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CASSAVA Fertilization: Why a 4R Approach is Important

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Our cover: High-yielding local cassava variety five months after planting, San Narciso, Zambales, Philippines.
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Dr. Zingore and Mr. Wafula (M.Sc. student) assessing a soybean fertilizer response trial in western Kenya.

Soil Fertility Management for Soybean Intensification in Western Kenya

By Evans Wafula, Shamie Zingore, and George N. Chemining'wa

Soybean yields in smallholder farming systems in sub-Saharan Africa (SSA) are severely constrained by poor soil fertility and a lack of nutrient management recommendations that are suited for the highly variable growing conditions within the region. Most smallholders practice continuous cropping with little or no nutrient inputs, which leads to severe nutrient depletion and soil acidification (Sanchez, 2002). Apart from widespread limitations of N and P across the highly weathered soils in SSA, deficiency of other essential nutrients, low organic matter, and soil acidity also contribute to low crop yields (Kihara et al., 2017).

Fertilizer recommendations for soybean in Kenya have been largely focused on P. However, there is a growing realization that integrated nutrient management practices that provide a balanced application of fertilizer, manure, and lime are essential to sustaining higher yields.

Study Description

On-farm experiments were conducted to investigate the effects of balanced fertilizer use in combination with manure and lime on soybean yield and biological nitrogen fixation (BNF) potential. The experiments were carried out for two seasons at two sites representative of low and moderate soil fertility conditions in Kenya. The first site at Masaba had an infertile, sandy clay loam soil (Cambisol) and much low-

Large soybean yield gaps on smallholder farms in Kenya are associated with multiple soil constraints, including nutrient depletion, low organic matter, and soil acidity. Integrated nutrient management practices are necessary to increase productivity, particularly on degraded course-textured soils.

KEYWORDS:
integrated soil fertility management; yield potential; smallholders; biological nitrogen fixation.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Mo = molybdenum; Zn = zinc; C = carbon.

https://doi.org/10.24047/BC10223

Table 1. Soil characteristics of the two experimental sites in Western Kenya.

Sites	pH	C, %	N, %	K, $cmol_c$/kg	P, mg/kg	Ca, $cmol_c$/kg	Mg, $cmol_c$/kg	Zn, mg/kg	Particle size distribution, % Sand	Silt	Clay
Masaba	5.2	1.2	0.13	1.38	5.7	0.55	0.64	1.5	58	15	27
Nyabeda	5.7	2.4	0.22	1.11	5.0	0.59	2.42	8.5	12	20	68

er organic C and available Zn compared to the moderately fertile, clay soil (Ferralsol) in Nyabeda (**Table 1**). Available soil P was very low at both sites and was below the critical value of 15 mg/kg (Nziguheba et al., 2002).

The experiment was laid out in a randomized complete block design with three replications. The treatments included: 1) Control - without inoculant and fertilizer; 2) Inoculation alone; 3) N+P+K; 4) P+K; 5) N+P; 6) N+K; 7) N+P+K+S+Ca+Mg+Zn+Mo (Complete Fertilizer) and 8) Complete Fertilizer+Cattle Manure+Lime.

Fertilizer application rates required to achieve the attainable yields for the study area were: 30 kg P/ha, 60 kg K/ha, 23 kg S/ha, 20 kg Ca/ha, 5 kg Mg/ha, 3 kg Zn/ha, and 3 kg Mo/ha. Starter N was applied at a rate of 20 kg/ha. Manure was applied at 10 t/ha and dolomitic lime at 5 t/ha. All fertilizer, manure, and lime treatments were incorporated to 20-cm soil depth at the time of planting. All the treatments, except the control, were planted with soybean inoculated with *Bradyrhizobium japonicum* (USDA-110 strain). The locations of trial plots were changed after the first season to avoid varying soil fertility conditions. Fields with similar soil conditions were selected for the second season.

Soybean Nodulation and Yield

At both sites, the nodule dry weight was the lowest for inoculated treatments without P, which suggested that P was the most limiting nutrient and its absence significantly impaired BNF (**Table 2**). The highest values for soybean nodule dry weight were achieved with the Complete Fertilizer+Manure+Lime treatment. Integrated nutrient management had its strongest influence on BNF potential at the poorer soil site at Masaba.

Table 2. Average dry weight of nodules in soybean plants grown on-farm in Masaba and Nyabeda for the two cropping seasons.

Treatment	Masaba	Nyabeda
	mg/plant	
Control	0.0 a	0.0 a
Inoculation alone	34.0 a	51.0 bc
NK	25.2 a	38.4 ab
PK	89.3 b	97.4 cd
NP	91.0 b	123.3 d
NPK	132.3 c	107.2 d
NPKSCaMgZnMo (Complete)	86.9 b	88.3 cd
Complete+Manure+Lime	182.8 d	107.3 d
LSD (p = 0.05)	37.5	47.9

Values in the same column followed by the same letter are not significantly different at p = 0.05.

Masaba – Low Yield Potential

Soybean yield for the control treatment at the coarser-textured Masaba site was very low in both seasons compared to more fertile Nyabeda site (**Table 3**). Neither inoculation alone nor application of N+K increased soybean yield at Masaba compared to the control in both seasons. The application of P significantly increased yield in most treatments, but the combination of P with other primary, secondary, and micronutrient fertilizers proved inadequate to achieve maximum attainable yields at each site. The addition of manure and lime along with fertilizers increased soybean yield by >150% in the first season and 68% in the second season. Despite these yield gains, they were less than 50% of the maximum yields obtained in Nyabeda.

Table 3. Average grain yield of soybean grown on-farm in Masaba and Nyabeda for the two cropping seasons.

Treatment	Masaba	Nyabeda
	Season 1	
	t/ha	
Control	0.04 a	1.36 a
Inoculation alone	0.06 ab	2.02 b
NK	0.04 a	1.95 b
PK	0.22 c	2.14 b
NP	0.42 d	2.47 c
NPK	0.16 bc	2.03 b
NPKSCaMgZnMo (Complete)	0.39 d	2.33 bc
Complete+Manure+Lime	1.40 e	3.15 d
LSD (p = 0.05)	0.10	0.30
	Season 2	
Control	0.85 a	1.34 a
Inoculation alone	1.11 ab	2.08 b
NK	1.40 abc	2.35 bc
PK	1.61 bc	2.46 c
NP	1.39 abc	3.04 d
NPK	1.86 c	2.44 c
NPKCaMgZnMo (Complete)	1.80 c	2.82 d
Complete+Manure+Lime	2.24 d	3.99 e
LSD (p = 0.05)	0.60	0.33

Values in the same column followed by the same letter are not significantly different at p = 0.05.

Nyabeda – Moderate Yield Potential

In Nyabeda, control plots showed relatively high yields (>1 t/ha) if compared to Masaba (**Table 3**). Inoculation alone increased grain yield over the control across seasons. Similar to Masaba, significantly lower grain yields were recorded in the NK treatment compared to the NPK, NP, and PK treatments. Adding manure and lime along with fertilizers increased yields by 35 to 42%. The highest soybean yields for both sites and years were associated with application of macronutrients, secondary nutrients, micronutrients, manure, and lime.

See Interactive Charts

Analysis of the yield responses showed that P and manure+lime application had the strongest effects on soybean yield in the first season for both sites (**Table 3**). Application of secondary and micronutrients consistently increased yields by at least 0.2 t/ha in the first season. During the second season, yield responses to P decreased at the moderately fertile Nyabeda site, while they increased at Masaba. Manure and lime application led to the overall largest yield responses (>1 t/ha) in both sites.

TAKE IT TO THE FIELD

Phosphorus application was responsible for significant yield increases at both sites, but the integration of fertilizers with lime and manure is essential to maximizing grain yield potential. Higher yield responses should be expected on clay soils with less severe fertility restrictions.

Conclusions

Adverse soil conditions in Western Kenya can be overcome with integrated nutrient management. The practice has been demonstrated to have a great impact on soybean yields, which provides an opportunity for profitable intensification among smallholders. **BC**

Acknowledgement

The work is an outcome of activities of IPNI sub-Saharan Program within the IPNI Working Group on Nutrient Decision Support for Soybean Systems.

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References

Kihara, J. et al. 2017. Agronomy for Sustainable Development 37: 25.
Nziguheba, G. et al. 2002. Plant Soil 243: 1-10.
Sanchez, P. 2002. Science 295: 2019-2020.

Integrating Crop and Fertilization Management Strategies for Soybean in the Central Pampas

By Juan Martin Enrico, Fernando García, Mike Stewart, Eros Francisco, Guillermo Balboa, Ignacio Ciampitti, and Fernando Salvagiotti

A. Williams/IPNI Image

A field study in the central Pampas of Argentina evaluated the relative impact of more intensively managed crop and fertilizer practices on soybean growth and yield.

The main objectives of sustainable intensification in agriculture are increased crop production, maximized resource use efficiency, and a reduction in negative environmental impacts within agro-ecosystems. To achieve each of these objectives, it is best to understand the many processes that affect crop production (e.g., the potential for biomass production, its partitioning to reproductive plant parts, the efficient use of resources [water, light, nutrients]), as well as the magnitude of the yield gap that exists from using current production practices rather than those recommended for more efficient use of resources and inputs.

The potential yield (PY) of soybeans is determined genetically, but it is difficult to estimate PY precisely in the field, even assuming no water and nutrient constraints or yield-limiting factors (insects, weeds, diseases). The concept of maximum attainable yield (MY) is more practical. MY will vary depending on the site's growing conditions and crop management. Under rain-fed conditions, where water is the most limiting factor, MY can be defined as MY_d (i.e., maximum attainable yield under dryland conditions). Combinations of row spacing, planting date, plant population or genotype contribute to narrow the gap between common practice and that recommended for high yields. Recent studies in Argentina have shown that various management practices increase soybean production, e.g., reduction of

Changes to specific crop management practices increased both biomass and seed yield. Seed yield improvements were mostly achieved through greater production of biomass and number of seeds. These effects were further enhanced under more intensive fertilizer management. Processes occurring at seed set (R2 to R5) and pod filling period (R5 to R7) were the most affected. Optimizing the growing conditions within these stages is critical when looking for higher yields. Increased yields under more intensive strategies were associated with higher uptake of N, P, and S.

KEYWORDS:
intensification; biomass; leaf area index; nutrient uptake.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; S = sulfur; B =boron; Zn = zinc; HI = harvest index.

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Table 1. Description of crop and fertilization management strategies studied during the 2014-2015 and 2015-16 seasons.

Treatments		Farm practice (FP)	Fertilizer intensification (FI)	Management intensification (MI)	Management + fertilization intensification (MFI)
		Crop Management Strategies			
Target population, pl/ha		290,000 (331,731)*	290,000 (320,513)	440,000 (413,462)	440,000 (431,090)
Row spacing, cm		52	52	26	26
Cultivar		DM 4970	DM 4970	LDC 4.7	LDC 4.7
Planting date	2014-15	28 Nov	28 Nov	7 Nov	7 Nov
	2015-16	18 Nov	18 Nov	5 Nov	5 Nov
		Fertilizer Management Strategies			
Inoculation		No	Yes	No	Yes
P		No	20 kg P/ha**	No	20 kg P/ha**
S		No	20 kg S/ha**	No	20 kg S/ha**
Micronutrients (R2 to R3)		No	Foliar B	No	Foliar B
N applied at R5		No	50 kg N/ha***	No	50 kg N/ha***

*Numbers in parentheses indicate the achieved population. **Surface-broadcasted in July. ***Surface-broadcasted.

row spacing (Rizzo et al., 2009; Bacigaluppo et al., 2011; Martignone et al., 2011), correct choice of genotype (Bacigaluppo et al., 2013), or early planting (Mercau et al., 2004; Enrico et al., 2013). So to reduce existing yield gaps it is necessary to know and apply best management practices. Soils may contain insufficient nutrients to support high yields and these deficits must be corrected in order to approach MY_d. These deficiencies are specific to each field and can be characterized with soil and tissue analysis. In the Pampas region of Argentina, limitations of N, P, S, or micronutrients such as Zn have all been identified (Salvagiotti et al., 2012; 2013; 2017; Barbieri et al., 2017).

It is generally accepted that it is difficult to consistently get further yield increases every year if the gap between actual and attainable yield is < 20%, or within 80% of MY_d. Soybean yields in Argentina have been increasing by 1.3% annually (30 kg/ha/yr) since 1990-91. But recent research suggests the current national gap between actual and MY_d is 32%, which leaves room for improvement (Merlos et al., 2015). Two experiments were planted in the 2014-2015 and 2015-16 seasons in Oliveros, Santa Fe, Argentina with the objective of evaluating the impact of crop and fertilization management strategies on MY under rain-fed conditions.

Study Description

Four treatments evaluated combinations of two fertilization and two crop management strategies (**Table 1**). Farm practice (FP) and fertilizer intensification (FI) were characterized by more conservative crop management decisions (i.e., use of a cultivar common to the area in recent years, planted in mid to late November with a row spacing of 52 cm). The more intensive crop management treatments (MI and MFI) tested narrower (26 cm) row spacing, a cultivar with higher yield potential, and planting in early November.

In FI and MFI, soybean was inoculated, and plots were fertilized with P and S by broadcasting in winter according to National Institute of Agricultural Technology (INTA) recommendations. Foliar B was applied during the R2 stage (Fehr and Caviness, 1977), and N was surface applied at R5. In contrast, MI and FP did not receive fertilization or inoculation. All treatments were organized in a randomized complete block design with three replications.

Aboveground biomass (expressed as dry matter, DM), and leaf area index (LAI; data not shown) were determined in the stages R2, R5, and R7. Grain yield (13% moisture), number of seeds, individual seed weight, number of fertile nodes located on the main stem, and seeds per fertile node were determined.

Watch video about this study

At R7, aboveground organs (leaves, stems, podwalls, and seeds) were sampled and analyzed for N, P, S, B, and Zn to estimate nutrient uptake. Harvest index (HI) for each nutrient was calculated as the ratio of nutrient in the seed to total nutrient uptake.

Weather and Soil Conditions

In the 2014-15 season, rainfall during the crop cycle (emergence to R7) was 633 and 574 mm for the early (MI and MFI) and late (FP and FI) planting treatments, respectively. These values were 40% and 25% higher than normal according to the historical record (1971 to 2014) for early and late sowing, respectively. Precipitation exceeded potential evapotranspiration (PET) for both management practices. In the 2015-16 season, rainfall during the crop cycle was 719 and 697 mm for the early and late-sowing treatments, respectively, which were 43% higher than the historical values.

During the period of seed growth (R1 to R5), precipitation exceeded PET in 2014-15, but fell short in 2015-16. During the period of seed filling (R5 to R7), precipitation

exceeded PET in both seasons. Soil analysis showed values of typically degraded soils in the southern area of Santa Fe. Organic matter was around 2% and pH was 5.3 and 5.2 for the 2014-15 and 2015-16 seasons, respectively. On the other hand, Bray P-1 concentration was high in 2014-15 (29 ppm) and closer to the critical threshold (15 ppm) for 2015-16.

Crop Growth

Early in the season at R2, DM production was 49% higher than FP in the treatments that had more intensive crop management (MI and MFI). However at the beginning of seed filling (R5), DM production was similar across treatments. A trend towards higher DM production was noted for treatments that included the more intensive fertilizer management strategy (**Figure 1**). The MI and MFI treatments had aboveground biomass production greater than 10,000 kg/ha at physiological maturity, exceeding FP and FI by 24%. The second year of study showed larger differences between treatments than the first year.

Seed Yield

Differences in early season precipitation during seed growth (R1 to R5) caused seed yields to be 26% higher (+1,100 kg/ha) in 2014-15 than in 2015-16 (**Table 2**). Since there was no year (Y) x treatment (T) interaction (i.e., treatment effects were similar between years), the effects of each treatment could be analyzed by examining specific treatment contrasts. This analysis found no yield benefit across years for either FI or MI over FP, but MFI did outyield FP by 8% or 360 kg/ha. Similarly, a comparison of FI + MFI vs. MI + FP (i.e., sum of treatments with intensive fertilization vs. treatments without intensive fertilization), determined that yields were 5% (220 kg/ha) higher if the intensive fertilization strategy was included.

