



# **Effectiveness of Potash Fertilization**

2016



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*Our cover: Rapeseed field with research plots on K fertilization in Central Russia  
Photo by Svetlana Ivanova*

*All photos in the section «Visual Indicators of Potassium Deficiency» are from IPNI Photo Collection*

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# Towards a 4R-consistent fertiliser industry

T. Bruulsema

*The concept of 4R Nutrient Stewardship has been embraced by a wide segment of the fertilizer industry, and many of its associated partners in agriculture, government, and the environmental movement. The 4Rs communicate the essentials of responsible management of plant nutrition to a wide range of stakeholders, technical and non-technical. The specific nutrient application practices being encouraged vary from one region to another, because the implementation of 4R Nutrient Stewardship is site-specific. The core concept is that the right source of plant nutrient be applied at the right rate, right time, and right place to obtain improved sustainability outcomes. Industry needs to support an adaptive management approach at all levels. Segments of the industry including agri-service providers, retail, wholesale, manufacturing, and investors, working together, can ensure that producers are empowered and enabled to make the right choices to improve the performance of their cropping systems.*

About 25 years ago, the United Nation’s World Commission on Environment and Development produced a report titled “Our Common Future”. This report provided the basis for the concept of sustainable development, and in particular, sustainable agriculture. Over the past few years, sustainability has become an important topic for corporations, including those in the agriculture and food sectors. Major food retailers are developing programs to assess and improve their own performance, along with that of their supply chain, extending all the way to the farm level and to the inputs used by farmers. These food retailers are engaging agri-business by participating in organizations like the Sustainability Consortium and the Keystone Alliance.

## The 4Rs connect to sustainability

4R Nutrient Stewardship encourages more sustainable choices for the source, rate, time and place of application of crop nutrients. The Keystone Alliance, for example, has developed a “Fieldprint Calculator” which includes elements of 4R Nutrient Stewardship in its greenhouse gas component, and a Water Quality Index currently under development is likely to be linked to 4R Nutrient Stewardship as well.

Definitions of sustainable agriculture abound, but most emphasize a need to accommodate growing demands for production without compromising natural resources. This entails a balance among economic, social and environmental impacts of management choices.

The fertilizer rights – source, rate, time, and place – are connected to the goals of sustainable agriculture through the cropping system, as shown in **Figure 1**. Fertilizer management, to be considered “right,” must support stakeholders’ goals for how that cropping system

performs, how it produces, how it affects the air they breathe, the water they drink, etc.

## Scientific principles apply to the 4Rs

The sciences of physics, chemistry, and biology provide fundamental principles for the mineral nutrition of plants growing in soils. The application of these sciences to practical management of plant nutrition has led to the development of the scientific disciplines of soil fertility and plant nutrition. The management components source, rate, time and place each have unique science which describes the processes related to plant nutrition, and can be condensed into principles (**Table 1**). Understanding the sciences underpinning these key principles is critical for those advising crop producers on plant nutrition.

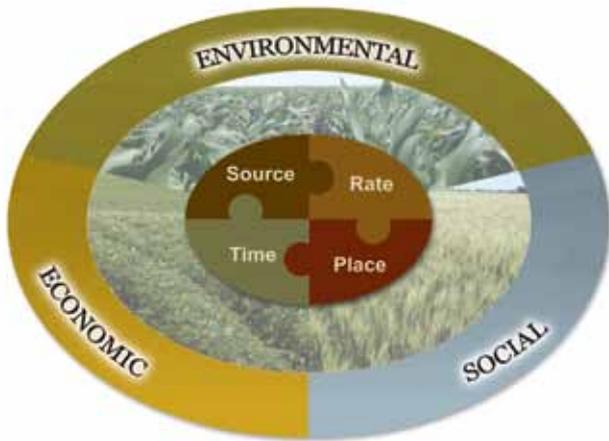
SOURCE, RATE, TIME, AND PLACE are completely interconnected in the management of plant nutrition. None of the four can be right when any one of them is wrong. It is possible that for a given situation there is more than one right combination, but when one of the four changes the others may as well. The 4Rs must work in synchrony with each other and with the cropping system and management environment. 4R Nutrient Stewardship emphasizes the impact of these combinations of management choices on outcomes, or performance, toward improved sustainability. For example, when potassium limits yield, application of potash fertilizer improves recovery and use efficiency of nitrogen and phosphorus.

## Adaptive Management

Adaptive management for plant nutrition includes cycles of decision, implementation and evaluation (**Figure**

**Table 1.** Key scientific principles associated with the 4Rs (IPNI, 2012).

Source	Rate	Time	Place
Provide essential elements	Assess plant demand	Assess timing of uptake	Consider where roots grow
Supply plant-available forms	Assess soil supply	Identify sensitive growth stages	Consider soil chemical reactions
Suit soil properties	Use all available sources	Assess dynamics of soil supply	Suit the tillage system
Recognise synergisms	Predict uptake efficiency	Recognise dynamics of losses from soil	Manage variability among fields
Respect blend compatibility	Maintain soil fertility	Evaluate logistics of field operations	Manage variability within fields
Recognize associated elements	Consider economics		



**Figure 1.** The 4R Nutrient Stewardship concept considers the right source, rate, time, and place for fertiliser application capable of producing the stakeholders' desired economic, social, and environmental outcomes for the ecosystem.

2). These cycles operate at several levels, including the farm, the regional and the policy levels. There is a role for industry at each level.

Agri-service providers—including retail dealers—often advise producers at the farm level. Producers review options for each crop, choosing recommendations for source, rate, time, and place of application which suit their

local site factors. These site-specific factors start with soil and landscape and extend to a wide range of considerations including local regulations and land tenure.

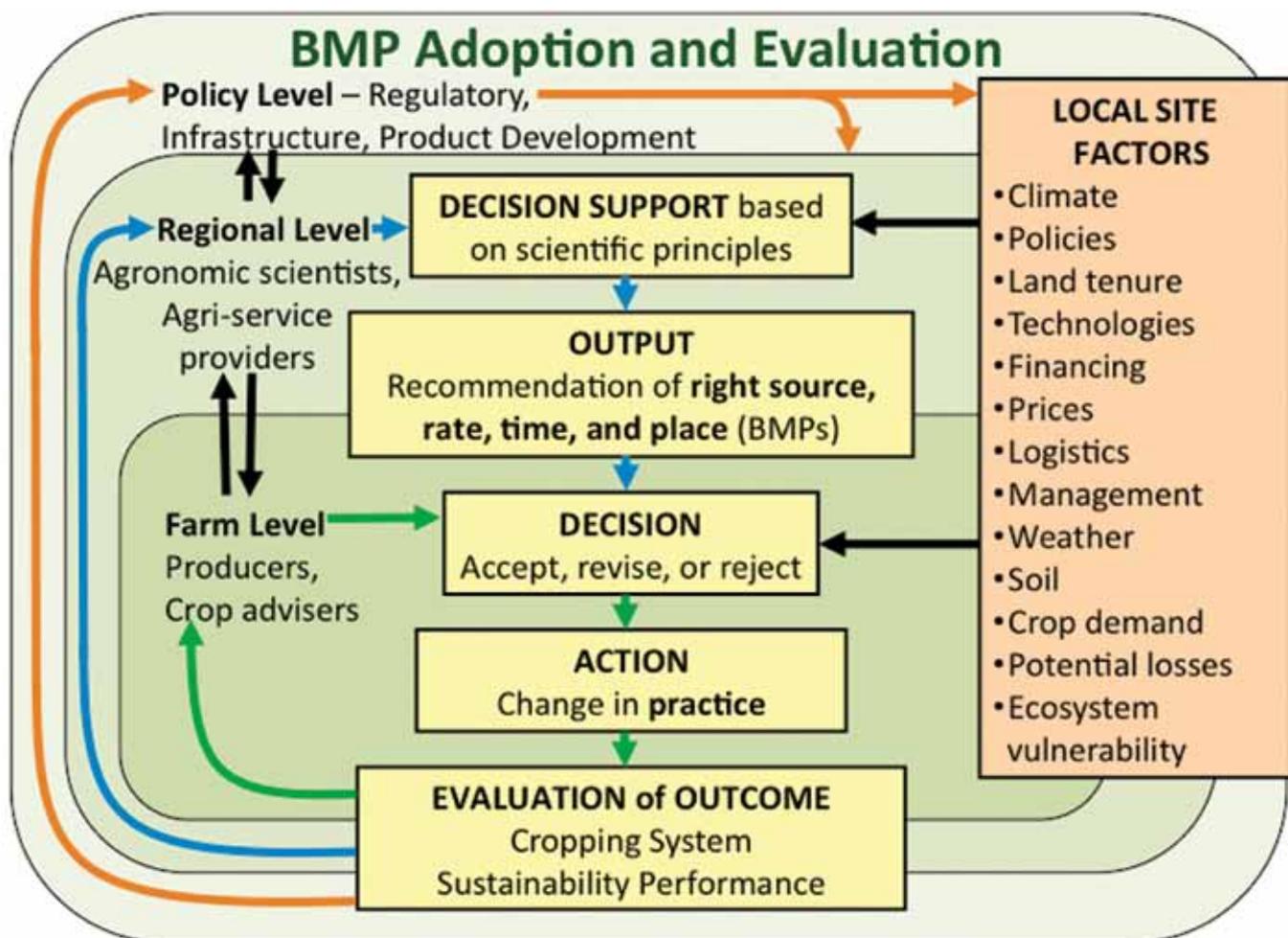
At the regional level, agri-service providers make decisions on the nutrient sources (products) they will offer and on the logistics of how they can be delivered at the right time to the farm or to the field. Industry agronomists interact with producers and crop advisers to implement and interpret on-farm trials that aid in the evaluation of selected practices.

At the policy level (often a national or global level), manufacturers, investors and governments make decisions on product development, and investments in production facilities and transportation infrastructure. These decisions influence the range of source and time options available to producers.

All three levels need to be consistent in the goals against which they evaluate outcome. Source, rate, time and place are central to all, but it's the full framework that we mean when we talk about 4R Nutrient Stewardship, or the 4Rs.

