@ipni.net. You can also view past winners of the photo contest at http://www.ipni.net/photocontest/history BC

A strip tillage implement designed to place phosphorus during the fall into winter wheat stubble **(example of 4R Nutrient Stewardship – Right Place)**. IPNI Image taken in Ontario, Canada.

Vibrant expression of phosphorus deficiency in corn **(First Prize winner in 2016)**. Taken near Limington, Maine, USA by Jim Valent, State College, Pennsylvania, USA.

Photo Contest Categories

1. 4R Nutrient Stewardship - New!

2. Primary Nutrient Deficiencies
- nitrogen (N), phosphorus (P), and potassium (K)

3. Secondary Nutrient Deficiencies
- sulfur (S), calcium (Ca), and magnesium (Mg)

4. Micro Nutrient Deficiencies
- boron (B), copper (Cu), chloride (Cl-), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

The Development of the Potash Fertilizer Industry

By Robert Mikkelsen

The growth and quality of many crops around the world suffer due to an inadequate supply of plant-available potassium (K) in the soil. IPNI has had a renewed emphasis on the importance of K for crop nutrition through recent international conferences and an upcoming book. The outputs of the 2017 IPNI Frontiers of Potassium Science Conference are archived at https://conference.ipni.net/conference/kfrontiers2017/article/home. It is timely to briefly review the development of this important industry that supports the global food supply.

Potassium salts have been valuable industrial chemicals for more than a thousand years, where they are used in making glass, soap, paper, and textiles. Leaching K salts from wood ash in vast hardwood forests in Russia and also harvesting kelp from the coast of northern Europe (especially Scotland) were some of the early sources of potash. Some of the kelp biomass was used as fertilizer, but most of the harvested kelp was treated to collect concentrated potash for industrial purposes.

Production of potash was an important source of income for the early North American colonies as forests were cleared and easy access to ports made shipping to Europe feasible. The income derived from potash sales after clearing and burning the forests often provided the necessary financial support during the first years while a new farm was being established.

Kelp cart on the Isle of Lewis, Scotland.

As the essential nature of K for plant nutrition was recognized in the 19th century, the demand for K fertilizer greatly expanded, leading to the development of the potash fertilizer industry from geologic sources. Large-scale K mining was made possible with technology from the industrial revolution to make potash affordable and available for farmers.

The early supply of mined potash was from the Stassfurt region of Germany, which still has an active K mining industry. The potash trade between North America and the German potash cartel was halted by World War I. This abrupt potash shortage prompted urgent exploration for new K sources.

Some of the North American K resources developed in the early 1900's include:

Nebraska: Potash was extracted from brines in the Western Sandhills of Nebraska. At the peak, there were ten plants operating in the region, with a dedicated railroad line for transportation.

California: Kelp harvesting was an important source of K during the early 1900's. Kelp was also a source of acetone, which was important for the war effort. Potassium and boron-rich brines from the Searles Lake region were extracted for commercial fertilizers and industrial chemicals

IPNI Image

Potash ore-loader working in Carlsbad, New Mexico, 1967.

New Mexico: Commercially valuable deposits were developed near Carlsbad, where potash mining continues today. Other deposits were developed in Michigan and Utah.

Large potash reserves were developed in the Ural Mountains of the Soviet Union in the 1930's, and later in Belarus, adding to the global supply.

Following World War II, the largest global deposits of potash were discovered at a depth of 1,000 m or more in Saskatchewan, Canada, with commercial production beginning in the 1960's.

Significant potash mining still continues in China, Germany, the Middle East, Chile, Spain, and the U.K. There are pilot projects currently underway in many additional countries that may bring additional potash fertilizer to the global marketplace.

Potash fertilizer largely comes from the minerals sylvite (KCl), sylvinite (KCl + NaCl), and increasingly from polyhalite ($K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$). A variety of other K-rich minerals are mined or processed into potash fertilizer to meet the needs of individual crops and soil conditions.

The six countries that utilize the most potash are China, Brazil, United States, India, Indonesia, and Malaysia who consume more than 70% of global production. This usage reflects the native soil K supply and the K demand of the crops grown in these countries.