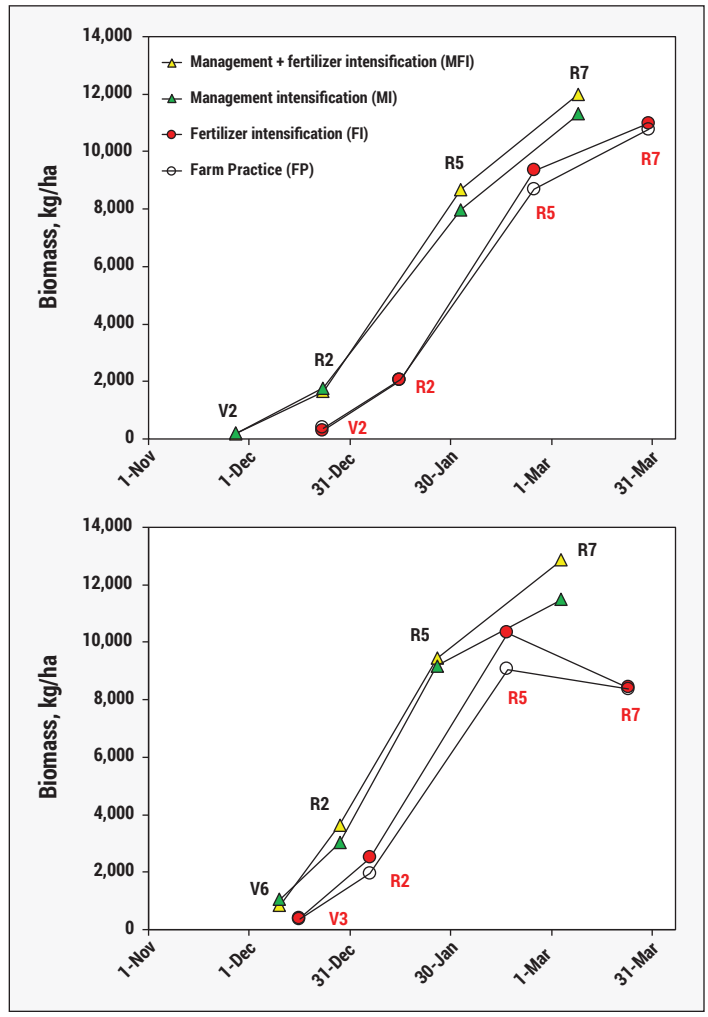

Figure 1. Aboveground dry matter accumulation for the different soybean production strategies in the 2014-15 season (top) and 2015-16 (bottom).

Treatments including management intensification (MI and MFI) produced more (+32%) fertile nodes per m^2. This was related to the higher populations (+36%) achieved with the narrower row spacing. Although the number of pods per reproductive node was 18% higher for the FP and FI treatments, this effect was not enough to compensate for the lower plant populations and lower numbers of fertile nodes per plant. The increased number of fertile nodes resulted in a significant (13%) increase in seed number for MI and MFI over FP in 2014-15 only.

Seed set efficiency, a trait representing how much reproductive biomass is invested in producing seeds, showed values that were 71% higher in MI and MFI than in FP or FI (data not shown). Thus early planting and narrower row spacing provided a better growing environment for transforming accumulated biomass into seed. Considering that all treatments reached the same biomass at R5 (**Figure 1**), and the larger num-

Table 2. Yield, seed number, and number of fertile main stem nodes for the different soybean production strategies.

Treatment*	Seed yield, kg/ha		Seed number/m^2		Fertile main stem nodes/m^2
	2014	2015	2014	2015	Average 2014-2015
FP	5,200	4,060	2,880	2,520	420
FI	5,490	4,190	2,880	2,600	400
MI	5,250	4,260	3,210	2,550	520
MFI	5,500	4,490	3,320	2,605	550
Year (Y)	0.01		< 0.01		0.14
Treatment (T)	0.19		0.05		< 0.01
Y x T	0.75		0.08		0.20
Treatment contrasts					
FI vs. FP	0.21		0.67		0.63
MI vs. FP	0.45		0.07		0.02
MFI vs. FP	0.04		< 0.01		< 0.01

*FP = current farm practice; FI = fertilizer intensification; MI = management intensification; MFI = management + fertilizer intensification.

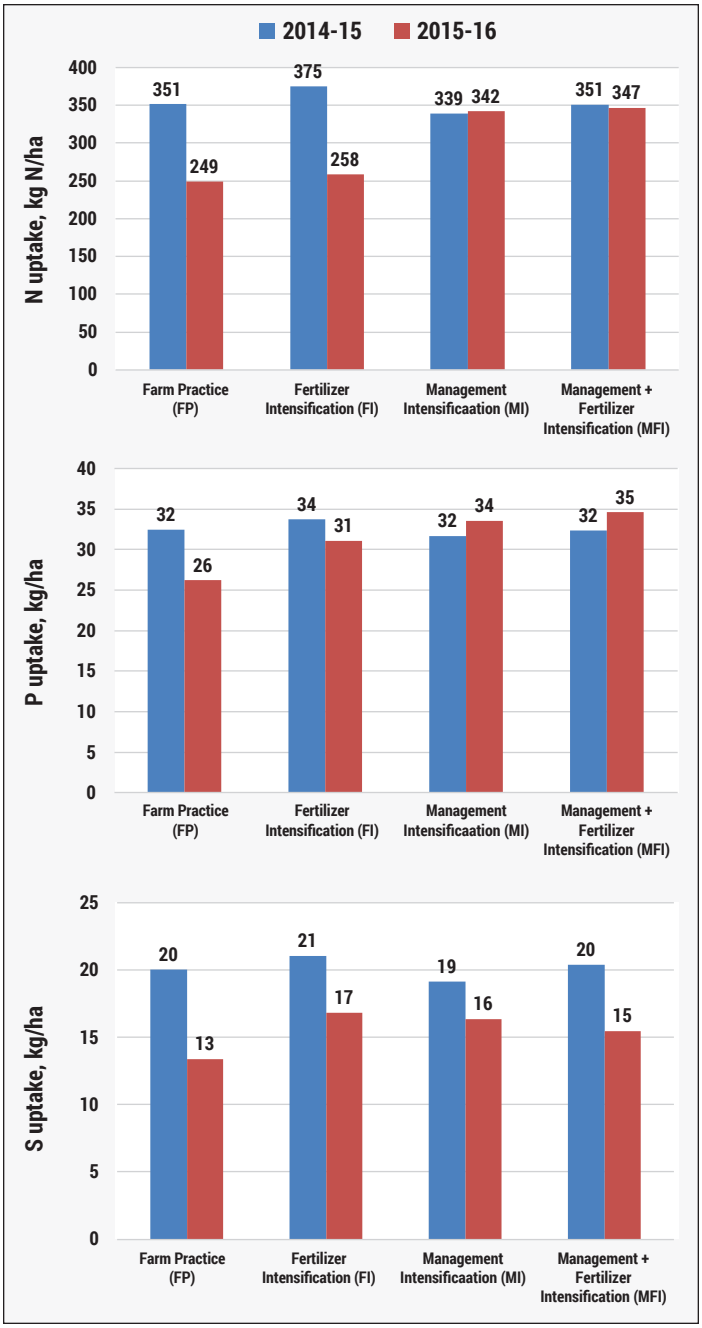

Figure 2. Total N, P, and S uptake for treatments testing different soybean production strategies in the 2014-15 and 2015-16.

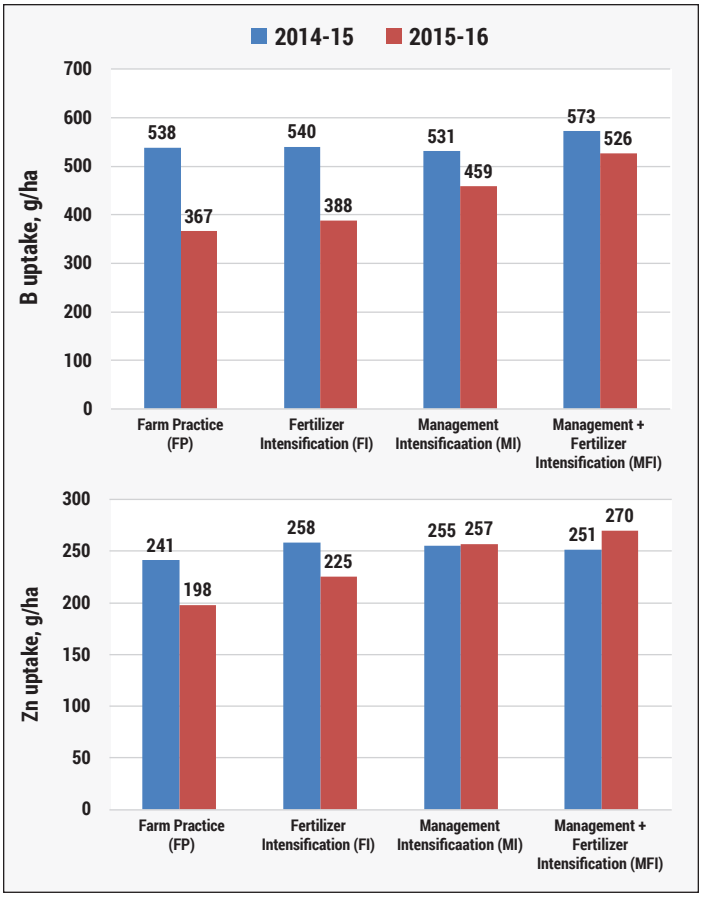

Figure 3. Total uptake of Zn and B for treatments testing different soybean production strategies in the 2014-15 and 2015-16.

ber of seeds produced in the MI and MFI treatments (**Table 2**), we suggest that the growing conditions between R5 and R7 are crucial for high soybean yields. Following this rationale, soybean yields might be improved by using genotypes that have longer duration R5 to R7 periods. However, these crops would need to extend their growth into conditions of declining radiation and temperature, which would likely be counterproductive. Also, early maturing soybean crops allow for early planting of cover crops, which are now being introduced in the Pampas due to their contributions to improved soil health and weed control.

Nutrient Uptake

For N, the average uptake across both seasons was 330 kg N/ha. No differences in N uptake were found between treatments in 2014-15, but MI and MFI had 36% higher N uptake than FP and FI in 2015-16 (**Figure 2, top**). This seasonal response was associated with differences in biomass production. Nitrogen harvest index, an indicator of how efficiently plants convert absorbed N into grain, was 25% higher in the treatments with more conservative crop management strategies (0.75 for FP and FI; 0.60 for MI and MFI). Average P uptake by soybean was 32 kg P/ha. MI and MFI had 7% higher P uptake than FP and FI (**Figure 2, middle**). Phosphorus harvest index was 11% higher for FP and FI (0.75) compared to MI and MFI (0.67). Average S uptake was 18 kg S/ha, and treatments failed to influence S uptake in either year (**Figure 2, bottom**). As with N and P, sulfur harvest index was higher (10%) for FP and FI (0.69) compared to MI and MFI (0.63). The average ratio for total N: P: S uptake was 18.4: 1.8: 1.

Average B uptake was 491 g B/ha. The MFI treatment had 11% higher B uptake compared to FP (**Figure 3, top**). HI_B was significantly higher in FP and FI (0.44) compared to MI and MFI (0.37). Average Zn uptake was 245 g Zn/ha, 15% higher in MI and MFI compared to FP (**Figure 3, bottom**). Zinc harvest index was not affected by treatment, but varied between 0.65 for FP and FI and 0.61 for MI and MFI.

Averaged across seasons, the higher yields obtained under intensification were associated with higher N (+16%), P (+14%), and S (+7%) uptake. But this increase in nutrient uptake can be mainly associated with higher biomass production since HI decreased for all three nutrients. Nutrient uptake responses to intensification also differed between seasons (i.e., N uptake was similar for FP and MFI in 2014-15 but MFI was 39% higher in 2015-16). The continuation of this study over additional seasons will provide better insight on this issue of variability.

Conclusions

These preliminary results show that more intensive soybean management practices increased biomass and seed yield in the central Pampas, mostly by affecting the number of seeds/m^2. Additional incorporation of more intensive fertilization practices magnified these responses. The growth and development that occurs at seed set and seed-filling stages is most affected by the intensification of crop management and fertilizer. Favorable growing conditions during these two critical crop stages contributes much to soybean yield.

Improved yields under crop and nutrient management intensification did result in variable increases in nutrient uptake in both seasons. Increased nutrient uptake was mainly related to increased biomass production. A follow-up to this study from work conducted in the 2016-17 and 2017-18 seasons will contribute further to this discussion on the relationship between seed yield and nutrient uptake under intensified soybean systems. **BC**

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References

Bacigaluppo, S. et al. 2011. Archivo TC 29 V Soybean Congress of the Mercosur. Mercosoja 2011. Rosario, Argentina. Sept. 2011.
Bacigaluppo, S. et al. 2013. Para mejorar la producción 50. INTA Oliveros.
Barbieri, P. et al. 2017. Soil Sci. Soc. A. J., 81(3), DOI10.2136/sssaj2016.09.0316.
Enrico, J.M. et al. 2013. Para mejorar la producción 50:71-78. INTA Oliveros.
Fehr, W.R. and C.E. Caviness. 1977. Stages of Soybean Development. Special Report 80. Iowa State University, Ames. IA.
Martignone, R. A. et al. 2011. Archivo TC 28 V Soybean Congress of the Mercosur . Mercosoja 2011. Rosario, Argentina. Sept. 2011.
Mercau, J.L. et al. 2004. Para mejorar la producción 27:122-129. INTA Oliveros.
Merlos, F.A. et al. 2015. Agronomy & Horticulture -- Faculty Publications. 974. http://digitalcommons.unl.edu/agronomyfacpub/974.
Rizzo, F. and P. De Luca. 2009. World Soybean Conference Research, August 10-15, 2009, Beijing China.
Rotundo, J.L. et al. 2012. Field Crops Res. 135:58-66.
Salvagiotti, F. et al. 2012. Field Crops Res. 135:107-115.
Salvagiotti, F. et al. 2013. Eur. J. Agron. 51:25-33.
Salvagiotti, F. et al. 2017. Field Crops Res. 203:128-138.

M. Pampolino/IPNI Image

Cassava Response to Fertilizer Application

By Lovely Luar, Mirasol Pampolino, Apolonio Ocampo, Arnold Valdez, Dale Francis Cordora, and Thomas Oberthür

Cassava is the third most important source of calories next to rice and maize in tropical countries. However, many years of inadequate attention has tagged cassava as the "poor man's crop." Ironically, cassava's on-going contribution to food security and its many industrial uses amounts to a large and positive impact on rural industrial development and on-farm income. Cassava's rising demand for food, feed, and industrial purposes is driving a need to increase its production.

In Southeast Asia, more than 8 million farmers grow cassava (CGIAR, 2015). Cassava production in the region accounts for 22% of world production (FAOSTAT, 2017). Traditionally, farmers produced cassava for food. However, over the past 50 years, particularly in Cambodia and Indonesia, cassava grown for industrial purposes has steadily increased. Thailand is now the world's second largest cassava producer next to Nigeria and is the world's top cassava exporter (Treesilvattanakul, 2015). Increased cassava production is serving a rising demand for cassava-based livestock feed, starch, and bio-fuels.

A large yield gap between average and potential yields of cassava in Southeast Asia indicates an opportunity to increase cassava production through intensification. The average yield of cassava in Southeast Asia ranges from 4 to 27 t/ha (**Figure 1**,

Continuous cassava cultivation without fertilizer application will lead to soil nutrient depletion and cause yield losses over time. Fertilizer recommendations based on the principles of 4R Nutrient Stewardship will help cassava farmers reap the benefits of their investment in fertilizer.

KEYWORDS:
yield gaps; tuber yield; food crop production; sustainable intensification.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium.

IPNI Project PHL-5

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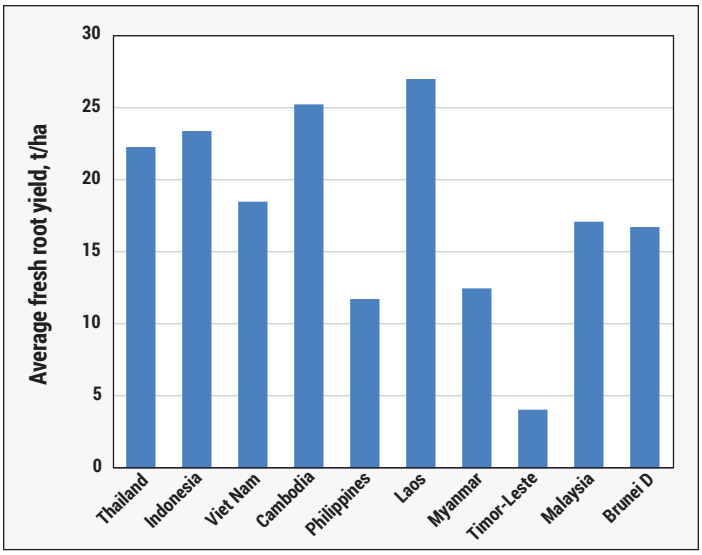

Figure 1. Average fresh root yield of cassava in Southeast Asian countries in 2014 (FAOSTAT, 2017).