### Accountability

Systems for sustainability improvement and certification generally require accountability. Accountability at the farm level often requires a nutrient management plan. The



**Figure 2.** The 4Rs are included in adaptive management to take into account local site-specific factors in cycles of continuous improvement at farm, regional and policy levels.

general principles that make a 4R Nutrient Stewardship plan distinct from a regulatory nutrient management plan are: 1) asking the producer to state sustainability goals and performance indicators for the farm, 2) allowing producers flexibility to implement adaptive management by ensuring that the details of practices implemented for each crop and in each field are documented but kept private, and 3) publicly reporting progress in using indicators or measures of performance reflecting the economic, social and environmental pillars of sustainability. These principles are at the core of a management system consistent with international principles of accountability for sustainability performance.

### Example – Managing Phosphorus Fertilizer in the Lake Erie Watershed

Phosphorus (P) is an essential nutrient for growing crops. But in the wrong place – in excess concentration in streams, rivers, and lakes – it can lead to algal blooms. In the Lake Erie watershed region in and around the state of Ohio, USA, levels of dissolved P in rivers and algal blooms in lakes have been trending upward from 1995 to 2011. Fertilizers applied to the predominant corn-soybean cropping system are not the only cause, but are one possible cause among many.

Research data show that when fertilizer P is broadcast and left on the surface, runoff resulting from rainstorms within a few days of application is enriched in dissolved P to levels far above those known to stimulate algal blooms, even though the losses amount to less than 5 to 10 percent of the fertilizer P applied. To mitigate these losses, 4R Nutrient Stewardship implemented in this region focuses on applying fertilizer at the “right time” and in the “right place.” Wherever possible, fertilizer P is recommended to

be placed below the soil surface, by injecting, banding, or by incorporating after broadcasting. Where incorporation is difficult, for example in no-till systems, producers are advised to pay close attention to the weather forecast, and avoid broadcasting P fertilizer when there is more than 50% chance of intense rain within the next few days.

A group of agri-business partners, government agencies and environmental organizations is working together to provide educational programs and raise awareness of how nutrient stewardship can contribute to reducing losses of dissolved P. This group includes The Nature Conservancy, the Ohio Agri-Business Association, the Ohio government departments of agriculture and natural resources, Ohio State University Extension, and several agri-retailers and crop producers. Further work is ongoing to develop better validated criteria for selecting practices, based on research monitoring actual edge-of-field losses. Further information on the program is available from The Nature Conservancy. By supporting management that is adaptive and addressed at economic and environmental goals at the same time, 4R Nutrient Stewardship assures continued progress in advancing crop yields in this highly productive watershed.

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## Visual Indicators of Potassium Deficiency in Corn

T.S. Murrell

*While marginal chlorosis and necrosis are the most widely recognized symptoms of K deficiency, they are not the only ones. Other plant manifestations can exist and may or may not be accompanied by marginal chlorosis or necrosis. As the number of visible symptoms increases, there is greater likelihood that the plant is experiencing a K deficiency.*

The most widely recognized visual expression of K deficiency is marginal chlorosis or necrosis on older, lower leaves on the plant, such as that shown in the accompanying photo. By the time this symptom appears, however, grain yield may have already been lost (Bly et al., 2002). Although this sign is the most well known, it is not the only visual indicator of K deficiency, as this can be also evidenced by many other visual manifestations that can occur, either with or without marginal necrosis, and with severity that varies considerably within a field. As the

number of visible symptoms increases, there is greater likelihood that the plant is experiencing a K deficiency. This article lists these additional evidences along with some key references. Seeing some of these indicators can be difficult, however, without a reference area in the field where K is known to be sufficient. Such an area can be created with an ample application of K that is replenished over time to keep up with the K removed by successive crop harvests.

### Shorter Plants

It has been known for many years that K deficiency can result in shorter plants. Younts and Musgrave (1958) demonstrated this effect decades ago in two

Abbreviations and notes for this article:  
GDD = growing degree days; K = potassium;  
N = nitrogen.

field studies examining different K rates, sources, and placement methods. Across all factors, they found that K fertilization significantly ( $p = 0.05$ ) increased plant heights by 11 to 28%, 10 to 12%, 9 to 16%, and 15 to 36% when measured at 26, 31, 44, and 65 days after planting, respectively.

### Reduction in Leaf Dimensions and Surface Area

A measurement quantifying relative differences in leaf area is the leaf area index, or LAI. Leaf area index is the ratio of leaf area to a given unit of land surface area (Watson, 1947). Jordan-Meille and Pellerin (2004) found that corn plants that were deficient in K had a lower LAI than healthy plants. Most of the leaves of K deficient corn plants were narrower and shorter than leaves of K sufficient plants, reducing their overall surface area (**Figure 1**). Leaf numbers 5-7 were most affected by K deficiency and showed reductions in length of approximately 25%. Similar reductions were observed for leaf width, resulting in a nearly 50% reduction in total leaf area. Leaves emerging earlier or later in the season were less affected. For example, leaf numbers 17-20 had lengths, widths, and surface areas equal to or greater than K sufficient plants. Even though these later-developed leaves had larger surface areas, increases were not great enough to compensate for the reductions coming from the older leaves, leading to an overall decrease in LAI.

### Slowed Vegetative Development

Potassium deficiency can also delay corn development. At all sampling periods, Jordan-Meille and Pellerin (2004) measured a slight but significant reduction in the number of visible and fully expanded leaves in K deficient plants. The maximum difference occurred when 15 leaves were visible in K sufficient plants. At this time, K deficient plants had 0.8 visible leaves less than K sufficient ones, indicating a delay in growth of nearly one vegetative stage. In an earlier greenhouse study, Koch and Estes (1975) reported no



**Marginal chlorosis** and necrosis on lower, older leaves – a visual symptom of K deficiency. The stake indicates zero K treatment.

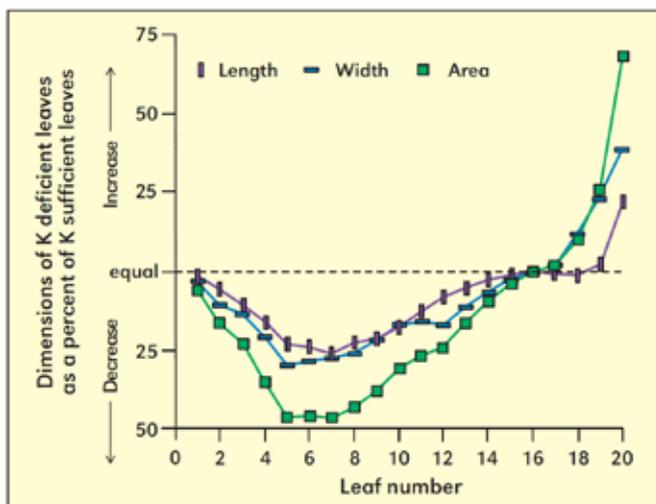
delay in the number of fully expanded leaves up to the end of their sampling period, which was leaf 11. These results are not necessarily inconsistent with those of Jordan-Meille and Pellerin (2004), since their maximum delay in maturity was less than one leaf and they reported visible, rather than fully expanded leaves.

### Delayed Tasseling

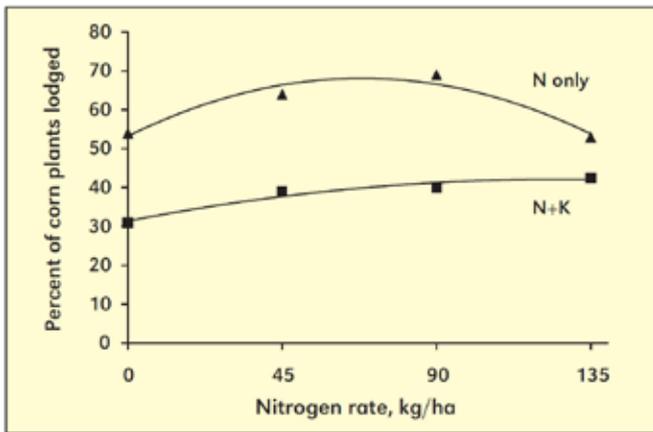
Corn plants with insufficient K may take longer to reach the VT growth stage (tasseling) than plants with sufficient K. Peaslee et al. (1971) found that unfertilized, K deficient plants sown early in the season took 84 growing degree days (GDD) longer to reach VT than plants well supplied with K. Unfertilized corn planted later took 53 GDD longer to reach VT. Younts and Musgrave (1958) made a similar observation at 65 days after planting in one of their experiments, where K fertilization significantly ( $p = 0.05$ ) increased the percent-age of plants that had reached VT by 8 to 16%. However, in their other experiment, K fertilization did not produce any significant increase in percent of plants tasseled. Conversely, one of their treatments, a 135 kg/ha (120 lb/A) rate of  $K_2O$  applied as KCl, caused a significant ( $p = 0.05$ ), 16% decrease in percent of plants reaching VT when sampled 61 days after planting. So while a delay in tasseling is possible, it may not be a consistent result.

### Delayed Silking

Like tasseling, crop development to silking (R1) may also be delayed by K deficiency. Younts and Musgrave (1958) observed that maize fertilized with K exhibited



**Figure 1.** Leaf dimensions (length and width) and surface areas of K deficient leaves, expressed as a percentage of the leaf dimensions and surface areas of K sufficient leaves (Jordan-Meille and Pellerin, 2004).



**Figure 2.** Percent of lodged corn as a function of N rate with and without K. Response to K was averaged over the 45 and 90 kg/ha (40 and 80 lb/A)  $K_2O$  rates (Fisher and Smith, 1960).

significant ( $p = 0.05$ ) increases in percentages of plants that had reached R1 at 69 to 73 days after planting, depending on the experiment. These increases ranged from 8 to 34%.

### Increased Lodging

Lodging in corn may result from disease, insect damage, poor plant development arising from K deficiency, or a combination of these factors.

Lodging caused by poor plant development arising from K deficiency was demonstrated by Liebhardt and Murdock (1965). In their research, they found that K deficiency led to a hastening of parenchyma cell (pith) breakdown in brace roots and caused parenchyma cell disintegration in the stalk. Poorly developed brace roots, observable in the field, led to “root lodging” which occurred earlier in the season, after R1. Parenchyma cell disintegration in the stalk led to “stalk breakage” which occurred later, during the dent stage (R5).

No disease in the stalk was observed until crop maturity (R6), when stalk parenchyma tissue had already significantly disintegrated. Boswell and Parks (1957) demonstrated that hybrids differed in their susceptibility to root lodging and stalk breakage. However, regardless of susceptibility, low soil supplies of K increased root lodging and stalk breakage by an average of 12%.