Potassium minerals are fairly common around the world and the estimated world resource is about 250 billion metric tons. Despite the abundance of potash, it is always appropriate to use all plant nutrients carefully and apply the principles of 4R Nutrient Stewardship when making crop fertilization decisions. BC

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Additional Reading

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47th North Central Extension Industry

SOIL FERTILITY CONFERENCE

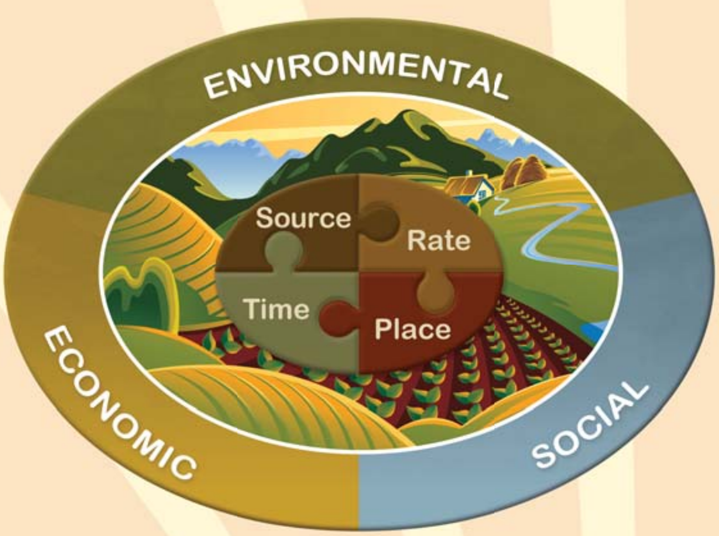
The International Plant Nutrition Institute (IPNI) would like to invite you to attend the North Central Extension-Industry Soil Fertility Conference being held on **November 15-16,** at the **Holiday Inn Airport** in **Des Moines, Iowa.**

Oral and poster presentations will highlight ongoing soil fertility research at universities in the North Central U.S. region (i.e., IL, IN, IA, KS, KY, MI, MN, MO, NE, ND, OH, ON, PA, SD, and WI). The Conference is attended by university extension soil fertility and crop production specialists, industry agronomists, crop advisers, and agency personnel, with representation from states encompassing the North Central region of the US as well as Ontario, Canada. The goal of the conference is to facilitate sharing of new soil fertility and nutrient management research information and fertilizer industry developments.

Registration opens on September 5th

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

The 4R oval has become one of my favorite diagrams. In one glance, it conveys a rich vision. It depicts both the simplicity and the complexity of the responsible management of plant nutrition. It shows the benefits to the human family through impacts on abundant food, healthy soil, clean water, and fresh air.



The diagram places the 4Rs in the center of an agricultural ecosystem. The three dimensions of sustainability surround it. The intent is to suggest that what we define as "right" for each nutrient application is the combination of source, rate, time and place that improves the sustainability of the cropping system. That combination is specific to each field, each farm, and each regional climate.

While the 4Rs form the core focus, the sustainability of the cropping system depends just as strongly on crop, soil and pest management practices as well. To be right, nutrient management needs to fit in with the site-specific management needs of each farm's crops, soils and resources. In addition, the cropping system is embedded in an ecosystem. Each ecosystem has its own sensitivities, which may require additional and complementary conservation practices. Responsible management of plant nutrition needs to focus on sustainable whole systems.

The crop nutrition industry is engaging more and more in the implementation of 4R Nutrient Stewardship. Industry associations, farm commodity groups, sustainability organizations, scientific societies, and environmental groups are all contributing to these efforts. The 4Rs benefit everyone—and we all play a role in its implementation. The task is large and beyond the capacity of any one organization.

IPNI has partnered and collaborated worldwide with many organizations to develop and promote the 4R concept, and to advance its implementation. As IPNI scientists, we are confident in continuing and expanding these efforts. Our mission and our plans are built around developing and delivering evidence-based information supporting the vision behind the 4R oval. For the science behind the diagram, IPNI scientists seek to serve all those engaged in its implementation.

Tom Bruulsema

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