FAOSTAT, 2017). In an optimal growing environment the yield of cassava could reach 90 t/ha (El-Sharkawy, 2004).

Improved crop management practices including high-yielding varieties, good quality planting materials, sufficient moisture, proper plant spacing, and pest and disease control are needed to close the cassava yield gap. Optimal nutrient management is also required to ensure that the crop is provided with the nutrients needed for full growth and development. However, farmers often grow cassava with minimal or even no fertilizer inputs. A study in Cambodia revealed that only 10 out of 45 sampled households applied fertilizers to their cassava crop. Application rates were low at 0 to 7 kg N/ha, 0 to 11 kg P_2O_5/ha, and no fertilizer K (Sopheap et al., 2012). A similar study of 450 farmers in the Philippines also found minimal fertilizer application at 0 to 109 kg N/ha, 0 to 26 kg P_2O_5/ha, and 0 to 29 kg K_2O/ha (PSA, 2014).

Although cassava can grow better than other crops in poor soils, the crop does respond well to fertilizer application. A study comparing the yield of fertilized and unfertilized cassava in four locations in the Philippines (with three varieties per location) showed that cassava yield can be increased greatly through fertilizer application (**Figure 2**).

The 4R Nutrient Stewardship concept of applying the right source of plant nutrients at the right rate, at the right time, and in the right place (IPNI, 2012) provides guidelines on fertilizer management that will help farmers reap the full benefits of their investment in fertilizer.
The following are practical tips for applying 4Rs in cassava:

Right Source
- Determine the availability of fertilizers or nutrient sources and check their nutrient content.
- Mixture of single and compound fertilizers can be used as long as it satisfies the nutrient requirement of the crop to achieve a certain target yield. Check fertilizer mixture compatibility at http://seap.ipni.net/article/SEAP-3024
- Check the price of the fertilizer source. The increase in benefit coming from the increase in yield of cassava through fertilizer application can mask the additional cost that comes from it.
- Use farm-available nutrient sources such as plant residues and animal manure. These organic nutrient sources can also improve soil properties.

Right Rate
- Use site-specific fertilizer application rates, if available.
- Determine the nutrient requirements of the crop. High-yielding varieties need higher fertilization rates than low-yielding varieties.
- Determine the fertility status of your soil. Soils with high fertility supply more nutrients than their low fertility counterparts.
- Consider other bio-physical constraints. Low yield is expected in sites that are prone to water logging or drought.
- Fertilizer rates can be adjusted based on farmer's budget for economic yield. Farmers with budget constraints can opt to target relatively lower yields thereby reducing fertilizer rates and investment.
- Over application of any particular fertilizer is not economical. Do not apply excessive amounts of N, as it will increase crop foliage and sacrifice tuber yield (Ukaoma and Ogbonnaya, 2013; Sangakkara and Wijesinghe, 2014).

Right Time
- Apply N, P, and K fertilizer 2 to 4 weeks after planting to ensure that the crop has enough nutrients to support its early growth.
- Moderate rates of N fertilizer can be applied in two or three splits to increase N recovery efficiency and induce good yields (Sangakkara and Wijesighe, 2014).
- A full dose of P should be applied in the first application to support root development.
- K fertilizer may be applied in two to three splits to minimize losses (i.e., if the required rate is high or if the soil is light textured).
- Ensure that soil moisture is sufficient and weeds surrounding the plants are removed before fertilizer application.
- Application of fertilizer during heavy rains is not advisable. It can cause nutrient losses due to erosion and leaching.

Right Place
- Make sure that the fertilizer is easily accessible to plant roots.
- Apply the fertilizer 15 to 20 cm from the base of the plant and cover with soil by hilling-up or by drilling holes. This can also minimize nutrient losses due to volatilization and run-off.

Similar results were obtained in studies conducted in Thailand, Indonesia, and Vietnam (Ngoan and Howeler, 2002; Yuniwati et al., 2012; Pongpet et al., 2016).

A study on the effect of fertilizer application on continuous cropping of cassava from 2004 to 2007 in Indonesia revealed that without fertilizer application, cassava yield decreased from more than 20 t/ha in the first year to less than 10 t/ha in the third year, after which the yield remained constant at about 9 t/ha (Yuniwati et al., 2012). Continuous cultivation of cassava without fertilizer application can lead to yield decline and soil degradation due to soil nutrient mining.

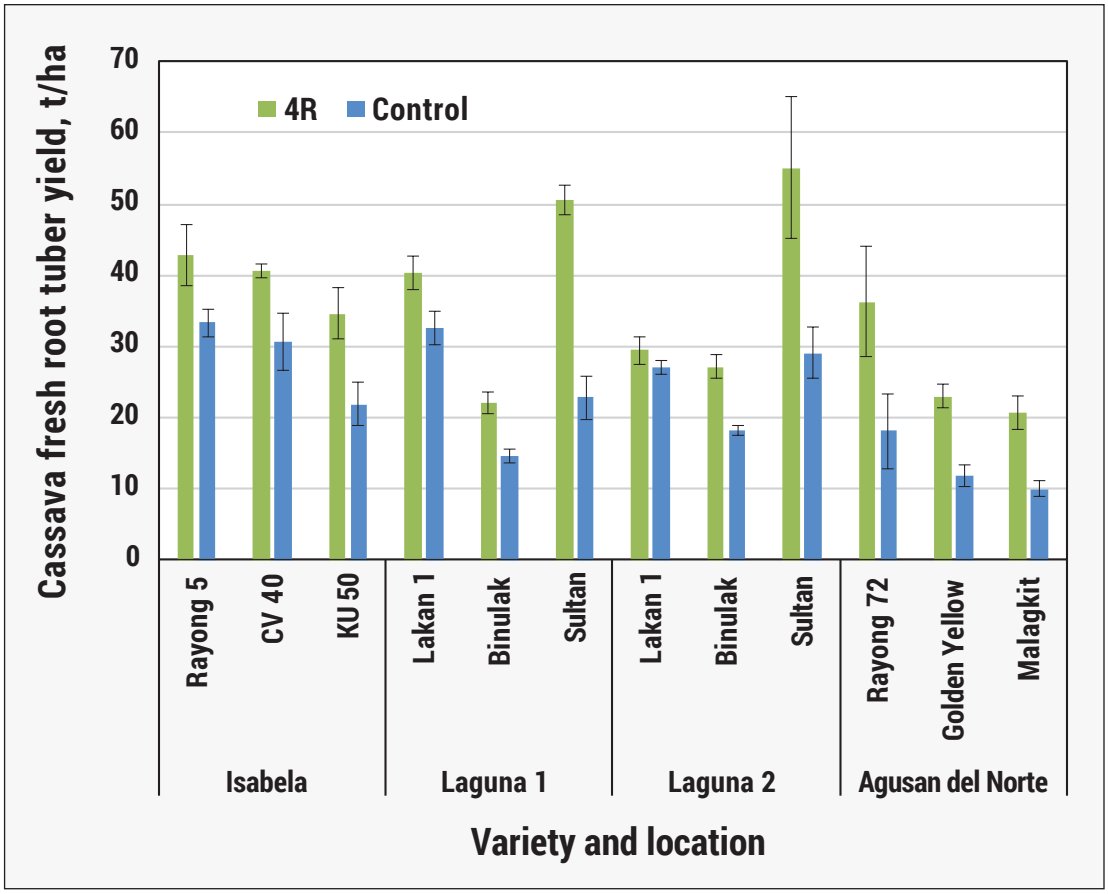

Figure 2. Effect of 4R-based fertilizer application on cassava fresh root yield at four locations in the Philippines using three varieties, 2015-2016. Error bars indicate the standard error of the mean.

Summary

Increasing demand for cassava drives the need for an increase in the crop's production. Optimal nutrient management is key in closing wide yield gaps and in attaining sustainable intensification in cassava. Farmers must be informed that, as with other crops, cassava needs fertilizer to achieve high yields. Continuous cropping of cassava without balanced fertilizer application can lead to soil nutrient depletion and yield decline over time. Fertilizer recommendations based on 4R principles are key to realizing the full benefits of fertilizer application in cassava. **BC**

TAKE IT TO THE FIELD

In cassava, optimal application of:

- N is needed to develop a large enough bulk of foliage as the assimilating area needed for the development of tubers
- P is essential for the synthesis of starch and normal root production
- K plays a special role in the translocation of photosynthates from the leaves to the tuberous roots
- N, P, and K together stimulates early growth, which provides a competitive advantages against weeds and reduces the impact of erosion

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References

CGIAR, 2015. Research for Results. From roots to riches: improved cassava reduces poverty, hunger and climate change. https://library.cgiar.org/bitstream/handle/10947/3932/Research%20for%20Results%20Brief%20Improve%20Cassava%20in%20Southeast%20Asia.pdf?sequence=1.

El-Sharkawy, M.A. 2004. Plant Mol. Biol. 56:481-501.

FAOSTAT, 2017. http://www.fao.org/faostat/en/#home.

IPNI, 2012. 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition, (T.W. Bruulsema et al., eds.), IPNI, Peachtree Corners, GA, USA.

Ngoan, T.N. and R.H. Howeler. 2007. In R.H. Howeler (ed.). Cassava research and development in Asia: Exploring new opportunities for an ancient crop. Bangkok, Thailand, CIAT, p.387-399.

PSA, 2014. Philippine Statistics Office. http://countrystat.psa.gov.ph/?cont=10&page-id=1&ma=A10PNVCP.

Pongpet et al., 2016. Mod. Appl. Sci. 10:11.

Sangakkara and D. Wijesignhe, 2014. Comm. Soil Sci. Plant Anal. 45:1446-1452.

Sopheap, U. et al., 2012. Inter. J. Plant Prod.6:37-58.

Treesilvattanakul, K. 2015. ICoA Conference Proc. p. 12-16.

Ukaoma, A.A. and C.I. Ogbonnaya, 2013. Acad. J. Agric. Res.1:172-179.

Yuniwati, E.D. et al. 2012. J. Basic and Appl. Sci. Res. 2:4975-4982.

Dr. Shutian Li visits an on-farm potato research site in northwest China.

Identifying Yield and Nutrient Gaps for Potato Production in Northwest China

By Shutian Li and Ping He

China's potato production is presently near 100 million t, which positions the country as the world's leading potato-growing nation. The northwestern region of China produces more than 30% of its annual harvest (MOA, 2014). Recently, the government of China launched a strategy meant to promote the consumption (and hence production) of potato in the hopes of solidifying the crop's place as the fourth most consumed staple food crop behind rice, wheat, and corn. Although China's northwest has great productive capacity, more information about the region's attainable yield is needed to determine how it can best support this policy-driven increase in potato demand.

Crop yield gaps can be calculated if one has knowledge of both the maximum attainable yield and the actual (on-farm) yield. Maximum attainable yield is achieved under field conditions when all the management factors are effectively managed. The difference in attainable yield and actual yield provides a realistic estimate of the yield gap that could be closed through improved management practices.

In northwest China, on-farm yield data from the Ministry of Agriculture shows an increasing trend between 1982 to 2014 (**Figure 1**). These data are similar to data collected by other farm surveys that are generally used to estimate actual yields (Haverkort et al., 2014; Svubure et al., 2015). The most recent 5-year (2010-2014) yield averages that combine rain-fed and irrigated potato production were 14.2, 16.7, 10.3, and 20 t/ha for the Inner Mongolia Autonomous Region (IMAR), Gansu, Ningxia, and Qinghai, respectively.

Maximum attainable yield can be estimated by several methods such as crop model simulation, field experiments, maximum farmer yields based on surveys, and yield contests amongst farmers (Lobell et al., 2009; van Ittersum et al., 2013). The International Plant Nutrition Institute (IPNI) used multiple-year field experimental data to analyze attainable yields of potato as well as yield responses to N, P, and K fertilization. This included a total of 288, 170, 84, and 114 on-farm trials conducted between 2002 and 2013 in the IMAR and the provinces of Gansu, Ningxia, and Qinghai (**Table 1**). Each trial had an optimum (OPT) nutrient recommendation treatment developed using the Agro Services International (ASI) "systematic approach" (Hunter, 1980; Portch and Hunter, 2002), as well as corresponding nutrient omission treatments (i.e., OPT-N, OPT-P, and OPT-K). Due to the arid climatic conditions in northwest China, it is reasonable to assume that reaching the 90th percentile yield

A yield and nutrient gap analysis for potato helps to evaluate the yield-limiting nutrient factors within northwestern China, and identifies the solutions to improving tuber yields to realistically attainable levels.

KEYWORDS:
attainable yield; yield gap; nutrient gap; balanced fertilization; partial factor productivity

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium.

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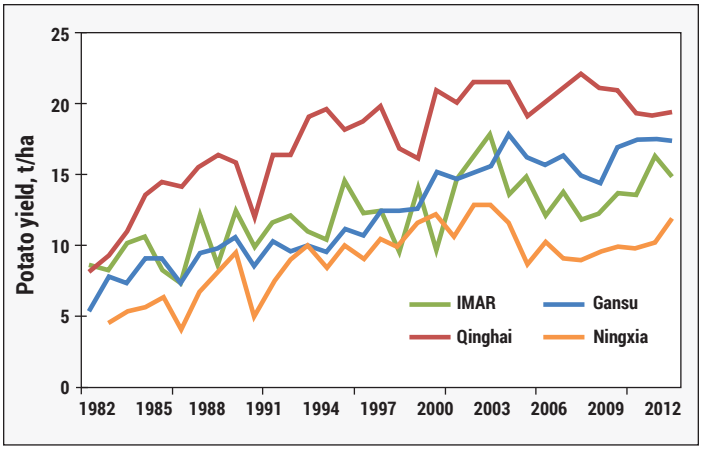

Figure 1. Trends in farmers' potato yield for the Inner Mongolia Autonomous Region (IMAR) and three provinces in northwestern China, MOA (1982-2014).

threshold under a OPT treatment would mark the maximum attainable yield.

Identifying Attainable Potato Yields

The network of field trials found good responses to applied NPK throughout northwest China. IMAR and Qinghai were most responsive, Ningxia was least responsive, and Gansu generated intermediate nutrient responses. The marginal nutrient responses in Ningxia point to a relatively small benefit from applied nutrients, and further suggests a need for the region's growers to focus on improving their management of factors other than NPK fertilization (e.g., water management) in order to make the investment in fertilizer more effective.

The distribution of potato yields obtained with soil test-based OPT treatments varied considerably within and across regions (**Figure 2**). In IMAR, Gansu, Ningxia, and Qinghai, the respective average yields were 31.1, 26.9, 16.4, and 42.4 t/ha, maximum yields were 61.2, 54.9, 34.3, and 69 t/ha, and the 90th percentile yields (maximum attainable yields for this study) were 50.1, 37.8, 30.3, and 56.6 t/ha.

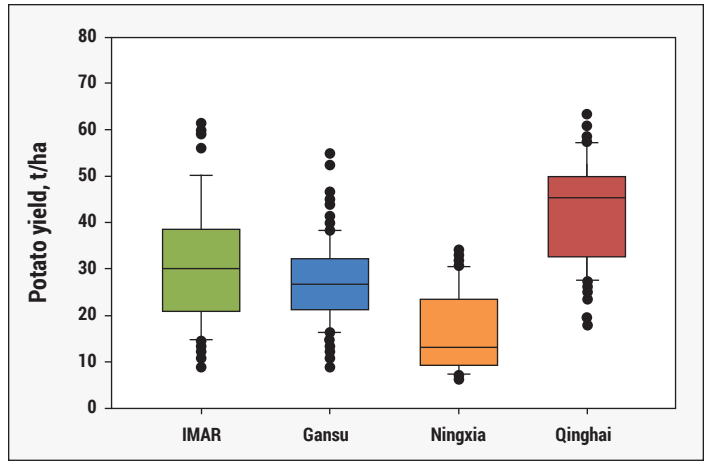

Figure 2. Box plots showing the distribution of yields within different regions of northwest China resulting from the application of optimum fertilizer NPK treatments (box indicates 25th, 50th and 75th percentiles; error bars indicate 10th and 90th percentiles; solid circles indicate 5th and 95th percentiles).

Yield Gaps

This information about on-farm and attainable yields indicates that there is considerable potential to increase potato productivity in all four regions studied. However, the magnitude of the yield increase required to narrow the yield gap differed significantly across regions (**Figure 3**). For example, in IMAR, Gansu, Ningxia, and Qinghai, yields would need to increase by 165%, 70%, 112%, 121% to reach a threshold equal to 75% of attainable yield.