Stalk breakage was shown to be related to the ratio

of N:K elemental concentrations in the stalk when K concentrations were low. Parenchyma cell breakdown was observed when N was 3 to 4 more times concentrated in the stalk than K (Liebhardt and Murdock, 1965).

Fisher and Smith (1960) isolated the effects of N and K on lodging and found that lodging incidence increased when N was applied without K on a low K testing soil (Figure 2), consistent with the results of Liebhardt and Murdock (1965). Lodging can also be caused by fungal diseases and K deficiency has been shown to increase the severity of them. In a recent review, Prabhu et al. (2007) catalogued three stalk rot pathogens (*Fusarium moniliforme*, *Gibberella zeae*, and *Diplodia zeae*) to which corn had greater susceptibility when deficient in K.

### Summary

While marginal leaf chlorosis and necrosis are the most well known visual signs of K deficiency, there are other indicators of K shortage exhibited by corn. Although not complete, several delays or changes in plant development have been listed here to assist farmers and crop advisers as they make observations in the field. Detecting these delays and changes can be difficult without a reference area that is known to have an adequate supply of K. It is therefore suggested that such an area be established and maintained over time to provide a basis for comparison.

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# Does Potassium or Chloride Play a Dominant Role in Suppression of Corn Stalk Rot?

Ji-yun Jin, Xiaoyan Liu, and Ping He

*Corn stalk rot is a serious and widespread disease in the main corn production areas of China. Previous research has indicated that KCl plays a significant role in suppression of corn stalk rot. This study compared the effects of K and Cl nutrition, and showed that K played an important role in the suppression of the disease.*

**S**talk rot is a disease of increasing importance to corn production in China. The average annual yield loss in China due to stalk rot infection is approximately 20% and in individual fields may reach 50%. Potassium has long been the nutrient most associated with plant disease reduction. Potassium fertilizer application is one of the few effective measures to suppress corn stalk rot. A 12-year fixed site field trial in Jilin Province showed that KCl application decreased the incidence of corn stalk rot by 48% (Liu et al., 2007). However, insufficient attention has been paid to the question of which element in KCl plays the dominant role in the suppression of corn stalk rot...an inadequacy addressed by this research.

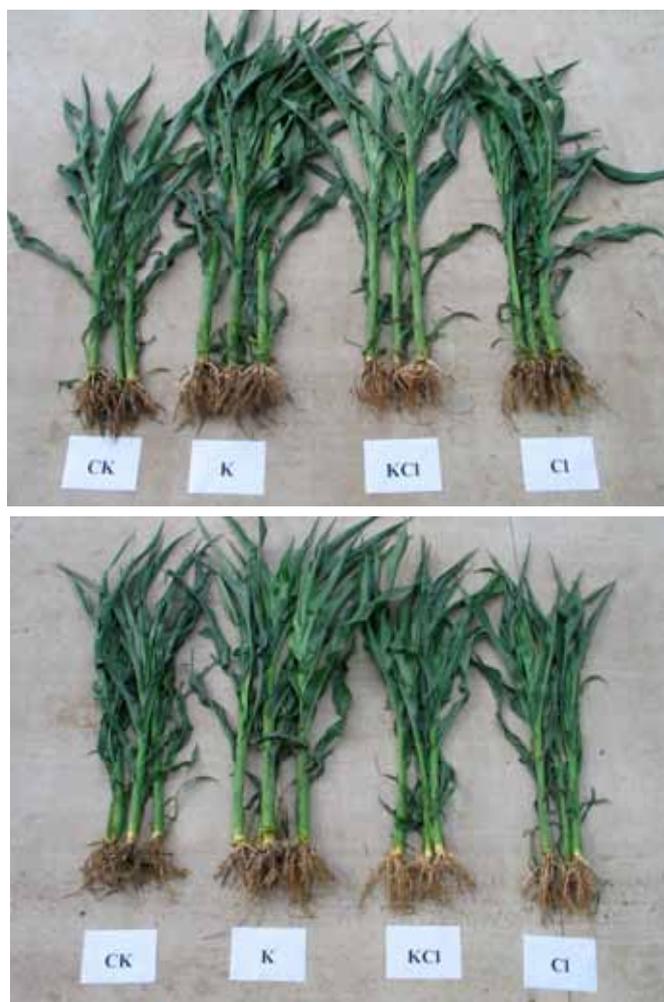
Jilin is designated the “Corn Belt” of China due to its top ranking in annual sown area (Jia, 2004). A field experiment was conducted in the Gongzhuling region of Jilin in 2005 using a set of treatments consisting of a check (CK) and six combinations of K and Cl (K120, K240, K120Cl90, K240Cl180, Cl90, and Cl180) laid out in a randomized complete block design with four replicates. All treatments had equal applications of N and P. Plot area was 40 m<sup>2</sup>. Soil pH and nutrient status at the 0 to 20 cm depth are shown in **Table 1**. Available nutrients in the soil were determined by ASI soil analysis methods (PPI/PPIC Beijing Office, 1992). Based on soil test results, applications of S, Zn, and Cu were done before sowing, at rates of 20, 10, and 1.0 kg/ha, respectively. Since soil Ca concentration was abundant and crops in the region have not responded to Ca fertilization, CaCl<sub>2</sub> was used to evaluate the effect of Cl on corn yield and disease severity. Potassium chloride was used to study the combined effect of K and Cl. Potassium nitrate was used to study the effect of K alone. The amounts of fertilizer used in the treatments are given in **Table 2**. The study used two commercial corn hybrids including Jidan 180, which is moderately resistant to stalk rot, and Jidan 327, which is considered susceptible to stalk rot. The plant density was 50,000 plants/ha. The incidence of corn stalk rot was investigated prior to harvest.

The treatment created obvious differences in growth between resistant and susceptible varieties at plant jointing stage (see photos). Prior to harvest of both varieties, significant reductions in stalk rot incidence, as well as yield increases, occurred in response to K and KCl, but not to Cl alone (**Table 3**). All K and KCl treatments reduced disease severity by 50 to 64%, and increased yield by 13 to 23% in Jidan 327. In Jidan 180, stalk rot was decreased by 44 to 60% and yield was increased by 20 to 29% compared to the CK. Thus, stalk

rot was more effectively suppressed in the susceptible variety, but yield was enhanced to a larger degree with the resistant variety.

No significant differences in disease incidence and yield were observed between the two fertilization rates of KCl and Cl. Stalk rot was reduced with the addition of K, regardless of source.

For Jidan 180, when K (as KNO<sub>3</sub>) application increased from 120 to 240 kg/ha, stalk rot incidence was unaffected, but grain yield decreased. The degree of yield loss in other K and KCl supplying treatments



Effects of K, Cl and KCl on the growth of Jidan 180 (top) and Jidan 327 (bottom) corn hybrids at jointing stage.

Abbreviations and notes for this article: K= potassium; Cl = chloride; KCl = potassium chloride; KNO<sub>3</sub> = potassium nitrate; K<sub>2</sub>SO<sub>4</sub> = potassium sulfate; S = sulfur; Zn = zinc; Cu = copper; Ca =calcium; N = nitrogen; P = phosphorus; ASI = Agro Services International.

**Table 1.** Initial soil characteristics at the experimental site, Jilin.

OM, %	N-NH <sub>4</sub>	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Cl	pH <sub>H2O</sub>
	mg/kg			g/kg			mg/kg						
2.4	8.6	5.9	42.4	3.0	0.4	12.9	1.8	102.5	12.8	2.7	1.0	30.2	5.8

**Table 2.** Nutrient application rates for the set of treatments.

Treatment	Ca(NO <sub>3</sub> ) <sub>2</sub>	Ca(H <sub>2</sub> PO <sub>4</sub> ) <sub>2</sub>	KNO <sub>3</sub>		KCl		CaCl <sub>2</sub>
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	K <sub>2</sub> O	Cl	Cl
CK	200	120	-	-	-	-	-
+ K <sub>120</sub>	158	120	120	43	-	-	-
+ K <sub>240</sub>	114	120	240	86	-	-	-
+ K <sub>120</sub> Cl <sub>90</sub>	200	120	-	-	120	91	-
+ K <sub>240</sub> Cl <sub>180</sub>	200	120	-	-	240	182	-
+ Cl <sub>90</sub>	200	120	-	-	-	-	91
+ Cl <sub>180</sub>	200	120	-	-	-	-	182



**The corn leaves** in the left rows received no K fertilizer and appeared dull gray-green, while the leaves in the right rows with K application were still green.

may have been partially influenced by stalk rot incidence, but it appears nutrient imbalance may have exerted a larger effect. Ash and Brown (1991) found a similar result showing that increased disease did not correlate with yield losses, but N fertilizer application rate had a large influence on the yield-loss relationship.

For both varieties, 120 kg K<sub>2</sub>O/ha seemed most appropriate, and 240 kg K<sub>2</sub>O/ha excessive, to maintain

high yields at this site. No positive interactions between K and Cl were detected at the 120 kg/ha rate, but there was evidence that Cl may help to moderate the yield-dampering effects of the 240 kg K<sub>2</sub>O/ha rate applied to Jidan 180.

Heckman (1998) found that the incidence of corn stalk rot was 67% lower with KCl application, compared to K<sub>2</sub>SO<sub>4</sub> application at an equivalent K rate. This result suggests that Cl played an important role in the suppression of the disease. In contrast, this research indicates that Cl plays a less important role in stalk rot suppression than K. This inconsistency may be due to differences in nutrient status of the test soils. Sanogo and Yang (2001) reported that soil amendment with KCl when the soil was not deficient in K resulted in 36% decrease in the severity of soybean sudden death syndrome (SDS), a soil-born disease. Conversely, disease severity was increased by 43% with K<sub>2</sub>SO<sub>4</sub> application, and by 45% with KNO<sub>3</sub>, compared to the study's controls. Thus, Cl was helpful in reducing SDS and K application was not found beneficial. A comparison of the available K concentration (0 to 20 cm depth) between this research and Heckman's U.S. study finds the initial K fertility in the U.S. study to be 92 mg/kg, which is over twice the level measured in this work (Table 1). Additionally, soil Cl in the 0 to 30 cm soil layer was only 6 mg/kg (low) in Heckman's experiment, while this study's soil Cl concentration in 0 to 20 cm layer was 30 mg/kg. Therefore, under conditions of

**Table 3.** Effects of K and Cl- on the stalk rot incidence and yield of corn.

Treatment	Jidan 180				Jidan 327			
	Disease incidence, %	Disease control, %	Yield, kg/ha	Yield increase, %	Disease incidence, %	Disease control, %	Yield, kg/ha	Yield increase, %
CK	24.6 a <sup>1</sup>	-	7114 c	-	34.1 a	-	6925 c	-
K <sub>120</sub>	13.7 b	44.4	9162 a	28.8	17.1 b	50.0	8544 a	23.4
K <sub>240</sub>	12.4 b	49.6	8546 b	20.1	12.3 b	63.8	7839 ab	13.2
K <sub>120</sub> Cl <sub>90</sub>	10.8 b	55.9	8615 ab	21.1	13.8 b	59.7	8164 a	17.9
K <sub>240</sub> Cl <sub>180</sub>	9.9 b	59.8	9050 ab	27.2	12.4 b	63.6	8252 a	19.2
Cl <sub>90</sub>	17.1 ab	30.3	7373 c	3.6	31.8 a	6.8	6340 c	-8.5
Cl <sub>180</sub>	17.3 ab	29.8	7166 c	0.7	30.4 a	10.8	6509 c	-6.0

<sup>1</sup>Means within a column followed by different letters are significantly different (LSD Test, p<0.05).



**Stalk lodging** and ear dropping are the typical symptoms of corn stalk rot. Stalk rot in plots without K application (left) was more severe than that with K application (right) in September.

soil K deficiency and Cl sufficiency, the influence of K nutrition on corn stalk rot was much more strongly pronounced than the influence of Cl. Apparently the result is opposite under soil K sufficiency and Cl deficiency.

In conclusion, the role of K and Cl in disease suppression must be examined in conjunction with the soil nutrient status. Therefore, whether K or Cl play the dominant role in corn stalk suppression will depend on the K and Cl status of the soil. A well-balanced fertilization strategy is necessary for both yield increases and disease control.

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## Visual Indicators of Potassium Deficiency in Corn



# Impact of Potassium Nutrition on Food Quality of Fruits and Vegetables: A Condensed and Concise Review of the Literature

Gene E. Lester, John L. Jifon, and Donald J. Makus

*Among the many plant mineral nutrients, K stands out as a cation having the strongest influence on quality attributes that determine fruit marketability, consumer preference, and the concentration of critically important human health-associated phytonutrients. However, many plant, soil, and environmental factors often limit uptake of K from the soil in sufficient amounts to satisfy fruit K requirements during development to optimize the aforementioned quality attributes. This was demonstrated in a study reported in this publication in 2007 (Lester et al., 2007) where foliar K markedly improved several cantaloupe fruit quality parameters, despite sufficient soil test K levels. This article expands on the previously reported work from the Rio Grande Valley of Texas by providing a review of published study abstracts on the effects of soil and/or foliar K fertilization on several fruit and vegetable quality characteristics, including phytonutrient concentrations.*

Potassium is an essential plant mineral element (nutrient) having a significant influence on many human-health related quality compounds in fruits and vegetables (Usherwood, 1985). Although K is not a constituent of any organic molecule or plant structure, it is involved in numerous biochemical and physiological processes vital to plant growth, yield, quality, and stress (Marschner, 1995; Cakmak, 2005). In addition to stomatal regulation of transpiration and photosynthesis, K is also involved in photophosphorylation, transportation of photoassimilates from source tissues via the phloem to sink tissues, enzyme activation, turgor maintenance, and stress tolerance (Usherwood, 1985; Doman and Geiger, 1979; Marschner, 1995; Pettigrew, 2008). Adequate K nutrition has also been associated with increased yields, fruit size, increased soluble solids and ascorbic acid concentrations, improved fruit color, increased shelf life, and shipping quality of many horticultural crops (Geraldson, 1985; Lester et al., 2005, 2006, 2007; Kanai et al., 2007).

Even though K is abundant in many soils, the bulk of soil K may be unavailable to plants, in part, because the pool of plant-available K is much smaller compared to the other forms of K. Potassium exists in several forms in the soil, including mineral K (90 to 98% of total), nonexchangeable K, exchangeable K, and dissolved or solution K ( $K^+$  ions), and plants can only directly take-up solution K (Tisdale et al., 1985). Uptake in turn depends on numerous plant and environmental factors (Tisdale et al., 1985; Marschner, 1995; Brady and Weil, 1999). For instance, adequate soil moisture supply is necessary to facilitate diffusion of K (which usually accounts for > 75% of K movement) to plant roots for uptake. Mass flow, which also accounts for some soil K transport, also requires sufficient water in the soil. Skogley and Haby (1981) found that increasing soil moisture from 10 to 28% more than doubled total soil K transport. Therefore, soil moisture deficits can limit soil K transport as well as uptake into the plant, thereby causing K deficiency.

Soil properties also have a strong influence on K availability. For instance, clay soils may have high K-fixing capacities and thus can show little response to soil-applied K fertilizers because much of the available K



**Dr. Lester** checks on muskmelon plants in a glasshouse experiment. Fine-tuning plant nutrition practices is an important consideration for improving fruit quality (inset).

quickly binds to clays (Tisdale et al., 1985; Brady and Weil, 1999). Such K retention can help reduce leaching losses and be beneficial in the long-term as storage reservoirs of K for subsequent crops. Sandy soils, on the other hand usually have a low K-supplying power because of low cation exchange capacity.

Calcareous soils tend to have high concentrations of calcium ions ( $Ca^{2+}$ ) that dominate clay surfaces and other exchange sites. Even though this can limit K sorption and increase solution K, high concentrations of cationic nutrients...particularly  $Ca^{2+}$  and magnesium ( $Mg^{2+}$ )... tend to limit K uptake by competing for binding sites on root surfaces. Consequently, crops grown on highly calcareous soils can show K-deficiency symptoms even though the soil test may report sufficient K (Havlin et al., 1999).

Potassium uptake also depends on plant factors, including genetics and developmental stage (vegetative versus reproductive stages; Rengel et al., 2008). In many fruiting species, uptake occurs mainly during vegetative stages, when ample carbohydrate supply is available

**Table 1.** Review of published abstracts on the influence of K: effects by crop, K application, and K form on fruit attributes.

Crop	K application	K form <sup>a</sup>	Attributes (improved) <sup>b</sup>	Reference <sup>c</sup>
Apple ( <i>Malus X domestica</i> )	Soil	KCl	Color, firmness, sugar;	Nava (2009)
		K <sub>2</sub> SO <sub>4</sub>	Size, color, firmness, sugars;	El-Gazzar (2000)
		K <sub>2</sub> SO <sub>4</sub>	Wt. yield, firmness, sugars	Attala (1998)
Apple	Foliar	Unknown	Size, color, firmness, sugars;	Wojcik (2005)
		KCl	No change	Hassanloui (2004)
Banana ( <i>Musa sp.</i> )	Soil	Unknown	Quality;	Naresh (1999)
		KCl	Size, sugars, acid	Suresh (2002)
Citrus ( <i>Citrus sinensis</i> )	Foliar	KCl, KNO <sub>3</sub>	No change	Haggag (1990)
		Unknown	Yield, quality;	Dutta (2003)
		K <sub>2</sub> SO <sub>4</sub>	Quality	Shawky (2000)
Citrus ( <i>Citrus reticulata</i> )	Soil	Unknown	Yield, quality;	Lin (2006)
		Unknown	Quality, shelf-life	Srivastava (2001)
Citrus ( <i>Citrus reticulata</i> )	Foliar	KCl > KNO <sub>3</sub>	Peel thickness, quality	Gill (2005)
Cucumber ( <i>Cucumis sativus</i> )	Soil	K <sub>2</sub> SO <sub>4</sub> > KCl	Amino acids, quality;	Guo (2004)
		KCl	No change	Umamaheswarappa (2004)
Cucumber	Foliar	KCl > KNO <sub>3</sub>	"Quality", disease tolerance	Magen (2003)
Grape ( <i>Vitis vinifera</i> )	Soil	K <sub>2</sub> SO <sub>4</sub>	"Quality", sensory	Sipiora (2005)
Guava ( <i>Psidium guajava</i> )	Soil	Unknown	Yield, weight, "quality"	Ke (1997)
Guava	Foliar	K <sub>2</sub> SO <sub>4</sub> > KCl	Acidity, "quality"	Dutta (2004)
iwifruit ( <i>Actinidia deliciosa</i> )	Soil	K <sub>2</sub> SO <sub>4</sub> > KCl	Firmness, acid, grade	He (2002)
Litchi ( <i>Litchi chinensis</i> )	Foliar	KNO <sub>3</sub>	Weight., yield,	Ashok (2004)
Mango ( <i>Mangifera indica</i> )	Soil	KNO <sub>3</sub>	No change	Simoes (2001)
Mango	Foliar	KNO <sub>3</sub>	No effect;	Rebolledo-Martinez (2008)
		Unknown	Texture, flavor, color shelf-life	Shinde (2006)
Muskmelon ( <i>Cucumis melo</i> )	Soil	Unknown	Yield	Demiral (2005)
Muskmelon	Foliar	Gly-amino-K;	Firmness, vitamins;	Lester (2005)
		Gly-amino-K; > KCl	Firmness, sugars, vitamins;	Lester (2006)
		Gly-amino-K; = K <sub>2</sub> SO <sub>4</sub> > KCl > KNO <sub>3</sub>	Firmness, vit. sugars, yield, marketable fruit	Jifon (2009)
Nectarine ( <i>Prunus persica</i> )	Soil	Unknown	Firmness, shelf-life, reduced cracking	Zhang (2008)
Okra ( <i>Abelmoschus esculentus</i> )	Foliar	Naphthenate-K	Chlorophyll, protein, carotene	Jahan (1991)
Passionfruit ( <i>Passiflora edulis</i> )	Hydroponics	K <sub>2</sub> SO <sub>4</sub>	Yield, seed number, "quality"	Costa-Araujo (2006)
Papaya ( <i>Carica papaya</i> )	Soil	Unknown	Weight, sugars, "quality"	Ghosh (2007)
Pears ( <i>Pyrus communis</i> )	Soil	K <sub>2</sub> SO <sub>4</sub>	No change	Johnson (1998)
Phalsa ( <i>Grewia subinaequalis</i> )	Foliar	K <sub>2</sub> SO <sub>4</sub>	Size, weight, "quality"	Singh (1993)
Pepper ( <i>Capsicum annum</i> )	Soil	KCl	Little change;	Hochmuth (1994)
		K <sub>2</sub> SO <sub>4</sub>	Pungency, "quality";	Ananthi (2004)
		K <sub>2</sub> SO <sub>4</sub> > KNO <sub>3</sub>	Pungency, yield, weight;	Golcz (2004)
		K <sub>2</sub> SO <sub>4</sub>	"Quality"	El-Masry (2000)
Pepper	Hydroponics	KNO <sub>3</sub>	No change	Flores (2004)
Pineapple ( <i>Ananas comosus</i> )	Soil	KCl	Vit. C, and reduced internal browning	Herath (2000)
Pomegranate ( <i>Punica granatum</i> )	Foliar	K <sub>2</sub> SO <sub>4</sub> > KCl	Growth, yield, "quality"	Muthumanickam (1999)
Strawberry ( <i>Fragaria X ananassa</i> )	Soil	KCl	No change	Albregts (1996)
	Fertigation	KCl > KNO <sub>3</sub>	"Quality"	Ibrahim (2004)
Strawberry	Hydroponics	K <sub>2</sub> SO <sub>4</sub>	Yield, total quality	Khayyat (2007)
Tomato ( <i>Lycopersicon esculentum</i> )	Soil	KCl	Lycopene;	Taber (2008)
		K <sub>2</sub> SO <sub>4</sub>	"Quality"	Si (2007)
		K <sub>2</sub> SO <sub>4</sub>	Yield, earliness, quality	Hewedy (2000)