Nutrient Gaps

Adequate and balanced nutrient input is one of the most important factors that can contribute to the narrowing of any yield gap. In order to assess how current on-farm fertilization practices are impacting the size of each region's yield gaps, the amounts of N, P, and K fertilizer (i.e., nutrient gaps) needed to reach the 75% attainable yield threshold were estimated. The nutrient gaps were calculated by dividing the size of the yield gap by the partial factor productivity (PFP) obtained for each nutrient at the 25th, 50th, and 75th percentiles, which represent a low, medium, and high nutrient use efficiency scenario, respectively (**Table 2**). PFP was calculated as potato tuber yield obtained under an OPT treatment divided by the amount of nutrient applied. PFP is an established nutrient performance indicator that provides a measure of the crop responsiveness to applied nutrients. For each scenario, a nutrient gap was calculated by dividing the

Table 1. Characteristics of the selected field trials conducted by the IPNI cooperative research network between 2002 and 2013.

Items	IMAR	Gansu	Ningxia	Qinghai
Potato areas, ha	512,000	665,000	171,000	90,000
Number of trials	288	170	84	114
Number of trials with irrigation	216	75	26	73
Soil type	Chestnut soil	Loess	Desert grey soil	Chestnut soil/Sierozem
Growth period	May-Sep	Apr-Oct	Apr-Sep	May-Sep
Annual rainfall, mm	211-549 (370)[a]	300-558 (424)	195-366 (318)	352-523 (425)
N rate, kg/ha	45-450 (200)	37-240 (172)	90-150 (116)	27-248 (186)
P_2O_5 rate, kg/ha	30-250 (99)	38-225 (97)	45-225 (125)	35-276 (93)
K_2O rate, kg/ha	30-338 (139)	30-210 (91)	45-300 (154)	84-203 (123)

[a]: Numbers in the parenthesis represent the average.

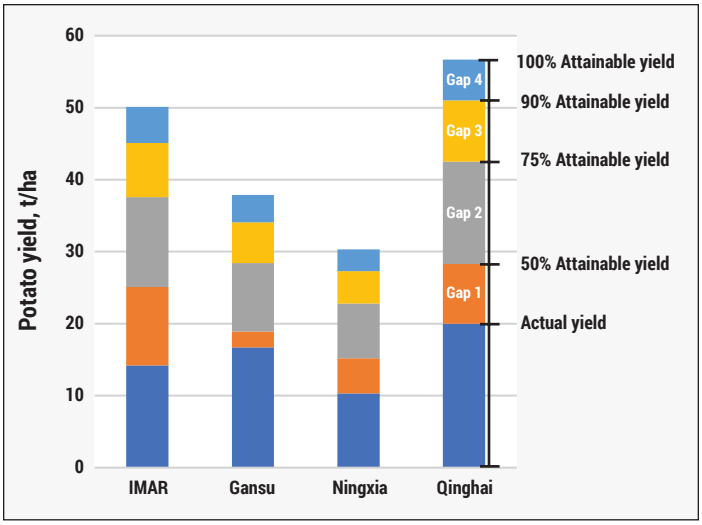

Figure 3. Potato yields need to move within 50%, 75%, 90%, and 100% of attainable yield.

yield gap by the PFP.

Compared with data for recent three-year average rates of fertilizer application by potato farmers (NDRC, 2014), in order to close the yield gap, N rates in IMAR, Gansu, Ningxia, and Qinghai need to increase by 68 to 102%, 36 to 61%, 30 to 56%, 49 to 81%, respectively (**Table 2**). Similarly for P, rates need to increase by 64 to 102%, 21 to 44%, 71 to 123%, 22 to 38%. Given the generally low K rates being used across northwest region, K rates need to increase several-fold in order to reduce the nutrient gap and improve productivity to near the 75% attainable yield threshold.

Considering the total combined NPK fertilizer rates for these regions, a 90 to 134% increase is recommended for IMAR, 43 to 69% for Gansu, 68 to 111% for Ningxia, and 48 to 84% for Qinghai.

Conclusions

High yield responses to N, P, and K application provide the opportunities to close the large yield gaps through balanced crop nutrition. Closing the yield gap to 75% of the attainable yield is a realistic goal that translates into 20 to 36.6 t/ha increases in tuber yields, which is the expected response to the application of 43 to 134% more NPK compared to current practice. **BC**

Example Nutrient Gap Calculation

Nutrient: Nitrogen
Region: IMAR
Yield Threshold: 75% Attainable Yield = 37,609 kg/ha
Average on-farm yield = 14,179 kg/ha
PFP at low scenario, where tuber yield is 30,677 kg/ha and N rate is 250 kg/ha

1. PFP_N (kg/kg) = Tuber yield (kg/ha) / N applied (kg/ha)
   = 30,677 / 250
   = 123 kg/kg
2. Yield gap (kg/ha) = 37,609 – 14,179
   = 23,430 kg/ha
3. Nutrient Gap_N (kg/ha) = Yield Gap (kg/ha) / PFP_N
   = 23,430 / 123
   = 191 kg/ha

Table 2. Projected nutrient gaps necessary to close yield gaps to 75% of attainable yields.

	IMAR (n=288)[1]	Gansu (n=170)	Ningxia (n=84)	Qinghai (n=114)
PFP_N scenarios[2]	N gaps, kg/ha			
Low	191	94	137	129
Medium	155	76	88	102
High	127	56	74	78
On-farm N rate[3]	188	155	243	161
PFP_P scenarios	P_2O_5 gaps, kg/ha			
Low	95	59	135	60
Medium	69	40	89	45
High	60	29	77	35
On-farm P rate	94	134	110	159
PFP_K scenarios	K_2O gaps, kg/ha			
Low	133	61	163	98
Medium	106	37	130	58
High	84	27	75	48
On-farm K rate	28	5	13	22
PFP_{NPK} scenarios	$N+P_2O_5+K_2O$ gaps, kg/ha			
Low	416	204	407	286
Medium	330	154	343	215
High	279	126	249	164
On-farm NPK rate	310	294	366	341

[1] Number of observations.
[2] Calculated under low (25th percentile), medium (50th percentile), and high (75th percentile) scenarios of PFP.
[3] Recent three-year average fertilizer rates applied by potato farmers (NDRC, 2014).

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References

Haverkort, A.J. et al. 2014. Potato Res. 57:13-31.
Hunter, A.H. 1980. Laboratory and greenhouse techniques for nutrient survey to determine the soil amendments required for optimum plant growth. Agro Service Inter. USA.
Lobell, D.B. et al. 2009. Ann. Rev. Env. Res. 34:179-204.
MOA. 1982-2014. China Agri. Stats. Rep. China Agri. Press.
NDRC. 2014. National agricultural product cost and income data compilation. China Stats. Press.
Portch, S. and A. Hunter. 2002. Modern agriculture and fertilizers, in PPI/PPIC China Program Special Publication No. 5, Beijing, China.
Svubure, O. et al. 2015. Field Crop Res. 178:77-90.
van Ittersum, M.K. et al. 2013. Field Crop Res. 143:4-17.

Subsurface Drip Fertigation: A Tool for Practicing 4R Nutrient Stewardship in Sugarcane

By R. Mahesh, B. Patil, and H.A. Archana

Dr. Mahesh amongst robust growth of sugarcane receiving the right method of fertilizer application through sub-surface drip irrigation (SSDF) using a mix of water soluble fertilizers (WSF).

Researchers are finding that India's sugarcane production systems are suffering from incremental stress as they attempt to raise production to meet growing demands. In recent years, yields have declined due to inappropriate water and nutrient management practices. Large vegetative growth with heavy tonnage removes substantial amounts of nutrients from the soil that need to be replenished. Conventional nutrient management practices lead to N losses through immobilization, denitrification, volatilization, and leaching. Applied P and K is susceptible to soil fixation, which contributes to their imbalance within the rhizosphere. Applying fertilizers in limited splits at inappropriate timings reduces nutrient use efficiency (NUE).

Study Description

The experiment described below compared subsurface drip fertigation (SSDF), surface drip fertigation (SDF), and traditional surface-applied granular fertilizers (GF) combined with in-furrow, surface irrigation (SI). Mixtures of

Subsurface drip fertigation , an advanced method for co-application of water and nutrients following the principles of 4R Nutrient Stewardship (right source, rate, time, and place), has the capability to deliver nutrients uniformly within the effective root volume zone where most of the active roots are concentrated.

When adopted in the sugarcane fields of Tamil Nadu, this system demonstrated an overall increase in cane yield of 62 t/ha while improving nutrient use efficiency and farm net income.

KEYWORDS:
4R Nutrient Stewardship; fertigation; water soluble fertilizers.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; DAP = diammonium phosphate; MAP = monoammonium phosphate; KCl = potassium chloride; KNO_3 = potassium nitrate; K_2SO_4 = potassium sulfate; US$1= 64.37 Indian Rupee (Rs.).

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Table 1. Outline of treatment details applied to sugarcane, Tamil Nadu, India.

Treatment/ Source	% of State rec.	Rate, kg N-P_2O_5-K_2O/ha	No. of applications
Subsurface Drip Fertigation (SSDF)			
T1: WSF[1]	75	225-75-150	27
T2: WSF[2]	100	300-100-200	
T3: WSF[2]	75	225-75-150	
T4: GF[3]	100	300-100-200	
T5: GF	75	225-75-150	
T6: WSF[2]+GF	75	225-75-150	
	25	75-25-50	
T7: WSF[2]+GF	50	150-50-100	
	50	150-50-100	
T8: WSF[2]+GF	25	75-25-50	
	75	225-75-150	
Surface Drip Irrigation			
T9: WSF[2]	100	300-100-200	27
T10: GF	100	300-100-200	
Surface Irrigation (SI)			
T11: GF	100	300-100-200	1

[1]Mixture of fertilizers (WSF grade) solubilized in water: 19-19-19, Urea phosphate (17-44-0), K_2SO_4 (0-0-50), Urea (46-0-0)
[2]Mixture fertilizers (WSF grade) solubilized in water: 19-19-19, MAP (12-61-0), KNO_3 (13-0-45), Urea
[3]Mixture of urea, DAP, and KCl (0-0-60)

solubilized fertilizer (WSF) were also compared with GF in different combinations designed around the state recommendation (SR = 300-100-200 kg N-P_2O_5-K_2O/ha) for a yield target of 200 t cane/ha (**Table 1**).

The SSDF design included 16 mm lateral distribution lines that were laid out belowground at a spacing of 1.65 m. The emitter spacing was 0.4 m. The water discharge rate was 4 l/hr. Nutrient stock solutions were prepared by dissolving fertilizers within a 1:5 mixture of fertilizer to water. During each fertigation schedule, the drip system was flushed with water prior to the application of the fertilizers. This was followed by another flushing of drip system for five to ten minutes every second day. Surface and subsurface drip fertigation were carried out by slightly wetting of the root zone before fertigation, followed by flushing the nutrients with water. The control for this study was the SI treatment, which applied all the P basally as granular DAP and all the N (granular urea) and K (granular KCl) were applied in three equal splits at 30, 60, and 90 days after planting. Irrigation occurred every second day and fertigation events occurred at one week intervals (**Table 2**). The fertigation schedule was designed to meet the sugarcane nutrient requirement at different stages of crop growth. A total of 27 fertigation applications occurred between 15 and 210 days after planting.

Table 2. Fertigation schedules for sugarcane growing season, Tamil Nadu, India.

Stage (days)	Concentrations of nutrients applied, % N	P_2O_5	K_2O	No of applications[1]
1 to 30	5.0	10.6	1.8	3
31 to 60	4.6	8.0	2.2	4
61 to 90	4.6	4.8	2.2	4
91 to 20	5.0	4.3	2.7	4
121 to 180	2.7	0	4.4	8
181 to 210	1.8	0	7.7	4

[1]Each application was scheduled at seven-day intervals.

The Case for Subsurface Drip Fertigation

The option of SSDF offers an ideal opportunity to place soluble nutrients from fertilizer in the root zone, along with irrigation water. SSDF also ensures that nutrients are sup-

View of subsurface drip fertigation system under sugarcane.

Location

Puttuvikki village, Coimbatore, Tamil Nadu
Semi-arid zone
Max/min temperature – 32/22° C
Daily evaporation – 5.5 mm (84% RH)
Annual rainfall – 605 mm

Soil Characteristics

Soil pH – 7.6
Org. C – 0.48%
Available N – 199 kg/ha (low)
Available P – 44 kg/ha (high)
Available K – 676 kg/ha (high)
Bulk density – 1.25 g/cm^3
Particle density – 1.82 g/cm^3
Pore space – 31%
Infiltration rate – 1.95 cm/hr
Field capacity – 29%

plied precisely in the area of most intensive root activity.

This study found SSDF to be most effective compared to the SDF or SI systems (**Table 3**). The average cane yield for all SSDF treatments was 158 t/ha, which was 5% higher than SDF, and 65% higher than the SI control. Bresler (1997) attributed higher cane yields under SSDF to minimizing the potential for wide fluctuations in soil water content during the irrigation cycle. This is an important and advantageous feature of drip irrigation. Its implementation leads to better water use, higher nutrient uptake, and better maintenance of soil-water-atmosphere relationship due to a higher oxygen concentration in the root zone (Raina et al., 2011).

Table 3. Interaction effect of 4R nutrient management on sugarcane (variety Co.86032) yield, NUE, and net income, Tamil Nadu.

	------ Yield ------		--------- NUE ---------		---- Net income[1] -----	
Treatment	t/ha	% increase over control	kg yield/kg NPK applied	% increase over control	'000 Rs./ha	% increase over control
Subsurface Drip Fertigation (SSDF)						
T1	160	67	356	122	195	53
T2	186	94	310	93	228	79
T3	165	72	366	129	197	55
T4	143	49	235	47	174	36
T5	127	32	282	76	148	16
T6	176	84	294	84	218	72
T7	156	63	261	63	186	46
T8	150	56	250	56	182	43
Average	**158**	**65**	**294**	**84**	**191**	**50**
Surface Drip Fertigation (SDF)						
T9	168	75	280	75	194	52
T10	133	39	222	39	162	22
Average	**151**	**57**	**251**	**57**	**178**	**37**
Surface Irrigation (SI) + Soil Applied Fertilizers						
T11	**96**	**-**	**160**	**-**	**127**	-
SEd	7.4	-	-	-	-	
CD (p = 0.05)	15.5	-	-	-	-	

[1]Data used to calculate net income: Price of sugarcane = Rs. 2,100/t, Prices of fertilizers (Rs./kg): urea = 5.36, DAP = 24.0, KCl = 16.8, 19:19:19 = 86, MAP = 78, Urea phosphate = 40, KNO_3 = 80, K_2SO_4 = 70, Total annualized drip cost for SSDF = 29,805/ha, Total annualized drip cost for SDF = Rs. 27,660/ha

Application of WSF at the full SR produced the best yield of 186 t/ha, which was 94% higher than the control (**Figure 1**). The next highest yield of 176 t/ha was achieved with a combination of WSF (75%) and GF (25%), which

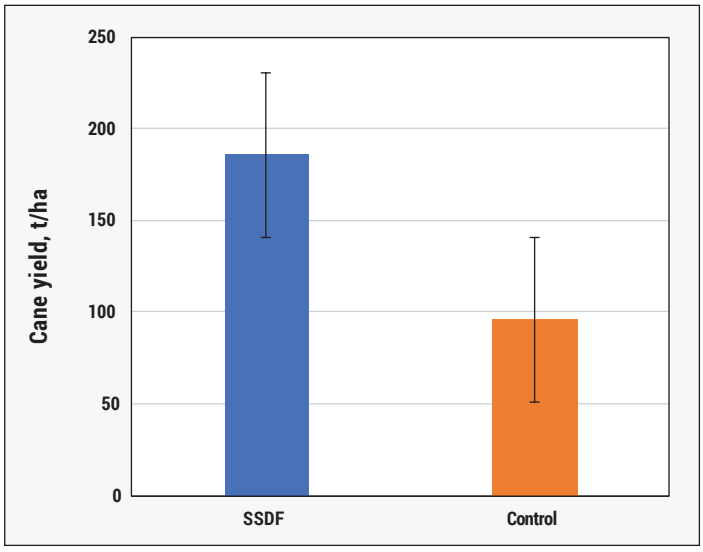

Figure 1. Comparison of cane yields resulting from the best treatment using subsurface drip fertigation (SSDF) of water soluble fertilizer at the state recommendation (SR) and the Control treatment of surface irrigation of surface applied granular fertilizers applied at the SR, Tamil Nadu.