**Table 1.** Review of published abstracts on the influence of K: effects by crop, K application, and K form on fruit attributes (continuation).

Crop	K application	K form <sup>a</sup>	Attributes (improved) <sup>b</sup>	Reference <sup>c</sup>
Tomato	Fertigation/soiless	KCl > KNO <sub>3</sub>	Appearance, quality;	Chapagain (2003)
		KCl > KNO <sub>3</sub>	Yield, "quality";	Chapagain (2004)
		K <sub>2</sub> SO <sub>4</sub>	Carotenoids, vit.E,	Fanasca (2006)
		Unknown	Antioxidants;	Li (2006)
		Unknown	Lycopene; "quality"	Yang (2005)
Tomato	Foliar	Unknown	Growth, protein, vit. C, sugar, acid	Li (2008)
Vegetables	Soil	K <sub>2</sub> SO <sub>4</sub> > KCl	Dry weight., vitamin C	Ni (2001)
Watermelon ( <i>Citrullus lanatus</i> )	Soil	KCl	No change	Locascio (2002)
		KCl	No change	Perkins-Veazie (2003)

<sup>a</sup>Sources from different studies are separated by a semi-colon; K form attributing to improved quality greater than another K form is indicated by the > symbol.

<sup>b</sup>Attributes from different studies are separated by a semicolon. The word "quality" indicates the authors listed no specific attributes, or the attributes were too numerous to list.

<sup>c</sup>References from different studies are separated by a semi-colon, and only first author names are listed for brevity.

for root growth and uptake processes. Competition for photoassimilates between developing fruits and vegetative organs during reproductive growth stages can limit root growth/activity and K uptake. Under such conditions, increasing soil K fertilization may not be enough to alleviate this developmentally-induced deficiency partly because of reduced root growth/activity during reproductive development and also because of competition from other cations for binding sites on roots (Marschner, 1995).

A study reported in this magazine and elsewhere (Lester et al., 2005, 2006, 2007) showed that foliar K improved cantaloupe fruit marketable quality by increasing firmness and sugar content, and fruit human health quality by increasing ascorbic acid, beta-carotene, and K levels in a soil that tested high in K. Nevertheless, there remains confusion in the literature regarding the benefit of K fertilization due to different K sources, soil vs. foliar applications, the environment (season), and timing and frequency of application. This review summarizes some of the published abstracts on K fertilization of several fruit crops, with special attention given to the effectiveness of various K fertilizer sources, and soil vs. foliar application on fruit quality.

### Fruit Studies Comparing K Sources

Although many examples have been reported on the positive effects of K fertilization improving fruit



disease control, yield, weight, firmness, sugars, sensory attributes, shelf-life, and human bioactive compound concentrations, the scientific literature also contains examples of studies with conflicting results of the beneficial effects of K fertilization on fruit quality (Table 1). These conflicting results cannot be resolved, but they can be explained by differences in modes of fertilization (e.g., soil vs. foliar, fertigation or hydroponic applied), and differences in sources of K fertilizer (e.g. KCl, K<sub>2</sub>SO<sub>4</sub>, KNO<sub>3</sub>, Glycine-complexed K).



A review of published abstracts spanning the last 20 years is shown in Table 1. The vast majority of the papers reviewed showed that K fertilization had an effect on some crop quality attribute. However, eight particular studies [apple, (Hassanloui, et al., 2004); cucumber, (Umamaheswarappa and Krishnappa, 2004); mango, (Rebolledo-Martinez et al., 2008); pear, (Johnson et al., 1998); bell pepper, (Hochmuth et al., 1994); strawberry, (Albregts et al., 1996); and watermelon, (Locascio and Hochmuth, 2002; Perkins-Veazie et al., 2003)] stand out because of their conclusions: there is 'little or no change' (i.e. improvement) in fruit quality due to K fertilization. Interestingly, except for the apple study, these studies have a common denominator in that K was applied directly to the soil and in many cases little information was given regarding timing of application or soil chemical and physical properties. These factors can influence soil nutrient availability and plant uptake, and soil fertilizer

K additions under some conditions may have little or no effect on uptake, yield, and fruit quality (Tisdale et al., 1985; Brady and Weil, 1999).

In a number of studies involving several fruiting crops (e.g. cucumber, mango, and muskmelon) where soil-applied fertilizer K was compared to foliar K applications, the latter approach consistently resulted in improved fruit quality attributes. On the other hand, soil applications generally had little or no effects (Demiral and Koseoglu, 2005; Lester et al., 2005, 2006; Jifon and Lester, 2009; **Table 1**).

Furthermore, in studies where several fertilizer K salts were evaluated, fruit quality improvements appeared to depend on K source. For instance, Jifon and Lester (2009) showed that when mid-to-late season soil or foliar K applications were made using  $KNO_3$ , there were little or no improvements in fruit marketable or human-nutritional quality attributes and in some instances, these attributes were actually inferior compared to fruit from control plots.

This article demonstrates that when making K fertilization decisions, the practitioner should be aware that soil test data alone might not be sufficient to make the best decisions. Soil test information is certainly important and useful in decision-making, but accounting for other factors such as timing, crop demand dynamics, and source are all important as well. High soil K level alone does not always guarantee there will be no response to K fertilizer. Moreover, where there is a high demand for K during fruit development foliar K can improve several fruit quality attributes.

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## How Potassium Nutrition Can Suppress Soybean Aphids

Tom Bruulsema, Christina DiFonzo, and Claudio Gratton

*The soybean aphid has become the most important insect pest of soybeans in the Northeast and Midwest regions of North America. It often damages soybean plants that are K-deficient more than those that are not. Recent research in Wisconsin and Michigan has found that K-deficient soybeans can in some, but not all, instances suffer more from aphids than soybeans without K limitation, and that the causes may be related to amino acid composition of the phloem sap.*

The soybean aphid, *Aphis glycines* Matsumura, is an invasive species that was first discovered in the United States in 2000. On-farm visits and observations in Wisconsin and Michigan indicated that many of the soybean fields most heavily infested with soybean aphids were also exhibiting symptoms of K

deficiency. This article summarizes results from recent research conducted to examine the association between

Abbreviations and notes: K = potassium; P = phosphorus; N = nitrogen; S = sulfur; ppm = parts per million; CEC = cation exchange capacity.

**Table 1.** Soybean leaf K and yield increased with increasing soil test K in a field experiment in Arlington, Wisconsin (means of 2 years, 2001-2002; adapted from Myers et al., 2005).

Soil test K <sup>1</sup> , ppm	Soybean yield, %	Soybean yield, bu/A	
		Sprayed	Unsprayed
60	0.76	33	26
93	1.20	47	38
114	1.43	52	41

<sup>1</sup>Soil test K in Wisconsin is by the Bray-1 extractant. Values below 80 and above 100 are considered low and high, respectively.



**Close-up** photo of an individual aphid (*Aphis glycines* Matsumura).

aphids and K, in order to determine the appropriate role of plant nutrition in the management of the aphid pest.

### Wisconsin, 2001-2002

In a controlled field experiment in which K fertilizer had been applied at different levels, soybean leaf K and yield increased with increasing soil test K (**Table 1**), but no differences were observed in aphid populations (Myers et al., 2005). Repeated foliar insecticide sprays reduced aphid populations and increased yields, but there was no interaction between spray and K on either parameter.

Yet, aphid populations were very high in both years in this experiment, substantially higher than those in farm fields. For example, in 2002 peak abundance in the unsprayed plots eclipsed 1,600 aphids per plant, compared to an average peak abundance of 280 in a survey of southern Wisconsin fields. It is possible that owing to the close proximity (< 3 ft.) and small size (10 by 23 ft.) of the plots, severe K deficiencies attracted and supported large aphid populations that led to colonization of plants both deficient and sufficient in K. Thus the design of this experiment may have hindered the ability to detect the observed effects that appear to be operational at the whole-field scale.

### Wisconsin, 2003

A laboratory experiment examined performance of aphids on leaf material collected from healthy and visually K-deficient soybean plants growing in an experimental

field in Arlington, Wisconsin, in 2003. The number of nymphs per adult and the population increase rate were substantially higher on the leaves low in K (**Table 2**). This effect indicates that K-deficient soybeans provide for greater potential expansion rates of aphid populations. These controlled laboratory conditions, however, do not allow expression of factors such as natural predators and parasites that would be operational in the field.

The mechanism for this effect was not identified, but others have noted that aphids are dependent on soluble amino acids for their nutrition, and that K deficiency can cause increased concentration of such amino acids in plant tissue.

### Wisconsin, 2004

In 2004, a year with low aphid pest pressure, soybean aphid populations were monitored in 34 production soybean fields across Wisconsin, ranging in soil test K from 80 to over 200 ppm (Myers and Gratton, 2006). These fields included some soils of sandier texture, whose critical level for soil test K (upper limit of the “low” range) is as low



**Potassium** deficient (left); **Aphid** infestation on a soybean healthy leaf.

**Table 2.** Aphids in a 2003 lab study grew more rapidly on soybean leaves with less K (adapted from Myers et al., 2005).

Soil test K, ppm	Leaf K, ppm	Petiole sap K, ppm	Population growth rate	Population growth rate
60	0.55	1000	68	0.48
160	1.68	2493	49	0.42

**Table 3.** Leaf K and soybean yield were increased, and aphid infestations were decreased, by addition of muriate of potash to bring soil test K to 113 and 142 ppm, in an open field trial in 2004 in Arlington, WI. (adapted from Myers and Gratton, 2006).

Soil test K, ppm	Leaf K, %	Clip-cage aphids		Natural aphids/plant		Soybean yield, bu/A
		Population growth rate	Population growth rate	19-Aug	26-Aug	
60	1.50	42	0.31	107	251	24
113	2.40	27	0.28	56	72	47
142	2.40	26	0.27	54	72	46

as 60 ppm. Across these fields, aphid population growth rate was negatively correlated with soil K and P and leaf K, N, P, and S. However, peak aphid densities were positively correlated with the same suite of soil and leaf nutrients.

In the same year, a controlled K response trial in field plots showed that medium and higher soil test K levels decreased aphid reproductive rates, slowed rates of population increases, and lowered peak abundance of naturally occurring aphid populations (Table 3). Clip-cages placed on leaves of intact plants allowed the study of reproduction of single aphids placed on single leaves in a small enclosure, isolated from other aphids and protected from predators and escape, but in the field environment.

The reasons why aphid populations were reduced by higher K levels in 2004 (Table 3), but not in 2001 and 2002 (Table 1) are not clear. It may be related to the lower pest pressure in 2004 which made it possible for the effects of plant nutrition on aphids to be detected without high overall aphid numbers swamping out any effects. Plot size in 2004 was the same as in the earlier studies.

### Michigan, 2003-2004

In mid-August of both 2003 and 2004, five to eight commercial soybean fields in southwest Michigan showing



**A clip cage** to measure growth and development of single aphids.

symptoms of K deficiency were surveyed (Walter and DiFonzo, 2007). Within each field, pairs of samples were selected such that one was in the center of an area of severe visual symptoms, and the other was in a nearby symptomless area. At each of the areas, soils, plant phloem, and aphid populations were sampled. Soil test K levels were found to be lower in areas showing symptoms in both years. In 2003, an outbreak year, aphid density was higher in the K-deficient sample areas (Table 4). In 2004, aphid populations were too low to detect differences in density.



**Soybean leaves** showing symptoms of K deficiency.

In 2004, in a commercial soybean field with low soil test K in Van Buren County, Michigan, a field trial was established containing five plots, each 20 by 120 ft., with and without application of potash fertilizer at a rate of 140 lb of K<sub>2</sub>O/A. Clip cages and exclusion cages were used to monitor reproductive performance of aphids. A clip cage was a small predator-proof enclosure clipped to a leaf to measure the growth and reproduction of individual aphids. Exclusion cages were 6 x 6 ft., covering 10 plants each, and prevented predation on the introduced aphids, but allowed escape of any aphids which morphed into alate (flying) form.

The first set of clip cages, installed on 10 June, showed no differences in aphid reproductive performance. The second set, installed 14 July, produced nymphs earlier and in greater numbers on soybeans that had not received K fertilizer (Table 5). In the exclusion cages, significantly higher populations of aphids were observed on the zero-K treatment from 30 June onward.

Samples of phloem sap were analyzed from all studies conducted in Michigan in 2003 and 2004. The sampling method measured the ratios of 18 common amino acids in the sap, but not the total amounts. The relative proportion of the amino acid asparagine was found to correlate negatively with soil test K, while the other amino acids showed no

**Table 4.** Surveys conducted in Michigan found higher numbers of naturally-occurring aphids in K-deficient field areas in 2003 but not in 2004 (Walter and DiFonzo, 2007).

Within-field area surveyed	2003		2004	
	Soil test K <sup>1</sup> , ppm	Aphids/leaf	Soil test K, ppm	Aphids/leaf
K-deficient	15-65	174	28-83	3
Symptomless	22-83	103	38-83	3

<sup>1</sup>Ammonium acetate extractable K; critical levels 75-100 ppm.

**Table 5.** Aphid populations in a K-deficient commercial soybean field in 2004. Exclusion cages were infested with one aphid per plant on 28 May. Initial soil test K was 67 ppm<sup>1</sup> (Walter and DiFonzo, 2007).

KCl applied, lb K <sub>2</sub> O/A	Clip cage		Exclusion cage	
	14-Jul		30-Jun	15-Jul
	Age at first nymph	Nymphs /adult	Aphids/plant	
0	8.8	88	703	6858
140	11.0	71	233	2315

<sup>1</sup>Critical level for this soil (CEC of 8.6 meq/100g) is 96 ppm.



**Predator-proof cages** used to measure population growth rate of aphids on K-deficient and K-amended soybean, southwest Michigan, July 2003.

relationship. That is, asparagines levels in plant sap increased as soil K tests decreased: at a soil test K level of 120 ppm, asparagine comprised 3 to 10% of the total amino acids but increased to 8 to 20% when soil tests were at 20 ppm.

Asparagine may play a critical role in relieving N-limitation of aphids. Weibull (1988) noted that sap from the most aphid-resistant accessions of oat and barley contained relatively low levels of asparagine. Richards and Berner (1954) reported that K deficiency caused higher asparagine content in barley leaves. Barker and Bradfield (1963) reported that higher levels of K in a nutrient solution resulted in reduced concentrations of free amino acids, especially asparagine, in young corn seedlings.

Aphids are thought to obtain all of their dietary N from amino acids translocated in the phloem sap. Aphids are not known to use proteinases as part of their nutritional digestion, probably because high levels of proteinase inhibitors and extremely low protein concentrations in typical phloem sap make plant proteins a poor N source. Godfrey and Hutchmacher (1999) reported that K applied on California cotton at 100 to 200 lb K<sub>2</sub>O/A had a “moderate negative effect on both the generation time and the fecundity of the aphid.” So, as plants become more stressed due to K-deficient soils, their response is to release more free amino acids such as asparagine into the phloem to counterbalance osmotic imbalances in plants. However, aphids can take advantage of these free-flowing and easy-to-digest N-containing compounds to develop faster and produce more offspring per female. This results in faster aphid population growth and ultimately higher population densities on soybean which further exacerbates yield loss.

## Conclusions

In both Wisconsin and Michigan, low soil K was associated with increased aphid populations only at the low end of the range of soil K in production fields, and well below the K levels recommended for soybean production. Soil test summaries conducted in 2005 for these two states indicate a median soil test K of 125 to 149

ppm, and that only about 10 to 15% of soils are expected to test below 80 ppm.

While these results from Wisconsin and Michigan show a strong “bottom-up” effect of soybean K nutrition on the soybean aphid, it does not imply that adequate K is a reliable control for aphids. Aphid populations are also affected by natural enemies such as Asian lady beetles, and by natural parasites. Both are examples of “top-down” factors that may be more or less important, depending on the year and the site, than “bottom-up” factors such as host plant nutrition. Aphid infestations can still occur when K nutrition is adequate.

However, preventing deficiencies provides at least one degree of protection or insurance against yield loss from these potentially damaging and disease-transmitting insects. From a practical standpoint, this means that soybean growers should manage soil K levels in their fields as part of their integrated pest management plan for the soybean aphid.

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# Economic Benefits of Potash Fertiliser Application in Major Cereals Grown in the Indo-Gangetic Plains

Sudarshan Dutta, Kaushik Majumdar, T. Satyanarayana

Potash (K) fertiliser cost has increased considerably in India over the past three years. This has raised doubts about the profitability of potash fertiliser application in cereals. Recent K response studies in rice, wheat and maize (corn), spread across the Indo-Gangetic Plains (IGP), highlighted substantial grain yield and economic response to K fertiliser application. Results suggested that skipping application of potash in the three cereal crops would cause variable yield and economic loss even at higher potash prices. The economic assessment based on projected cost of K fertiliser and projected minimum support payment of the cereals also showed favourable return on investment for K fertiliser

The general perception that Indian soils are rich in potash and do not require K fertilisation is no longer relevant in the intensive crop production scenario. In fact, there is a growing evidence of increasing deficiency of potash as a result of sub-optimal or no application of

K fertilisers, and unbalanced use of nitrogen (N) and phosphorus (P).

The situation becomes even worse with the recent increase in K fertiliser price. It is clear that there are two ways of coping with increasing fertiliser prices: (1) by improving crop yields by a certain yearly increment or (2) by increasing crop prices. Earlier studies across regions in India revealed sizable yield response of crops to K fertilisation and economic returns associated with K application. The economic return of potash application in the above response scenario, based on minimum support payment of crops and prevailing unit price of  $K_2O$  indicated that investment of one rupee on K fertiliser could result in a return of more than 15 rupees. This current study was initiated across the IGP region to assess (1) the yield response of rice, wheat and maize to potash application in a range of growing environments and (2) the economic returns of K fertiliser application in major cereals at the increasing fertiliser price scenario. On-

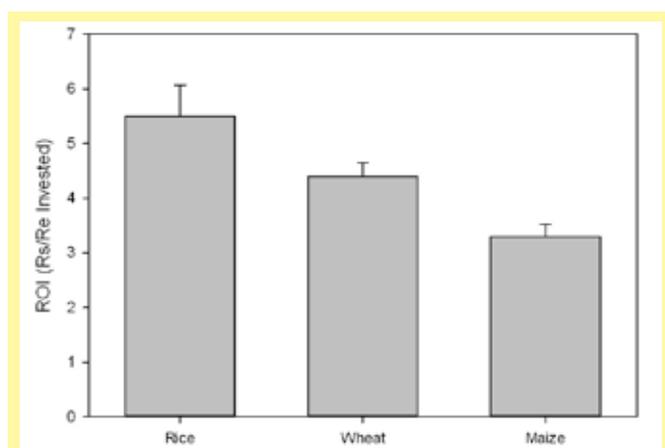


Figure 2. Return on investment (ROI) of K application in cereals in the IGP at Rs. 18.83/kg  $K_2O$ .