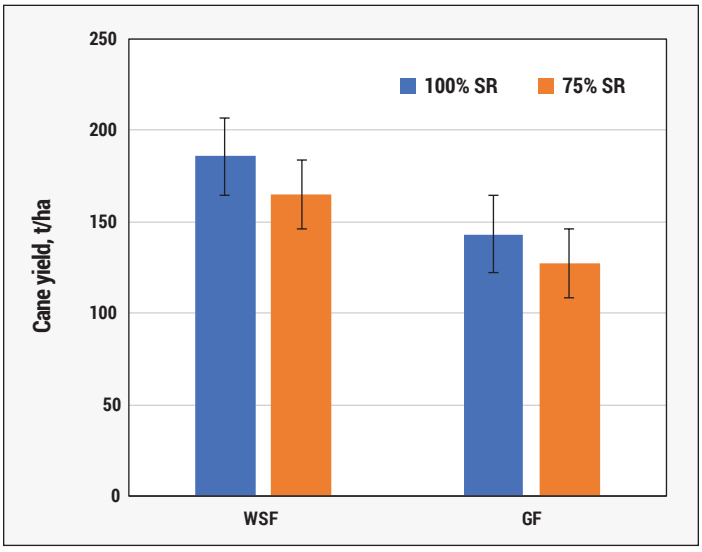

Figure 2. Comparison of cane yields resulting from either the full or reduced (75%) state recommendation (SR) using either water soluble fertilizers (WSF) or granular fertilizers (GF) using subsurface drip fertigation, Tamil Nadu.

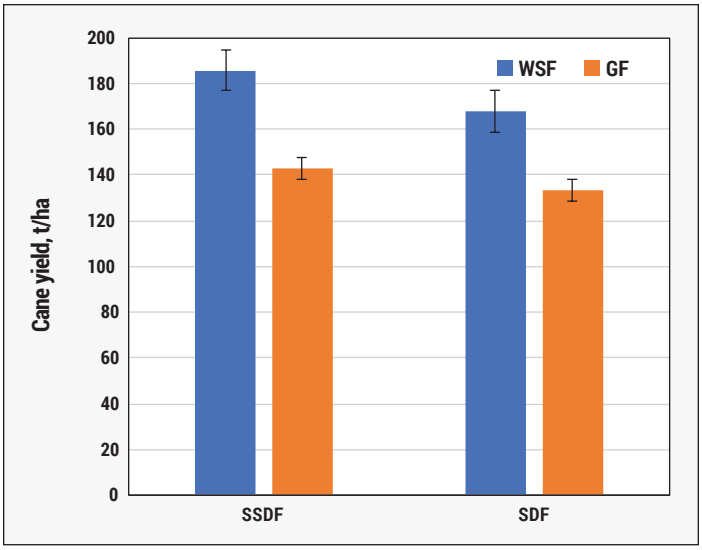

Figure 3. Comparison of cane yields resulting from either water soluble fertilizers (WSF) or granular fertilizers (GF) applied at the state recommendation (SR) under subsurface drip fertigation (SSDF) and surface drip fertigation (SDF), Tamil Nadu.

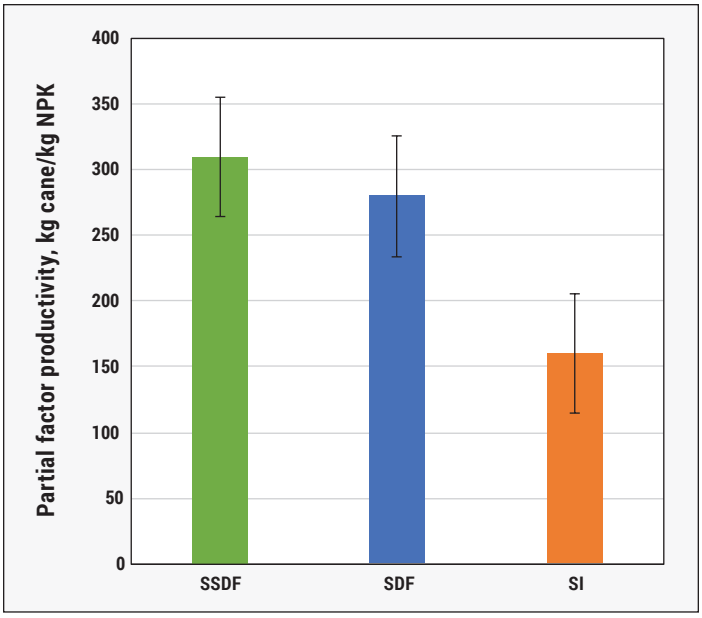

Figure 4. Comparison of partial factor productivity obtained from subsurface drip fertigation (SSDF), surface drip fertigation (SDF), and surface irrigation (SI) using the state recommendation for 200 t cane/ha, Tamil Nadu.

also fulfilled the SR. Application of either WSF or GF at the full SR was superior (+13%) to the reduced rate tested (**Figure 2**), which confirms fit of the current SR in meeting a 200 t/ha yield goal.

Mixes of WSF were superior to GF in both SSDF and SDF (**Figure 3**). Yield was 30% higher with WSF+SSDF and 26% higher with WSF+SDF (**Figure 3**). Amongst the options tested, the WSF mix of 19-19-19; MAP, KNO_3, and urea proved to be more effective than the mix of 19-19-19; urea phosphate, K_2SO_4, and urea.

This study measured differences in NUE amongst treatments through the performance indicator called partial factor productivity (PFP), which answers the question ... How did the crop respond to the nutrient input?

$$PFP_{NPK} = \frac{\text{kg cane yield/ha}}{\text{kg applied NPK/ha}}$$

The highest-yielding SSDF treatment using the full SR had a PFP of 309 kg/kg NPK applied, which was 11 and 94% higher than the corresponding treatment under SDF and SI, respectively (**Figure 4**).

The SSDF treatments using the reduced rate (75% SR) did record even higher PFP values (**Table 3**), but lower fertilizer inputs can commonly intersect on a steeper part of the yield response curve, and as in this case, one should consider the value of the yield gap caused by a reduction in fertilizer input. Economic data found SSDF of WSF at the SR to be most favorable—mainly due to higher cane yield. In spite of an additional investment of Rs.40,040/ha for WSF over GF (data not shown), WSF returned an additional Rs.55,290/ha.

Conclusion

Subsurface drip fertigation facilitates the practice of efficient nutrient management through 4R principles of Nutrient Stewardship, which resulted in higher cane yield, improved NUE, and better net income. Results of the above experiment showed that for achieving a yield target of about 200 t/ha, sugarcane required an application of the right rate of nutrients (300-100-200 kg N-P_2O_5-K_2O/ha) applied through a mixture of water soluble fertilizers (urea, 19-19-19, MAP, and KNO_3). This was most probably due to the right timing of nutrients through 27 split applications at an interval of seven days, applied through the subsurface drip fertigation system. Large-scale adoption of 4R nutrient management through subsurface drip fertigation provides an opportunity to bridge nutrient-related yield gaps in sugarcane and increase the net income for sugarcane growers in an environmentally sustainable manner. **BC**

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References

Bresler, E. 1997. Adv. Agron. 29:343-393.
Raina, J.N. et al. 2011. J. Indian Soc. Soil Sci. 59:268-277.

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Long-Term Impacts of Poultry Litter on Soil pH and Phosphorus in No-Till

By Catherine Fleming-Wimer, Mark Reiter, Rory Maguire, and Steve Phillips

Continuous no-till corn, wheat, and soybean systems are commonplace in the mid-Atlantic U.S. region. These no-till systems feature less soil mixing than conventional tillage systems, and are susceptible to stratification of soil pH and relatively immobile nutrients, such as P. Traditional use of poultry litter (PL) also lends itself to stratification due to the concentration of P in PL. Applying PL at rates meant to satisfy crop N requirements can increase P concentrations in the soil surface beyond crop P requirements. Excess soil test P can lead to high P concentrations in agricultural runoff and increases nutrient leaching when the soil's P saturation point is reached (Moore and Edwards, 2007). Mixing alum (aluminum sulfate) into PL to produce PLA is a popular management practice to improve in-house conditions for poultry and also mitigate nutrient losses in runoff. Alum works by acidifying PL to form ammonium instead of ammonia, and by converting water-soluble P into less soluble aluminum phosphate forms. Previous research on tall fescue in conventionally tilled, silt loam soil (Moore and Edwards, 2005; 2007) suggested less leaching of soluble P from PLA than PL, more stratification of soil test P in the top 2 in., and that both could increase soil pH, PL more so than PLA.

Study Description

A long-term no-till two-year rotation was initiated in 2003 in Painter, Virginia on a Bojac sandy loam that consisted of a corn (summer) – wheat (winter) – soybean (summer) – fallow (winter) rotation. Fertilization included ammonium nitrate as a no-P control (34% N), inorganic P fertilizer (TSP; 46% P_2O_5), PL, and PLA. Nitrogen application was equalized across all treatments and was based on Bitzer and Sims (1988), assuming 80% inorganic N and 60% organic N was available to the current cash crop. Lime was not applied to any plot during the study so that the liming capabilities of PL and PLA could be monitored. The TSP treatment received inorganic P as soil tests suggested (Maguire and Heckendorn, 2011). Poultry litter and PLA treatments were applied at 2 t/A prior to planting wheat and 5 t/A prior to planting corn, resulting in P application rates presented in **Table 1**. Soil cores were collected by depth (0 to 2 in., 2 to 6 in., and 6 to 12 in.) in 2000, 2004, and 2011. Mehlich-1 extractable P was determined using the double acid method and pH was measured following Virginia Tech Soil Testing Laboratory procedures (Maguire and Heckendorn, 2011).

Soil pH (0 to 2 in.)

In 2000, prior to any treatments being applied, there were no differences in soil pH between land areas, which

Common N–based rates for poultry litter (PL) application in the mid-Atlantic region were tested over nine years to track changes in soil profile pH and P concentration. A common in-house best management practice of modifying P solubility by lowering PL pH with alum did little to prevent P build-up over time and did not reduce plant available P that would limit growth.

KEYWORDS:
poultry litter; alum; stratification; soil test phosphorus; soil pH.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; $CaCO_3$ = calcium carbonate; triple super phosphate (TSP); Mehlich-1 extractable phosphorus (M1-P); ppm = parts per million; poultry litter (PL); poultry litter with alum (PLA).

IPNI Project USA-VA25

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Table 1. Phosphorus (P) application treatments for a continuous no-tillage corn-wheat-soybean rotation on a Bojac sandy loam on the Delmarva peninsula.

Season	Year	Crop	TSP†	PL‡	PLA§
			-------- lb P/A --------		
Winter/Spring	2003/2004	Fallow	0	109	107
Summer	2004	Corn	0	0	0
Winter/Spring	2004/2005	Wheat	0	77	82
Summer	2005	Soybean	0	0	0
Winter/Spring	2005/2006	Fallow	0	88	104
Summer	2006	Corn	0	0	0
Winter/Spring	2006/2007	Wheat	0	55	61
Summer	2007	Fallow*	0	0	0
Winter/Spring	2007/2008	Fallow	0	0	0
Summer	2008	Fallow	0	0	0
Winter/Spring	2008/2009	Fallow	0	91	86
Summer	2009	Corn	0	0	0
Winter/Spring	2009/2010	Wheat	9	107	163
Summer	2010	Soybean	0	0	0
Winter/Spring	2010/2011	Fallow	0	111	89
Summer	2011	Corn	0	0	0
Total			9	638	692

†Triple superphosphate (TSP) treatment.
‡Poultry litter (PL) treatment.
§Poultry litter amended with alum (PLA) treatment.
*Plots were maintained without litter treatments till Summer 2009.

Table 2. Soil pH (0 to 2 in.) from four fertilizer regimes in a long-term no-till rotation on a Bojac sandy loam on the Delmarva peninsula.

Treatment	2000	2004	2011
	---------- pH ----------		
Control	6.2 a A†	6.3 c A	5.4 c B
TSP	6.1 a A	6.3 bc A	5.4 c B
Poultry litter (PL)	6.4 a B	6.6 a A	5.6 b C
Poultry litter + Alum (PLA)	6.2 a B	6.5 ab A	5.8 a C

†Means followed by different lower case letters within a column are significantly different (p = 0.10). Means followed by different upper case letters within a row are significantly different (p = 0.10).

averaged 6.2 (**Table 2**). Soil pH increased with PL and PLA applications between 2000 and 2004, most likely due to their $CaCO_3$ content. After several more years of study, acidity produced by applications of inorganic N fertilizers, acid rain, and soil microbial activity overcame the liming capacity provided by PL and PLA, and soil pH started to decrease by 2011.

Comparing treatments within a year, PL and PLA had similar soil pH in 2004, and were significantly higher than the control (**Table 2**). In 2011, soil pH with PLA and PL was higher than the control and TSP treatments. Little difference was noticed between the PL and PLA treatments. Although a liming effect was observed with PL and PLA in 2011, soil pH fell below the 6.2 target. Soil pH plays an important role in nutrient availability to plants as low pH can bind P and cause toxicity issues from aluminum and other elements.

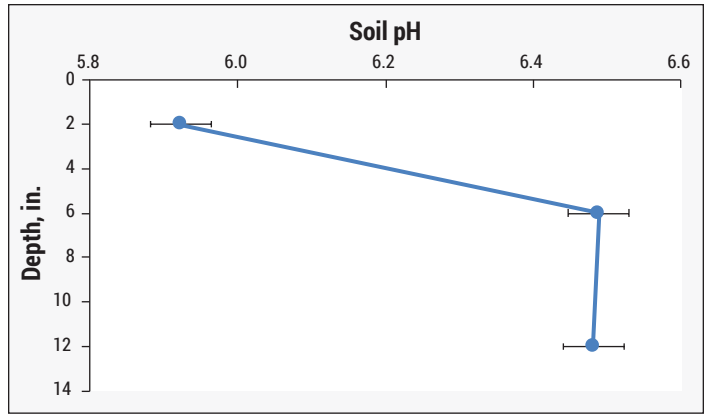

Figure 1. Soil pH (averaged over treatments) in 2011 ($LSD_{0.10}$ = 0.1) by depth in a long-term no-till rotation on a Bojac sandy loam on the Delmarva Peninsula.

Soil pH (at depth)

In 2011, lower pH readings in surface soils versus subsurface soils demonstrated stratification due to no-till. The lack of soil mixing, yearly surface N applications, microbial activity, and acid rain all contribute to a decline in surface soil pH. However, no change in pH was observed below 2 in., which remained similar to the target pH of 6.2 (**Figure 1**).

Mehlich-1 Extractable Phosphorus (0 to 2 in.)

All soil test P values in 2000 were "Very High" for Virginia (>55 ppm P). In 2011, PL and PLA treatments were similar (157 and 141 ppm P, respectively), and were greater than the control and TSP treatments (62 and 67 ppm P, respectively) (**Table 3**). This difference demonstrates the potential for M1-P buildup with repeated application rates above crop removal, which are approximately 21, 18, and 29 lbs P/A for 90, 50, and 150 bu/A for wheat, soybean, and corn, respectively. Over time, a significant decrease in M1-P was observed in the control and TSP treatments, which was the first indication of P drawdown in the soil. Poultry litter and PLA application resulted in similar M1-P values in 2004 and 2011, indicating comparable availabilities regardless of the presence of alum.

As observed, "Very High" M1-P concentrations (>55 ppm P) can take years to reduce to concentrations where crops would be expected to respond to P applications. The control treatment experienced a decline of 3 ppm P/yr. At these rates, it will take 14 years to reduce M1-P concentrations to where fertilizer is needed. This is an economic benefit to growers, as they can forego P fertilizer applications in "Very High" P testing soils for many years without an

Table 3. Mehlich-1 extractable P (0 to 2 in.) from four fertilizer regimes in a long-term no-till rotation on a Bojac sandy loam on the Delmarva peninsula.

Treatment	2000	2004	2011
	ppm P		
Control	95 a A†	89 b A	62 b B
TSP	96 a A	92 b A	67 b B
PL	101 a B	139 a A	157 a A
PLA	88 a B	120 a AB	141 a A

†Means followed by different lower case letters within a column are significantly different (p = 0.10). Means followed by different upper case letters within a row are significantly different (p = 0.10).

expected reduction in yield.