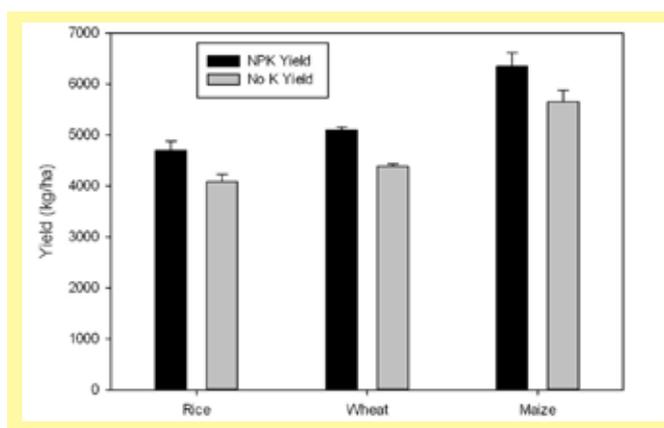


Figure 1. Average yield increase (kg/ha) with K fertilization in different crops across growing environments.

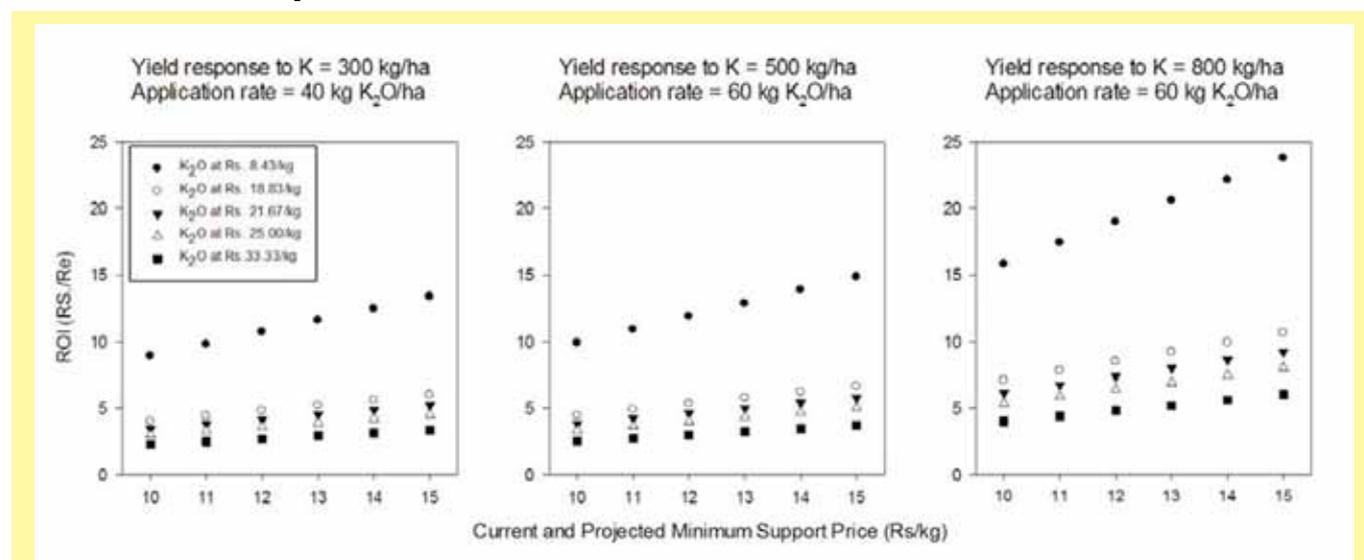
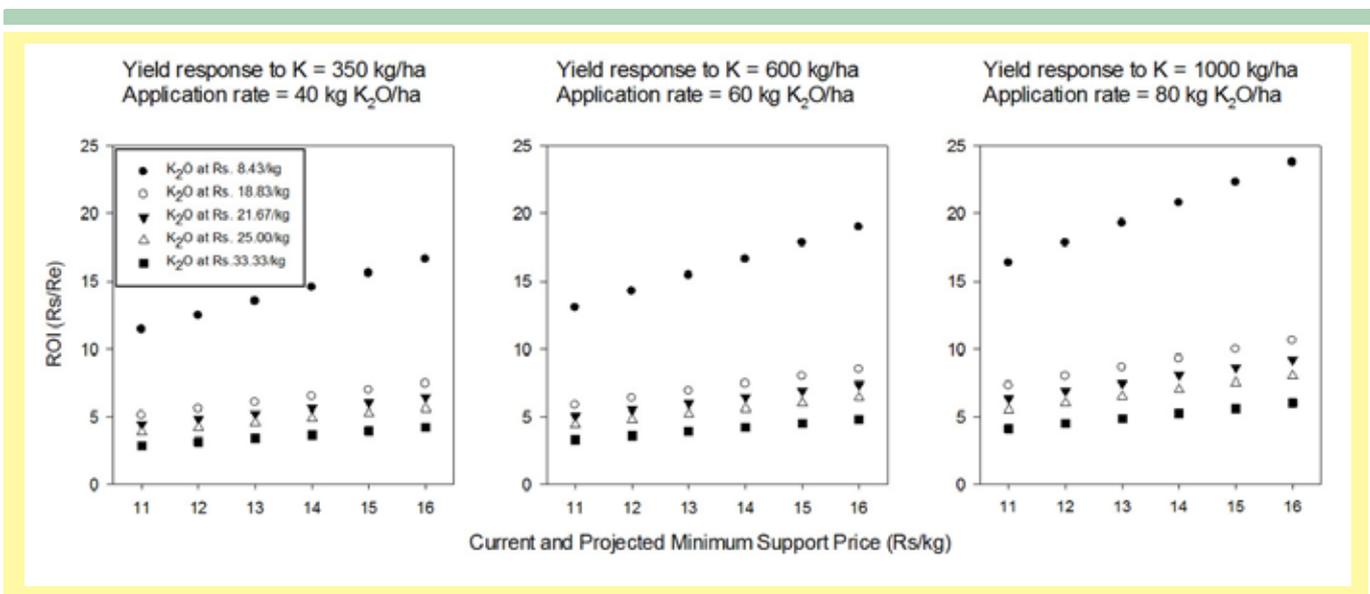
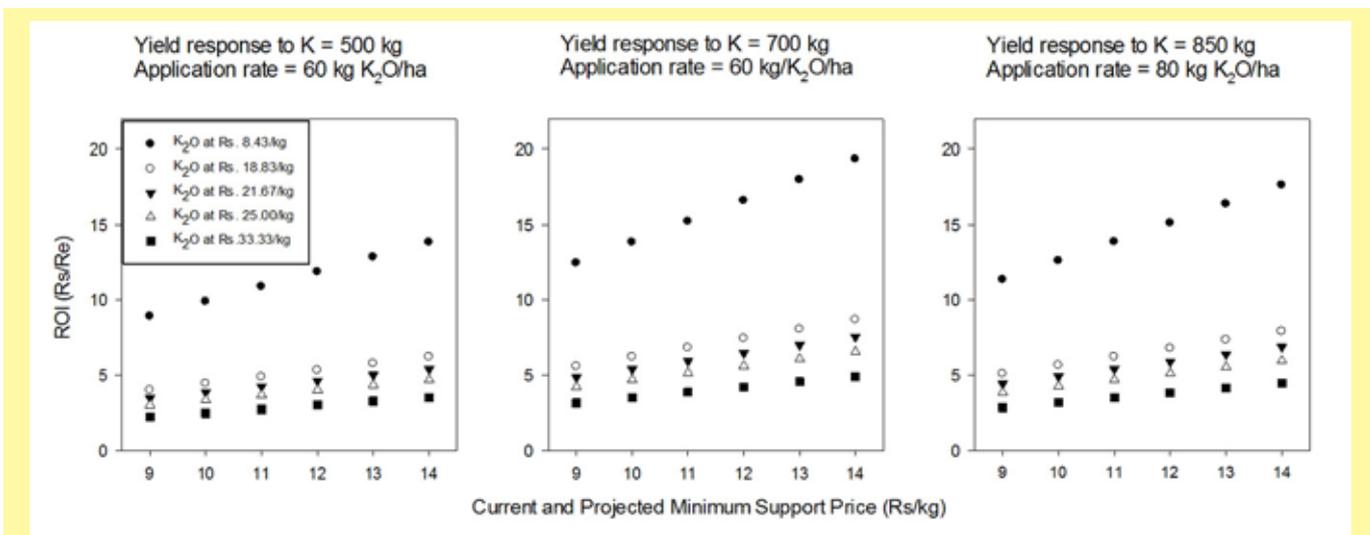


Figure 3. Return of investment (ROI) in K fertiliser at different K response levels, projected costs of K fertiliser and minimum support prices for rice.



**Figure 4.** Return on investment (ROI) of K fertiliser at varying K response levels, cost of  $K_2O$ , and minimum support price of wheat.



**Figure 5.** Return on investment (ROI) of K fertiliser at varying K response levels, cost of  $K_2O$ , and minimum support price of maize.

farm trials were conducted across the IGP during 2009-2011 by the International Plant Nutrition Institute (IPNI) in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT) under the Cereal Systems Initiative for South Asia (CSISA) project to capture the nutrient response of crops under variable soil and growing environments. Overall, 45, 141 and 36 on-farm trials on rice, wheat and maize were conducted respectively in the states of Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, and West Bengal, representing irrigated intensive production systems and relatively large farms in the western IGP to rainfed, low intensity fragmented farming systems of eastern India.

## Results

On-farm potash response studies in major cereals across a large geographical area highlighted that:

1) Grain yield response to K fertiliser is significant and skipping application of potash in the three cereal crops will cause variable yield and economic loss to the farmers.

2) Average yield losses in rice, wheat and maize in farmers' fields due to K-omission were 622, 715 and 700 kg/ha, respectively. This strengthens the concept of low

potash supply levels of most soils in India.

3) Generalised potash recommendations would lead to under or over application in most cases, causing economic losses to farmers. The strategy for deciding potash application rates should, therefore, be based on the expected crop response at a location for improved yield and profitability instead of considering the native soil test status for potash alone.

Overall, the study showed a variable reduction in yields of rice, wheat, and maize due to potash omission trials in farmers' fields. The return on investment in K fertiliser was reasonably high in most of the cases dispelling the myth that potash application is uneconomic in cereals.