Mehlich-1 Extractable Phosphorus (at depth)

Analysis of M1-P concentrations found stratification by depth. In 2011, PL and PLA treatments had very high M1-P concentrations at the 0 to 2 in. and 2 to 6 in. sample depths, which were significantly higher than M1-P concentrations of the TSP and control treatments at all depths. The significant difference between the control and PL/PLA treatments at 2 to 6 in. implies P leaching from the surface due to applied P exceeding plant uptake and the P sorption capacity of the sandy loam soils found on the Virginia coastal plain. It is interesting to note higher M1-P concentrations with PL applications as more P was applied with PLA over the system (638 vs. 692 lbs P/A for PL and PLA, respectively; **Table 1**).

Conclusions

Surface soil pH generally decreased over time; however, PL and PLA treatments resisted acidification. By 2011, all treatments had surface soil pH values below 6.2. Soil test P was greater with PL and PLA compared to control and TSP treatments in all years after the initiation of the study due to N-based manure applications that provided P rates above crop removal. Concentrations of M1-P at depth indicated P leaching in the PL and PLA treatments by 2011, with no P movement observed from TSP as P was only applied as required per soil tests. Overall, alum amendments to fresh PL had little effect after field application on crop yields but did reduce M1-P at depth. Surface concentrations of M1-P in the 0-P control did not fall below the agronomic threshold of 55 ppm P during the study, suggesting soils testing "Very High" may take over 10 years before additions of P fertilizer would benefit crop production. Overall, no visual differences were seen between sources regarding crop production so optimal best management strategies for bird health along with N and P management should be utilized in-house. **BC**

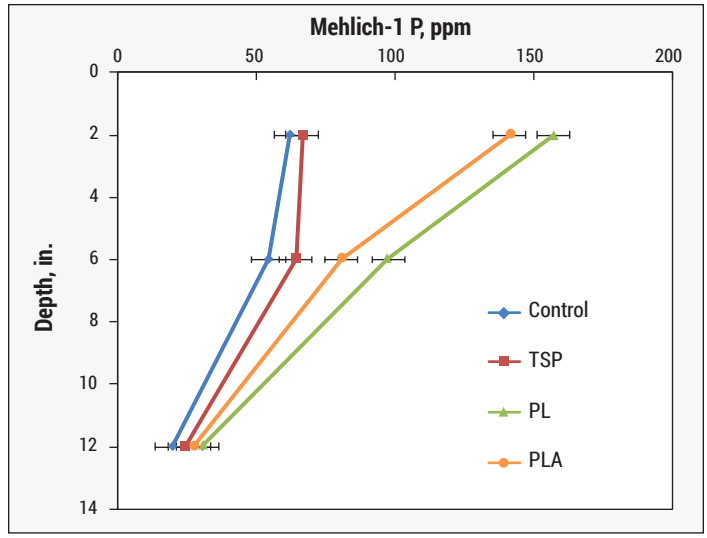

Figure 2. Mehlich-1 extractable P (M1-P) in 2011 ($LSD_{0.10}$ = 12) by depth from four fertilizer regimes in a long-term no-till rotation on a Bojac sandy loam on the Delmarva Peninsula.

TAKE IT TO THE FIELD

Amending PL with alum does not substantially reduce crop P availability, but may slightly alter overall P solubility in the system. Sustainable use of PL involves P-based rates when soil test P is already high, and using other sources to supply N in situations where surplus P is not required and could pose a risk of water contamination.

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References

Bitzer, C.C. and J.T. Sims. 1988. J. Environ. Qual. 17:47-54.

Maguire, R.O., and S.E. Heckendorn. 2011. Virginia Cooperative Extension. http://www.soiltest.vt.edu/PDF/recommendation-guidebook.pdf (accessed 17 June 2013).

Moore, P.A., and D.R. Edwards. 2005. J. Environ. Qual. 34:2104-2111.

Moore, P.A., and D.R. Edwards. 2007. J. Environ. Qual. 36:163-174.

Quality: Potassium Management is Critical for Horticultural Crops

By Robert Mikkelsen

Quality, What is it?

Potassium is frequently referred to as the "*quality*" nutrient for plants. Quality has many characteristics and the most important aspects of quality will depend on the specific crop. For example, with citrus, it may be the thickness of the peel and Vitamin C concentration, for apples, sugar concentrations, while for tomatoes, the development of uniformly red fruit rich with lycopene. The specific quality parameters for each crop will vary and should be well understood to maximize crop nutritional practices and market profitability (Kumar et al., 2006).

While many "quality" benefits are generally understood, it can be difficult to define and quantify the exact benefits of K (Lester et al., 2010a). Most notably, the lack of quality is frequently observed when the plant K supply becomes

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deficient. An inadequate K supply becomes especially important for horticultural crops where the visual appearance of the fruit and leaves is critical for marketing. Although the total yield may be reduced with insufficient K, it is possible that the entire crop may be unsalable due to poor quality and visual appeal.

The growth and longevity of cut flowers and ornamentals can also be diminished by a lack of adequate K. Shipping, handling, and freshness are particularly important for ornamental horticulture.

Consumer Preference

Consumers have a strong preference for fresh fruits and vegetables with appealing appearance and texture. Quality and freshness of fruits and vegetables are often cited as the primary characteristics for making purchase decisions.

Potassium plays a critical role in many of the metabolic processes that enhance the quality, nutrition, flavor, appearance, and longevity of fresh food crops. These beneficial improvements clearly are desirable for farmers and will add to the marketability of crops.

Vitamin C

Application of K to the soil or plant foliage has been shown to increase the concentration of Vitamin C in a variety of fruit crops. While citrus is the most frequently cited example, increased Vitamin C has been reported in crops such as cucurbits, cauliflower, onion, banana, guava, and papaya (Imas, 2013). Muskmelon also had higher concentrations of Vitamin C as a result of foliar K sprays (Lester et al., 2010b).

Nitrate Assimilation and Protein Synthesis

Potassium plays an important role in converting nitrate into amino acids and proteins. An insufficient supply of K may result in both lower nitrate uptake from the soil and slower nitrate assimilation into amino acids and proteins. Potassium deficiency can result in accumulation of low molecular weight sugars and carbohydrates, along with soluble-N compounds in the plant.

Nitrate accumulation in K-deficient plants can be a concern where limits have been established (such the European Union nitrate limit for leafy vegetables). When nitrate is rapidly converted to protein, the concern for healthier food is satisfied.

Appearance of Fruits and Vegetables

An adequate K supply has been linked to improved visual appearance of many horticultural crops. For example, banana is a crop that frequently responds favorably to K fertilization. Sufficient K improves banana fruit weight and number of fruits in each bunch, increases soluble solids, sugars, and starch. Low K results in thin and brittle bunches with a shorter shelf life. A lack of K has been linked with premature color development and harder, dry fruit sacs in

Potassium is essential for the growth of all plants, but particular attention has been placed on its role in improving the quality of horticultural crops because of their high value and short shelf-life. Parameters of quality are expressed differently in each plant species, but the fundamental role of K for promoting quality is consistently and widely reported. This brief review examines the role of K in producing quality food that meets consumer demands and preferences.

KEYWORDS:
crop quality; human nutrition; functional foods.

ABBREVIATIONS AND NOTES:
K = potassium.

https://doi.org/10.24047/BC102224

https://uconnladybug.wordpress.com

Lower K concentrations in tissue analysis studies have preceded the development of yellow shoulder symptoms in tomato.

citrus. Potassium-deficient grapes are less firm and have less juice.

An adequate supply of K increased marketability traits of muskmelon fruit (maturity, yield, firmness, and sugars) and quality parameters (ascorbic acid and β-carotene) (Lester et al., 2010a). The yield, quality, and shelf-life of tomatoes are improved with an adequate K supply. A lack of sufficient K results in uneven ripening, yellow shoulder fruit, and irregularly shaped fruit with poor internal quality (Hartz et al., 2005).

IPNI Image

A comparison of banana shelf-life after 19 days. The banana bunch on the right came from a plant that was adequately supplied with potassium while the plant producing the bananas on the left did not receive potassium.

Extending Shelf-life and Reducing Food Waste

Potassium has been shown to have a beneficial impact on properties that improve shelf life, storage, and shipping of many fruits and vegetables. Some of this occurs as an adequate K supply generally increases the firmness and strength of skins, allowing greater resistance to damage during transport and storage. Extending the longevity of freshness provides immediate benefits to both the farmers and the consumers.

The positive impact of K on fruit storage has been reported on many crops, including bananas (shelf-life), citrus (decreased post-harvest mold and rot), potatoes (storage longevity), carrots (crispness), pineapple (greater vitamin C leading to reduced browning and rot), figs, and apples.

Disease and Insects

Plants that are deficient in K are likely to be more sus-

ceptible to infection and insect damage than when sufficient K is present. In a significant literature review, Perrenoud (1990) examined 2,449 scientific citations and concluded that the use of K reduced the incidence of fungal diseases by 70%, bacterial infection by 69%, insects and mites by 63%, viruses by 41%, and nematodes by 33%. Reducing these pathogens and insects had a large benefit of allowing higher yields to be achieved.

A review by Wang et al. (2013) presented an excellent summary of how optimal K nutrition imparts significant plant resistance to both biotic and abiotic stresses. They reviewed the important role of K in protecting plants against diseases, pests, drought, salinity, cold and frost, and waterlogging.

Consumers are sensitive to the use of plant protection chemicals in production of horticultural crops. This sensitivity partially accounts for the growth of the organic farming sector (Mikkelsen, 2007). Whenever possible, providing adequate K should be used as a first line of protecting plant health. Decreased damage to harvested fruits and vegetables from pathogens and stresses will also result in a more attractive, marketable, and hence profitable crop.

Nutrient Composition

Fruits and vegetables are the most important sources of dietary K in the human diet. However, a trend for a decline in the mineral concentration of many foods has been suggested for over 75 years (Davis, 2009). A decline of 5% to 40% or more in minerals, vitamins, and proteins has been measured in many foods, especially vegetables. The cause for this decline may be due to dilution, changes through plant breeding, and changes in farming cultural practices. Recent reviews indicate that the decline in nutrient concentration of fruits and grain may not be as severe as earlier claimed (Marles, 2017).

Whatever the cause of this dilution, clearly there is a need to reexamine how the K concentration of food can be enhanced to better meet the dietary and health needs of consumers.

Functional Foods

"Functional food" is a term used to describe foods that provide health benefits in addition to the regular vitamins and minerals contained in common foods. Including them in a human diet is often considered to promote health beyond a more typical diet. Lycopene found in tomatoes, allicin present in garlic, and resveratrol in grapes are examples of nutraceutical compounds in functional foods that may provide health benefits.

The concentrations of all these functional food compounds listed above have been shown to increase in the presence of an adequate or abundant K supply to plants. The direct metabolic link between K and these functional food compounds is not always clear, but the trends are consistent.

Human Health

Animals and humans have an absolute requirement for K for proper growth and health. Potassium is involved in many essential functions in nerves, biochemical reactions, muscle function, heart health, and water balance. However, almost all human diets are quite low in K compared with the recommendations for health (Weaver, 2013). For example, in the United States the average daily K consumption is only 55% of the recommended dietary intake.

A diet rich in fruits and vegetables is one of the best ways to increase K intake, with potatoes being one of the highest sources of dietary K. Increasing the K concentration of the harvested portion of fruits, vegetables, and other plant-based products would make an important contribution to improving human health.

Conclusions

Potassium is essential for sustaining both the yield and the quality of many horticultural crops. Enhanced quality is frequently observed in many vegetables and fruits from an abundant supply of K. This quality can be observed in different ways for each species, but includes parameters such as size, appearance, longevity of storage, sugar and acidity, soluble solids, and nutritional benefits. Damage from disease, insects, and environmental stresses are frequently reduced when adequate K is present. All these considerations combine to underline the importance of maintaining an adequate supply of K for the production of high quality horticultural crops. **BC**

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References

Davis, D.R. 2009. HortScience 44:15-19.
Hartz, T.K. et al. 2005. HortScience 40:1862-1867.
Imas, P. 2013. Potassium - The quality element in crop production. International Potash Institute: Horgen, Switzerland.
Kumar, A.R. et al. 2006. Agric. Rev. 4:284-291.
Lester, G.E. et al. 2010a. Better Crops 94(1):18-21.
Lester, G.E. et al. 2010b. Plant Soil 335:117-131.
Marles, R.J. 2017. J. Food Comp. Anal. 56:93-103.
Mikkelsen, R.L. 2007. HortTechnology 17:455-460.
Perrenoud, S. 1990. Potassium and Plant Health, 2nd ed., International Potash Institute: Bern, Switzerland.
Wang, M.Q. et al. 2013. Int. J. Mol. Sci. 14:7370-7390.
Weaver, C.M. 2013. Adv. Nutrition 4:368S-377S.

Series Introduction: Can we relate fertilizer management to nitrogen losses?

Climate, soil, and nutrient management impact nitrogen (N) losses in predictable ways. By applying the 4Rs of nutrient stewardship, managers can make changes to N management practices for more sustainable outcomes. This entails minimizing N losses by supplying enough of the appropriate source of N when and where the crop demands it. However, optimizing N practices is complicated by:

1. The inability to readily measure all important fates of N, such as ammonia volatilization, nitrous oxide (N_2O) emission, and nitrate leaching;
2. Interactions among 4R management, soil, and climatic factors that limit yield and crop recovery of N;
3. The identification of management strategies that target multiple loss pathways (e.g., reduce ammonia volatilization, N_2O emissions, as well as nitrate leaching).

In this series, we are devoting one article to each of these three challenges.

John Deere

Part 1: Can Lower Nitrogen Balances and Greater Recovery by Corn Reduce N_2O Emissions?

By Tai McClellan Maaz, Rex Omonode, and Tony Vyn

Current methodologies to estimate N_2O emission are rate based. This means that emissions are calculated by multiplying fertilizer N rates by a single emission factor of 0.01 (IPCC, 2006). However, the microbial production of N_2O from a given nutrient application varies widely depending on how the soil interacts with local weather and the source, rate, timing, and placement of the nutrient applied. Therefore, the effectiveness of a single emission factor based on N rate is limited, and alternatives must be explored.

Nitrogen use efficiency indicators, such as N recovery or partial N balances, may relate better to N_2O emissions. The rationale is that these measures reflect the N not used by the crop and therefore at risk of loss. However, for a N use efficiency indicator to be useful, it must reliably relate to N_2O emissions across a range of management practices and environments.

In 2017, Omonode et al. published a study investigating this issue. The authors asked the following research questions:

Nitrous oxide (N_2O) emissions are related to N use efficiency indicators across a range of geographies and management conditions for North American rain-fed and irrigated corn. Suites of 4R management practices that reduce N balances through more efficient fertilizer recovery can reduce N_2O emissions. Performance indicators that estimate N surplus in the system, such as partial N balances when grain N concentrations are known, may be more effective than fertilizer N rate alone at predicting N_2O emissions. However, multiple indicators are needed to assess the sustainability of these cropping systems.

KEYWORDS:
use efficiency; nutrient performance; uptake; recovery; economic optimal N rate.

ABBREVIATIONS AND NOTES:
N = nitrogen; N_2O = nitrous oxide.

https://doi.org/10.24047/BC102227

Table 1. Definitions of N uptake, recovery efficiency, and N balance indicators.

Indicator	Calculation	Assumptions
Grain N uptake, kg/ha	Grain N	0.64 x aboveground N, if not reported
Total N uptake, kg/ha	Grain + stover N	Grain N / 0.64, if not reported
N recovery efficiency, %	(Total N uptake$_{fertilized}$ – total N uptake$_{unfertilized}$) / Applied N x 100	Nitrogen recovery is approximated by the difference in N uptake between fertilized and unfertilized corn relative to the amount of fertilizer applied
Grain-based net N balance, kg/ha	(Fertilizer N + manure N + rotational N) – grain N	Manure N = recoverable N; rotational N = N credits following legumes based on state/region recommendations
Crop-based net N balance, kg/ha	(Fertilizer N + manure N + rotational N) – total N uptake	Manure N = recoverable N; rotational N = N credits following legumes based on state/region recommendations
N surplus, kg/ha	Fertilizer N – Total N uptake	Manure is not factored into surplus calculation

1. Do increases in crop N uptake and recovery efficiencies and decreases in N surpluses reduce cumulative seasonal N_2O fluxes?
2. Are these relationships consistent across suites of 4R nutrient management practices?

These authors limited their study to North American corn production due to its importance; the region produces 37% of the world's corn supply and consumes about 13% of N fertilizer applied. In the United States, about 40% of N fertilizer consumed is applied to corn. The authors conducted a literature review to assess the cumulative seasonal N_2O fluxes relative to corn yield, crop N uptake, and grain N uptake. In total, 379 mean observations were collected from 25 papers that had more than three replications, at least two years of observations, with at least weekly in-season measurements of N_2O fluxes during most of the growing season, and more than three fertilizer rates (for rate-based studies) including control plots. The studies were conducted in Nebraska (1), Indiana (4), Ontario (3), Minnesota (6), Colorado (8), Kentucky (1), Quebec (1), and New Brunswick (1). Fifteen of the studies were conducted under rain-fed conditions, ten were irrigated, but one of the ten was partially rain-fed.

Of the total, 94 mean observations were focused on N rate treatments, 94 on N sources, and 191 on N rate or N sources in combination with timing and/or placement options. Data were used to calculate N recovery and N surplus or balances using indicators defined in **Table 1**. Aggregated across all soils, management, and climate conditions, single-factor linear and non-linear regressions were conducted to characterize the response of N_2O emissions, and each indicator, to N rate. The relationship of N_2O emissions to each indicator was also assessed across 4R practices. Finally, multiple regressions were conducted to identify whether a combination of indicators could more completely explain the observed variation in N_2O emissions.

How Does Nitrogen Rate Relate to Seasonal N_2O Emissions?

Cumulative N_2O fluxes were reduced most by optimizing N rate, followed by smaller effects of timing and source. Adding more fertilizer increased N_2O emissions. However, this study showed the following limitations in estimating N_2O emissions by just N rate.

Limitation 1: Large amounts of unexplained variation in emissions

Although N_2O emissions were best predicted by fertilizer N rate, this single variable only explained 43% of the variability.

Limitation 2: Inconsistency in emission factors

For global inventories, emissions of N_2O-N are estimated by multiplying fertilizer N rates by a single emission factor of 1%. However, emission factors are reported to vary from 0.07 to 1.7% (Asgedom et al., 2014; Burton et al., 2008; Gao et al., 2017; Maharjan and Venterea, 2013). The emission factor for corn in this study was 0.6%, less than the reported global average.

Emissions factors also varied across N source. Omonode et al. (2017) provide evidence that supports lower emission factors with polymer-coated urea and stabilized-N products containing urease with and without nitrification inhibitors (**Table 2**). Therefore, source can have an effect additional to N rate.

Limitation 3: The extent to which N rate can be reduced without agronomic losses

The economic optimal N rate (EONR), for the entire dataset can be easily calculated using the regression parameters reported by Omonode et al. (2017). Across all soils, management, and climates, the EONR was 215 kg N/ha (**Table 3**).

TAKE IT TO THE FIELD

Partial N balance can be used to evaluate on-farm performance of 4R practice implementation and to assure that reductions in N_2O emission have been achieved at optimal yields. Additional reductions in emissions, independent of N balance, may be achieved through use of urease/nitrification inhibitors.

The N fertilizer rate can be adjusted from the rate for maximum yield to that for optimum economic yield. Doing so reduces yield by less than 1% while reducing N_2O emissions by 11%. However, even with optimized N rates, 1.57 kg N/ha was emitted as N_2O, and N balances were largely positive. Nitrous oxide fluxes increased by approximately 5 g N/kg of fertilizer N as fertilizer rate increased from 130 to 220 kg N/ha. To put this into perspective, agronomic optimal N rates typically range from 150 kg N/ha in Minnesota to 220 kg N/ha in Indiana, corresponding with emissions of 1.0 to 1.6 kg N/ha. Other fertilizer management practices, such as source and timing, need to be considered for further reductions beyond the 11% achieved through optimizing fertilizer rate economically.

Table 2. Nitrogen source effects on seasonal N_2O emissions, fertilizer-induced emission factors, N recovery efficiencies, and crop-based net N balances.

		Nitrous oxide and N use efficiency indicator			
Location	N source	N_2O, kg N/ha	Emission factor, %	Crop net N balance, kg N/ha	N recovery efficiency, %
Colorado (irrigated)	Polymer-coated urea	0.92 b	0.36 b	23 a	54 a
	Stabilized urea†	0.59 c	0.21 bc	12 a	56 a
	UAN	0.74 bc	0.29 b	19 a	51 a
	Urea	1.14 a	0.45 a	22 a	54 a
Indiana (rain-fed)	UAN	2.35 a	1.23 a	20 a	53 a
	UAN + Nitrification inhibitor	1.69 b	0.58 b	9 a	58 a
Minnesota (irrigated and rain-fed)	Polymer-coated urea	1.17 ab	0.44 ab	-22 a	48 a
	Stabilized urea	0.86 b	0.26 b	-28 a	53 a
	Urea	1.46 a	0.60 a	-25 a	52 a

†Stabilized urea includes Agrotain® with urea, Agrotain®Plus with UAN, and SuperU®.

Do Increases in Nitrogen Use Efficiencies Reduce Cumulative Seasonal N_2O Fluxes?

Nitrous oxide emissions increased as total aboveground and grain N uptake increased. Therefore, emissions associated with higher N rates were not fully offset by increases in crop uptake of N. Instead, N use efficiency indicators were more suitable measures, and N_2O emissions decreased as apparent N recovery increased or N balances decreased. In general, the relationships of these indicators with N_2O fluxes were consistent across timing and N rate combinations.

The usefulness of N recovery and N surplus was demonstrated with the timing of fertilizer applications. Omonode et al. (2017) found that N_2O emissions were lower for the same amount of N taken up by the crop, or a given partial N balance, when fertilizer was applied at planting rather than side-dressed, or when N was side-dressed earlier (V6) rather than later (V14). These findings suggest that the benefits of in-season applications are only obtained when rates are more accurately adjusted to improve N use efficiency. Even during periods of rapid nutrient uptake, poor recovery and high N surpluses can increase N_2O emissions, particularly if environmental conditions are more conducive to losses between V6 and V14 (e.g., a warmer, wetter summer) rather than between planting and V6 (e.g., a drier, cooler spring).

However, the N fertilizer recovery indicator had limitations as a predictor of N_2O emissions. For example, the use of stabilized urea with inhibitors reduced N_2O emissions by 19 to 48%, with such emissions being less at planting than at side-dressing. However, this reduction in N_2O emissions did not correspond with enhancements in N recovery efficiency. Without leaching or denitrification data, it is difficult to assess whether the offset in N_2O emissions through the use of inhibitors came at the expense of later N losses through other pathways such as leaching. This latter concern is the topic of two articles to come, in which we discuss recent research that examined climate, soil, and management impacts on N_2O emission and nitrate leaching. **BC**

Table 3. N_2O emissions and indicators at economic optimal N rates based on the yield response of 84 mean observations at economic optimum and maximum yields.

Indicator	Equation	EONR*	Maximum
Grain yield, kg/ha	Quadratic	11,379	11,469
N rate, kg N/ha	Quadratic	215	247
N_2O emission, kg N/ha	Linear	1.7	1.76
Grain N uptake, kg N/ha	Linear	135	146
Total N uptake, kg N/ha	Linear	211	229
N recovery efficiency, %	Linear	54	49
Grain-based net N balance, kg N/ha	Linear	115	137
Crop-based net N balance, kg N/ha	Exponential	38	63
N surplus, kg N/ha	Exponential	-1	21

*Economic optimal N rates were calculated using regression parameters with the highest R^2 provided in **Table 1** of Omonode et al. 2017.

View Interactive Charts
Explore where values from Table 3 fall upon the response curve to nitrogen fertilizer.

Acknowledgement

This article is based upon the original paper by Omonode, R.A. et al. 2017. Achieving Lower Nitrogen Balance and Higher Nitrogen Recovery Efficiency Reduces

Nitrous Oxide Emissions in North America's Maize Cropping Systems. Frontiers in Plant Science 8:1080. https://doi.org/10.3389/fpls.2017.01080.

Trade names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or IPNI.

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References

Asgedom, H. et al. 2014. Agron. J. 106:732-744.
Burton, D.L. et al. 2008. Can. J. Soil Sci. 88:219-227.
Gao, X. et al. 2017. Am. J. Potato Res. 94:390-402.
IPCC. 2006. Chapter 11. *In* 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry and Other Land Use, Eggleston H.S. et al. (eds), Prepared by the National Greenhouse Gas Inventories Programme, IGES, Japan.
Maharjan, B. and R.T. Venterea. 2013. Soil Biol. Biochem. 66:229-238.
Omonode, R.A. et al. 2017. Front. Plant Sci., 23. https://doi.org/10.3389/fpls.2017.01080

Enhancing Cover Crop Nitrogen Uptake with Improved Establishment

By Reagan Noland, M. Scott Wells, and Heidi Peterson

Although cover crops have been promoted for their ecological benefits and ability to improve the resiliency of annual cropping systems, producers across the Midwest region of the U.S. have been hesitant to implement them due to challenges in establishment within the short growing season of a humid continental climate and a lack of reliable management practices. In the Midwest, summer-annual crops, specifically corn and soybean, are actively growing in the field for only a few months out of the year. This leaves fallow soils and a window of vulnerability extending between the time of harvest in the fall until planting in the spring. During this time the soils are susceptible to erosion and since crop nutrient uptake is minimal, any residual fertilizer in the soil is at risk of off-site movement, leaving the potential for surface runoff, leaching, and tile-drain discharge.

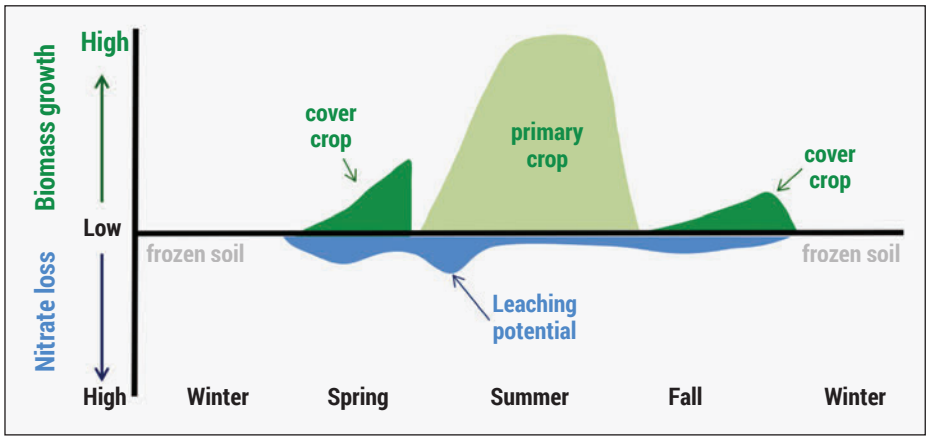

Figure 1. Proper implementation of a cover crop can reduce the opportunity for nutrient runoff and leaching by increasing plant biomass to cover the soil and utilize the available soil nutrients. Adapted from Heggenstaller et al., 2008.

If an adequate cover crop is established across the soil surface, the increased plant biomass will scavenge for residual fertilizer N, reducing the opportunity for nutrient runoff and leaching (**Figure 1**). This also helps to keep the N in the root zone so that it can be used by a future cash crop, improving overall nutrient use efficiency.

The main limitation to properly implementing cover crops following corn harvest in northern climates is the lack of adequate time and favorable soil and weather conditions for their establishment prior to freezing winter temperatures. To get the seed planted before harvest is completed, the cover crop could be interseeded into standing corn. One practice that has been researched and applied across the Midwest uses an aerial broadcast method from an airplane or helicopter. With an aerial application, however, cover crop establishment can be inconsistent due to seed getting caught in the corn canopy, poor seed-soil contact, and seed predation by rodents and insects. Good seed-soil contact and precipitation within a week of aerial seeding are determining factors of successful establishment (Wilson et al., 2013).

Innovative producers are now beginning to interseed cover crops using high-clearance drills to deliver cover crop seed directly between the rows of a standing crop without the need of an aerial application. A study was initiated by the University of Minnesota in 2014 to evaluate establishment success of a range of cover crop species and planting methods, and to determine whether successfully interseeding cover crops into corn will utilize excess N without reducing corn and subsequent soybean yields (Noland et al., 2018).

Study Description

Field experiments were conducted in 2014 through 2016 at the University of Minnesota's Southern Research and Outreach Center at Waseca, MN and at the Southwest Research and Outreach Center at Lamberton, MN. Both field sites were in primary corn production areas of Minnesota and situated in watersheds that drain into the Minnesota River, a tributary to the Mississippi River Basin. Fertilizers were applied in spring prior to seedbed preparation according to preplant soil analysis and University of Minnesota recommendations for corn production (Kaiser et al., 2016).

The experimental design was a randomized complete

In the north central part of the US Midwest, the growing season often offers only a small opportunity for cover crop growth in the corn-soybean cropping system. In Minnesota fields, we show that with planting techniques that produce good seed to soil contact, along with choice of a species that will grow to produce at least 390 kg DM/ha, cover crops can effectively take up residual N to reduce risk of nitrate loss.

KEYWORDS:
cover crop; nutrient loss; interseeding; residual nutrients.

ABBREVIATIONS AND NOTES:
N = Nitrogen; DM = dry matter.

https://doi.org/10.24047/BC102231

Table 1. Cover crop species.

Common name	Functional group
Cereal rye	Grass / small grain
Field pennycress	Oilseed brassica
Medium red clover	Legume
Hairy vetch	Legume
Mixture (48% oat , 48% field pea, 4% tillage radish)	Grass, legume, brassica

block with six replicates. The treatments were a factorial arrangement of five cover crop options (**Table 1**) planted using three interseeding methods, resulting in a total of 15 treatments and an experimental control without a cover crop. Cover crops were interseeded into corn at the seven-leaf collar stage (V7) in late June. All legumes were inoculated with appropriate rhizobia species at planting.

Three cover crop planting methods were evaluated. Direct broadcast of seed into the inter-row (DBC) was simulated by hand broadcasting the seed into the three inter-rows of each plot with no soil disturbance. Directed broadcast into the inter-row with light soil incorporation (DBC+INC) was achieved by modifying a high-clearance no-till drill. The drill units were raised so that the seed fell onto the soil surface and were incorporated using a light closing chain followed by a harrow-tine rake to achieve a light soil disturbance. The third method used the same high-clearance no-till drill (DRILL; 3-in-1 InterSeeder™, InterSeeder Technologies). The DRILL treatment had three drill units spaced 7.5 inch apart and centered within three inter-rows per plot, leaving a 15-inch-wide gap for each corn row (**Figure 2**). Seeding rates for each treatment were selected to ensure ample opportunity for comparable establishment with all three planting methods.

Cover crop biomass and N content were measured at corn maturity and in the spring prior to termination. Corn grain, stover, and cob biomass were also sampled and analyzed for N content at maturity. Soil was sampled to a depth of 1.2 meters (about 50 inches) and analyzed for nitrate-N content following corn harvest in the fall, and immediately prior to cover crop termination in the spring.

Cover Crop Biomass and Seeding Method

All cover crops established and survived through the fall except for the mixture, which was not winter-hardy and senesced under the corn canopy at both locations. Cover crop biomass in the fall, averaged by species, ranged from 9 to 84 kg DM/ha (average = 41 kg DM/ha) and was generally greater with planting methods that increase seed-soil contact compared to broadcast seeding without incorporation. The DRILL resulted in greater fall biomass than the other two planting methods for hairy vetch, the mixture, and rye. Red clover fall biomass was greater with DRILL and DBC+INC than DBC, and planting method did not affect fall biomass in pennycress.

Spring cover crop biomass was greater overall with the DRILL and DBC+INC planting methods (average = 641 kg DM/ha) compared to DBC (514 kg DM/ha). Within species, the DBC method resulted in less red clover and hairy vetch biomass compared to other planting methods, but rye and pennycress spring biomass were not affected by planting method.

Figure 2. Main photo shows planting cover crops into V7 corn using a high-clearance InterSeeder™ (inset photo represents DBC+INC) at Lamberton, MN.

Rainfall was above-average during the growing season in all site-years of this study, which likely influenced the success of the broadcast planting methods. Under drier conditions, similar establishment would not be expected of broadcast planting with no incorporation (Wilson et al., 2013). Corn grain and silage yields were not affected by cover crop species or planting method, indicating that the interseeded cover crops did not interfere with corn production when planted at the V7 growth stage. With the exception of hairy vetch that was poorly terminated at Lamberton, subsequent soybean yield was also not affected by the previous cover crop species or planting method.

Cover Crop Nitrogen Uptake

A cover crop that readily winterkills, similar to what was observed in the mixture, will not likely assimilate and retain as much N as winter-hardy species, but it could be a valuable option if an early-spring herbicide application is undesirable, or in no-till organic systems.

The low cover crop biomass accumulation in the fall corresponded to low N uptake (average 1.3 kg N/ha) in the fall. However, spring soil nitrate-N was reduced by rye cover crops at Lamberton compared to other treatments, and by rye, hairy vetch, red clover, and pennycress at Waseca compared to the mixture and check treatments (**Table 2**). An important finding is that differences in spring soil nitrate-N coincided with spring cover crop biomass production (**Table 3**). In all cases where spring soil nitrate-N was reduced, spring cover crop biomass was greater than 390 kg DM/ha. As the spring cover crop biomass increased, the soil nitrate-N decreased (R = -0.70; p = 0.003) compared to the no cover check. This supports that cover crop biomass can serve as an indicator for ecological services in the reduction of excess soil nitrate-N. In this study, the greatest effect was from the interseeded rye cover crops, which reduced spring soil nitrate-N compared to the no cover crop check by 53 kg NO_3-N/ha at Waseca and by 39 kg NO_3-N/ha at Lamberton. Nitrogen content in the aboveground rye biomass did not account for the entire difference in soil nitrate-N, which suggests that there was assimilation by the roots.

Summary

Cover crops can be successfully established into corn at the V7 stage using interseeding practices without affecting corn yield; however, effective termination of cover crops is important to avoid risk of reducing soybean yield. Although it is common for producers in the Midwest to judge the quality of their cover crop on the observed fall biomass, this study indicated that winter-hardy cover crop varieties interseeded to produce 390 kg DM/ha in the spring reduced soil NO_3-N compared to the no-cover crop check. To achieve the conservation benefit and minimize the yield reduction risk, USDA conservation programs (2014) require that zones extending across the Midwest should terminate the cover crop either at planting or before cash crop emergence. The cover crops in this study were terminated with glyphosate within 3 to 16 days of planting.

Planting methods with increased seed-soil contact produced more reliable cover crop establishment, which will be amplified during periods of drought or low precipitation. All cover crop species were successfully established, although over the three-year study, winter rye was consistently amongst the highest in spring cover crop biomass and N uptake, consequently resulting in lower spring soil NO_3-N.

Implementing cover crops as a way to scavenge residual nutrients may not be feasible on every hectare across the Midwest. Producers looking to target cover crop establishment to their most vulnerable land should consider interseeding techniques that increase seed-soil contact to produce the most reliable results for effective nutrient management. **BC**

Table 2. Effects of interseeded cover crops on two-year (2015, 2016) mean spring soil NO_3-N content to a depth of 1.2 m.

	Soil NO_3-N	
	Lamberton	Waseca
Cover crop species	kg NO_3-N/ha	
No cover crop	75 a[1]	109 a
Winter rye	37 b	56 b
Pennycress	70 a	74 b
Red clover	79 a	69 b
Hairy vetch	75 a	64 b
Mixture	67 a	102 a

[1] Within columns, means with the same letter are not significantly different at $p \leq 0.05$.

Table 3. Cover crop species effect on two-year (2015, 2016) mean spring tissue N content.

	Aboveground tissue N content			
	Hairy vetch	Pennycress	Red clover	Winter rye
Planting Method	kg N/ha			
DBC	6.7 b[1]	11.7 a	11.7 b	21.7 a
DBC+INC	14.9 a	11.6 a	19.4 a	25.8 a
DRILL	18.9 a	10.8 a	21.1 a	26.0 a

[1] Within a column, means with the same letter are not significantly different at $p \leq 0.05$.

TAKE IT TO THE FIELD

When looking to use cover crops to effectively scavenge residual nitrate-N, interseeding techniques that increase seed-soil contact compared to direct broadcast should be considered.

Acknowledgement

This article is adapted from Noland et al. 2018. Establishment and function of cover crops interseeded into corn. Crop Sci. 58:1-11. http://doi.org/10.2135/cropsci2017.06.0375, a project funded by the Minnesota Clean Water Fund.

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References

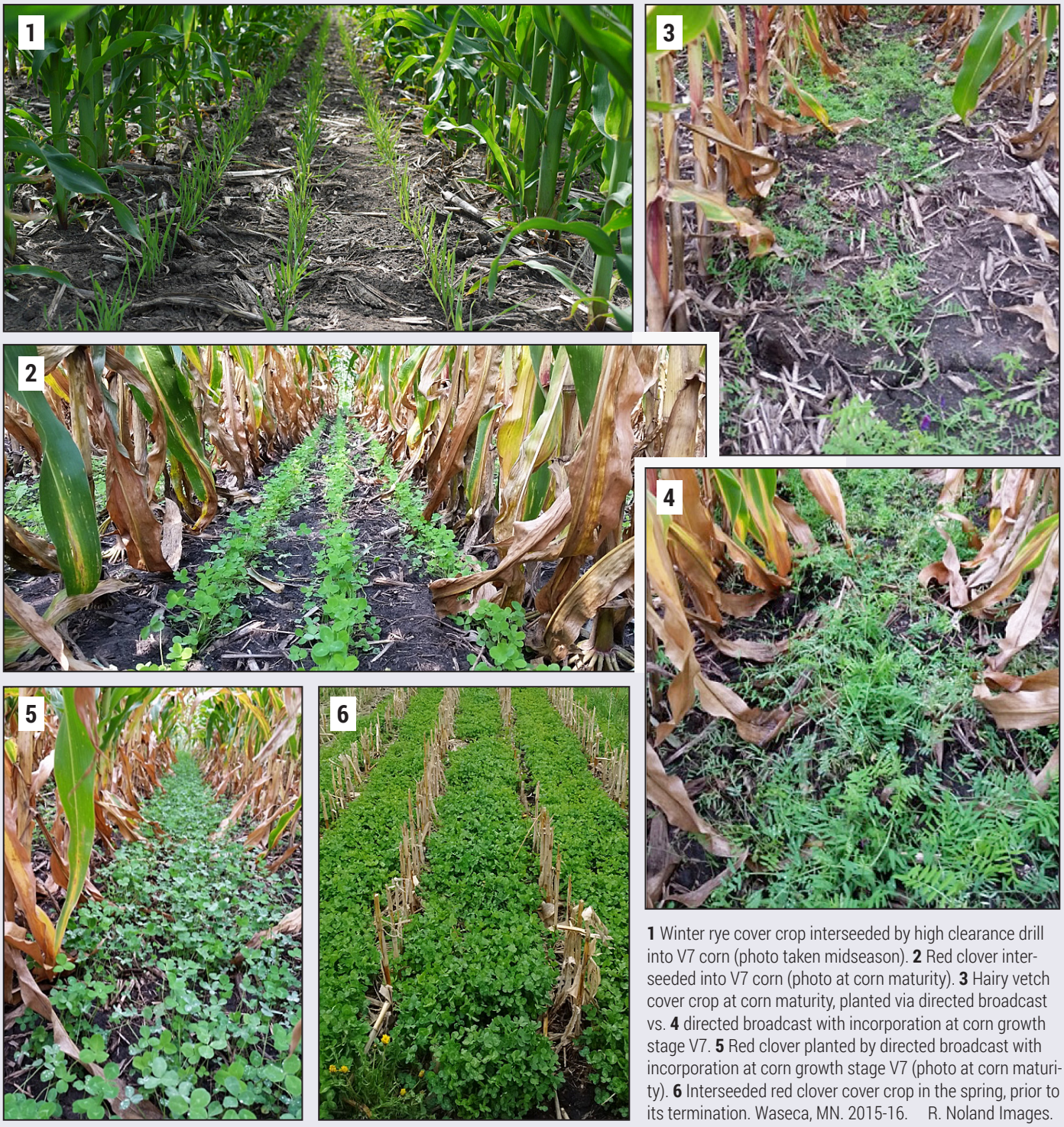
Heggenstaller, A.H. et al. 2008. Agronomy Journal 100: 1740-1748.

Kaiser, D.E. et al. 2011. BU-06240-S. Univ. of Minnesota Ext., St. Paul. http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/fertilizer-recommendations-for-agronomic-crops-in-minnesota/docs/BU-6240S-PUB.pdf (accessed 18 June 2017).

Noland, R. et al. 2018. Crop Science 58:1-11. doi:10.2135/cropsci2017.06.0375.

USDA. 2014. NRCS Cover Crop Termination Guidelines. Sept. 2014, Version 3, https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=stelprdb1263099&ext=pdf.

Wilson, M.L. et al. 2013. J. Environ. Qual. 33:1010–1016. doi:10.2134/agronj2013.0133.



1 Winter rye cover crop interseeded by high clearance drill into V7 corn (photo taken midseason). **2** Red clover interseeded into V7 corn (photo at corn maturity). **3** Hairy vetch cover crop at corn maturity, planted via directed broadcast vs. **4** directed broadcast with incorporation at corn growth stage V7. **5** Red clover planted by directed broadcast with incorporation at corn growth stage V7 (photo at corn maturity). **6** Interseeded red clover cover crop in the spring, prior to its termination. Waseca, MN. 2015-16. R. Noland Images.

Annual IPNI Photo Contest Starts Up for 2018

The International Plant Nutrition Institute (IPNI) is pleased to announce the start of its annual photo contest for 2018. Photo entries can be gathered throughout the remainder of the year and winners will be announced during the first quarter of 2019.

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

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

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

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

A. Ibarra

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

R. Atchoglo

Localized placement of Urea to Maize, Lomé, Southern Togo.

S. Jadhao

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

J. Kaur

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

New Publication - Plant Nutrition Diagnostics: Potato

Potato growers need a range of decision support tools to help them defend their crops against yield-robbing nutritional deficiencies, disease and pests, and environmental stress.

The International Plant Nutrition Institute (IPNI), J.R. Simplot Company, and Tennessee State University have collaborated on a new publication that provides readers with access to a unique collection of hundreds of high resolution photographs that document a wide range of nutrient deficiency symptoms in potato plants with remarkable clarity.

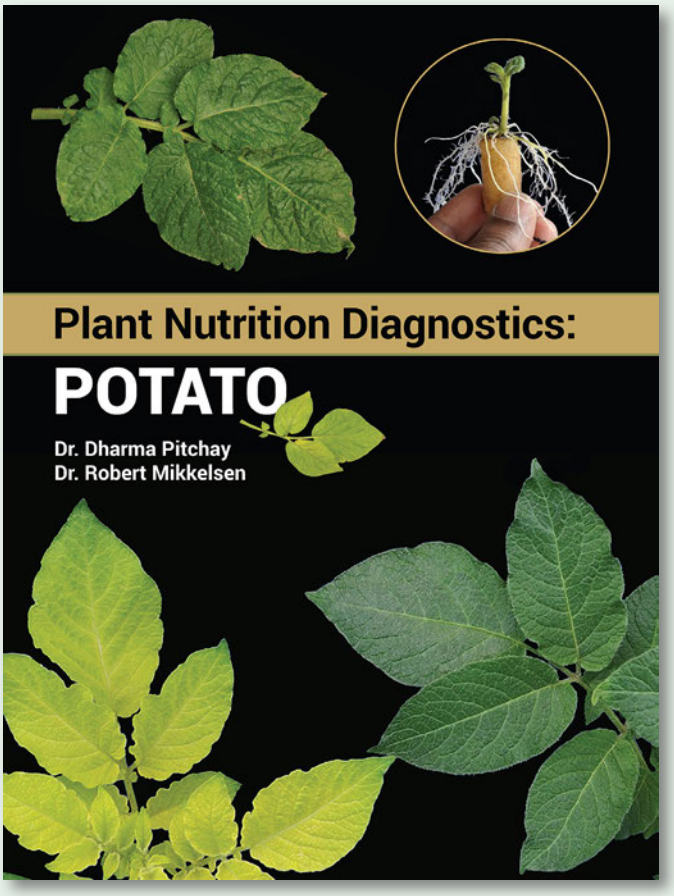
The book is now available to download from the IPNI Store https://store.ipni.net. You can contact IPNI at circulation@ipni.net for information on purchasing this ebook as an institution/company.

"*IPNI is fortunate to collaborate with Dr. Pitchay and Simplot in producing this world-class collection of photographs and information*," said Dr. Robert Mikkelsen, vice president, IPNI Communications and co-author of the book.

Developed within a unique greenhouse system at Tennessee State University, this collection provides examples of mild, moderate, and severe cases of deficiencies of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn).

"*This has been a tremendous opportunity to work with leading scientists to develop a world class collection of fully documented photos describing the major crop nutritional problems commonly observed in the field*," explains Dr. Terry Tindall, director of agronomy for Simplot.

The identification of nutrient deficiencies in the field can be a difficult process and this collection provides farmers, crop advisers, and mineral nutrition researchers with a valuable diagnostic tool. Once the underlying deficiency is known, strategies can be developed to help avoid losses in yield or crop quality. **BC**



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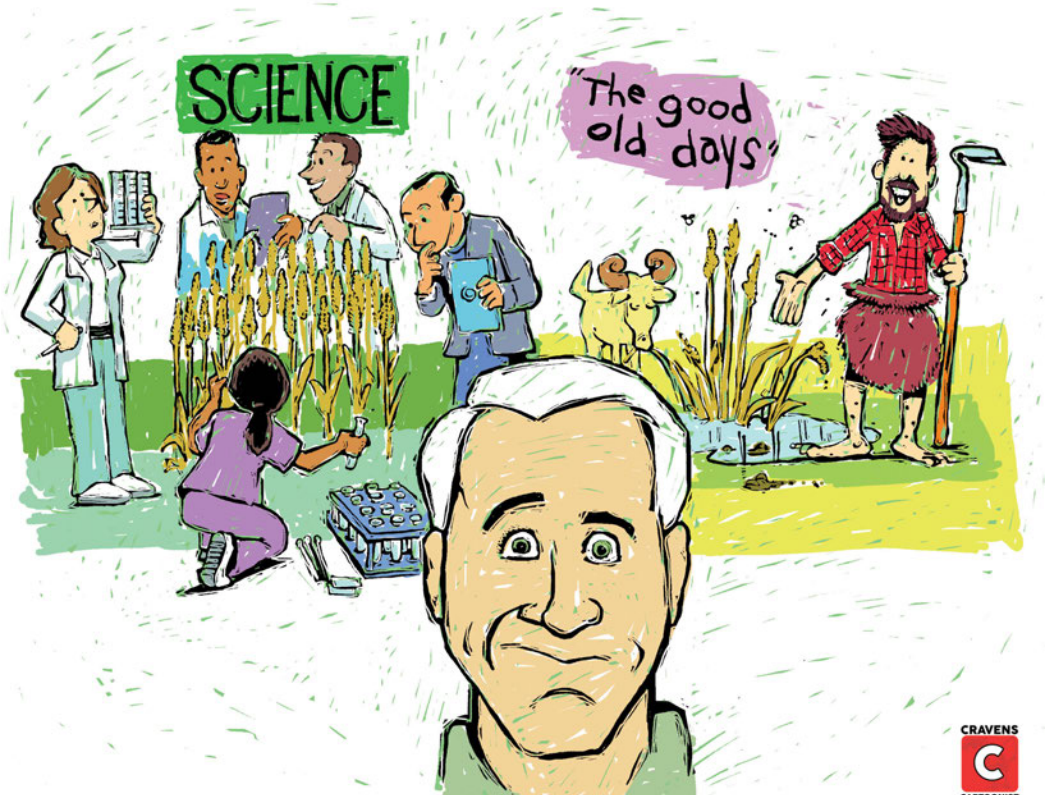

I was recently visiting with a prominent professor at a leading U.S. land-grant university. He explained to me that undergraduate students in their Agronomic Science and in the Agroecology majors are no longer expected to take coursework in soil fertility or plant nutrition.

This reminded me of the rapidly growing enthusiasm about the principles of agroecology and my confusion of what that term means. I've interpreted agroecology to mean applying ecological principles to our food production systems, including consideration of environmental, economic, and social implications. That reminds me a lot of the goals of 4R Nutrient Stewardship!

Agriculture is by its very nature a disruptive human activity that we engage in to meet our existential need for farm products. The pressures to increase global food security will undoubtedly grow, with the expectation of minimizing environmental damage and social disruption. The success of accomplishing these goals turns on our ability to apply good science and policy in the face of uncertainties related to factors such as farm prices, government regulations, water supplies, and climate change. It does not, as one enthusiast recently suggested to me, include "a return to peasant practices."

The need for well-educated students and practitioners to meet these growing challenges has never been greater. Successful agriculture will require increasingly efficient plant nutrition using tools such as precision agriculture and modern data analysis. We also need to better identify how to boost low crop yields and assist farmers to achieve a dignified lifestyle. Yes, the economic and social aspects of agroecology are important, but they will never be successful without application of correct scientific principles.

There is no getting around it. Plant nutrition remains key to successful agriculture.

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