## Methodology

The following four treatments were assessed in the on-farm experiments:

- 1) Ample NPK
- 2) Omission of N with full P and K

3) Omission of P with full N and K

4) Omission of K with full N and P

The ample application rates of NPK for rice were 125–175 kg N/ha, 50–80 kg P<sub>2</sub>O<sub>5</sub>/ha and 60–90 kg K<sub>2</sub>O/ha based on estimated yield target of 5–8 t/ha. For wheat, N application rates were 150–180 kg/ha for 5–6 t/ha of yield target, while P and K rates were fixed at 90 kg P<sub>2</sub>O<sub>5</sub> and 100 K<sub>2</sub>O per hectare. The ample NPK rates of maize were 150–180 kg N, 70–115 kg P<sub>2</sub>O<sub>5</sub> and 120–160 kg K<sub>2</sub>O per hectare for yield targets between 6–8 t/ha. The ample NPK treatment received nutrients in excess of actual requirement of the crops, following the omission plot experiment protocol, to ensure no limitation of nutrients except the omitted one. The omission plot experiments allowed us to estimate the yield response due to K, which is equivalent to the yield difference between K omission plots as compared to the ample NPK plot, in each location. We estimated the return on investment (ROI) for K (i.e. rupees returned per rupee invested on K fertiliser) at four price scenarios of potash fertiliser, Rs. 4,455\* , Rs. 5,055 , Rs. 11,300 and a further higher price of Rs. 13,000/tonne, at four different crop response levels, 200, 500, 1,000, and 1,500 kg/ha, and at three different K application rates (100, 80 and 60 kg/ha) (\*1 USD = Rs. 50 approx.). The range of K response used in the calculation was taken from the current set of on-farm trials. In addition, we also used current and projected prices of K fertiliser and MSP of rice, wheat and maize to estimate ROI for the three crops under future scenarios.

## Rice

On-farm studies across 45 locations revealed that average yield with ample application of NPK was 4,701 kg/ha and yield loss due to no K application was on average 622 kg/ha across locations (**Figure 1**). Even areas traditionally known as less responsive to K application, such as Punjab and Haryana, showed yield loss of 500–1,000 kg/ha in the K omission plots. Economic analysis showed that ROI of K ranged between 0.8–16 Rs/Rs, which suggests that every rupee invested in fertiliser K produced additional rice yield worth Rs. 0.8 to Rs. 16, with a mean of Rs. 5.5 across the locations (**Figure 2**). Economic return of less than Rs. 1 per rupee invested on K was registered at three locations only. The economic calculations based on projected crop and K prices (**Figure 3**) showed that the ROI at the highest projected price of K (Rs. 33.33/kg of K<sub>2</sub>O) and the lowest MSP (Rs. 10/kg rice) was 2.3 at an application rate of 40 kg K<sub>2</sub>O/ha for a 300 kg/ha crop response, suggesting profitable return on potash application. Obviously the profitability increased as the MSP of the crop was increased. At higher crop response levels of 500 and 800 kg/ha, ROI was 2.5 and 4.0, respectively at the lowest MSP and at an application rate of 60 kg K<sub>2</sub>O/ha. In the on-farm omission plot experiments, 60–100 kg K<sub>2</sub>O/ha was applied based on the yield targets of rice. A yield loss of ≥ 500 kg/ha of rice due to no application of K was observed in more than 50% of locations. This suggests that in such locations, application of K at 40–60 kg K<sub>2</sub>O/ha will provide a good ROI to

the farmers and will maintain the K fertility status of the soil. It should be understood that the vast rice growing soils of the IGP have large variability in K supplying capacity and K management decisions in this area must be based on expected K response at a particular location.

## Wheat

In our present study, on-farm trials (141 locations) across the trans and upper Gangetic Plains showed that wheat yield with ample application of NPK was 5,096 kg/ha and the gap between K omission plot yield and full NPK plot yield ranged from 0–2,222 kg/ha with a mean of 715 kg/ha (**Figure 1**). The average yield loss of 715 kg/ha translates to economic loss of Rs. 8,366/ha at the current MSP of wheat (Rs. 11.7/kg). The majority of these omission plot trials were set up in Punjab, Haryana and Western Uttar Pradesh that are typically thought of as areas rich in inherent soil K and require either no, or less external K application. ROI of K in the wheat experiments was 0–13.22 Rs/Rs with a mean return of Rs 4.44 (**Figure 2**). The ROI of K was lower than 2.0 only in 24 out of the 141 sites studied (17%). ROI was calculated based on MSP of wheat and cost of potash (Rs. 18.83/kg of K<sub>2</sub>O).

Economic calculations based on projected cost of K and MSP of wheat showed that ROI declined sharply as the K price increased from Rs. 8.43/kg K<sub>2</sub>O to a projected price of Rs. 33/kg K<sub>2</sub>O (**Figure 4**). Nonetheless, ROI at the current MSP and the projected maximum price of K<sub>2</sub>O would be 2.9, a return ratio of 1:3 even at the low-response locations. At high-response locations (K response ≈ 1,000 kg/ha) the ROI at highest projected K price was 4.1 at the current MSP of wheat, making it a profitable option for the farmers. K response was >1 t/ha in 25% of the locations in the present study and those locations would produce a ROI of 8.0 at the current cost of K and current MSP of wheat.

## Maize (corn)

Maize omission plot trials were conducted in Bihar and West Bengal where maize is coming up as a preferred alternative crop to both rice and wheat during monsoon and winter seasons, respectively. Maize yield reduction in K omission plots, as compared to ample NPK application, ranged from 140–1,320 kg/ha and mean yield loss due to no K application was 700 kg/ha (**Figure 1**). At the current MSP of maize (Rs. 8.80/kg grain), the yield losses in these experiments were equivalent to economic loss of Rs. 1,232–11,616/ha, with a mean of Rs. 6,160/ha. Maize is grown in India in winter, spring and rainy seasons. The present data includes both winter and spring maize. Spring maize average yield in these trials was 4,936 kg/ha whereas that of winter maize was 7,748 kg/ha. Average yield response to K application in winter maize alone was nearly 200 kg/ha higher than the pooled data of both crops. Return per rupee invested on K in maize ranged Rs. 0.65–6.17 and the average return across all sites was Rs. 3.27 (**Figure 2**). Even with the lowest MSP among the three cereals, there were only six of the 36 locations reported here that had return below Rs. 2.0 per rupee

invested in K fertiliser.

Application of potash fertiliser at existing price is profitable where maize yield response to K is more than 500 kg/ha. The results of the on-farm trials showed that 75% of the experimental sites had > 500 kg/ha of K response, and would give reasonably high ROI even at application rates of 100 kg K<sub>2</sub>O/ha and fertiliser price of Rs 18.83/kg K<sub>2</sub>O. Maize MSP is lowest among the

three cereal crops. ROI at the current MSP and cost of K was 4.0, 5.6 and 5.1 at the 500, 700 and 850 kg/ha crop responses, respectively. Calculation based on projected K price and crop price showed that ROI was 2.3, 3.2 and 2.9 for a 500, 700 and 850 kg/ha K response, respectively, at the current MSP and the highest projected price of K<sub>2</sub>O (Rs. 33/kg K<sub>2</sub>O), giving reasonable return to farmers (**Figure 5**).

## Potassium Fertiliser Use and Efficiency in China

Fang Chen, Ping He, Shutian Li, Shihua Tu

*Out of the total 1.3 billion hectares (B ha) being farmed globally, only 10% has little or no nutrient stress. Of the remaining area, about 40% has shown signs of potassium (K) deficiency (Yang, 1988; Jiang et al, 2003). In recent years, increasing crop yields with intensive farming has resulted in the extension of K deficient area within China. Sheldrick et al (2003) indicated that Chinese farmland lost 7.7 million metric tonnes of K<sub>2</sub>O per year because of the removal of K in harvested crops.*

According to its biological availability, soil K can be defined in four forms: water-soluble K, exchangeable K, fixed K, and structural K (Huang et al, 1979). Water-soluble K concentration is usually low in agricultural soils and always occupies a small proportion (less than 1%) of total soil K content (Jin, 1993). However, this low soluble K concentration can only support lower yields. Commercial K fertilisers are readily available soluble sources and are critical in modern high yield agriculture. Except for some high yield forage crops and tuber crops such as potato, which need high levels of soluble K in soil, most crops need a moderate level of soluble K supply to achieve a normal yield.

Agricultural potash resources in China are quite limited so it is always critical to improve the use efficiency of commercial and natural potash resources.

With higher temperature, rainfall and intensive soil weathering in South China, nutrient loss by leaching and runoff is high. In addition, a high cropping index (average of 2.1 crops per year) removes more nutrients from fields in the absence of sufficient K supplementation. In the last three decades, about 2/3 of the paddy soil and 1/2 of the upland soils in south China showed K deficiency, which represents 80% of the total K deficient area in the country

(Zheng and Chen, 2004).

In North China, with lower temperature, rainfall, and cropping index, soils usually contain more K-bearing minerals resulting in a lower efficiency of potash fertiliser than occurs in the south. Liu et al. (2011) and He et al. (2012) reported that K application increased wheat grain yield and its net profitability in most cases in North central China, but the average yield response was less than 1,000 kg/ha and efficiency parameters of K fertiliser use were relatively low.

### Farmland soil potassium balance

Since 1980, commercial potash application in China has been greatly promoted with a number of research and technology demonstration projects. China's total commercial potash fertiliser consumption significantly increased from 386,000 tonnes in 1980 to 1.98 million tonnes in 1990 and 8.49 million tonnes in 2010. The average K application rates for farmland in different regions of China have varied in recent years from 87 to 178 kg K<sub>2</sub>O/ha. Of all of the K used for agriculture, 38% has come from commercial K fertilisers, 35% from human and animal excretion, 17% from crop straw residues, 4%

**Table 1.** Farmland soil NPK balances (kg/ha/year) in three provinces of south China

Province	N			P <sub>2</sub> O <sub>5</sub>			K <sub>2</sub> O		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
Jiangsu	481	394	87	155	91	64	163	196	-33
Hunan	583	253	330	188	156	32	318	361	-43
Shanghai	365	144	221	102	69	33	70	164	-94

Source: IPNI China Programme.

**Table 2.** Farmland soil NPK balances (kg/ha/year) in north China.

Province	N			P <sub>2</sub> O <sub>5</sub>			K <sub>2</sub> O		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
Northeast	355	326	29	156	103	53	131	198	-67
Northcentral	475	391	84	246	118	128	219	226	-7
Northwest	401	309	92	172	89	84	170	170	0

Source: IPNI China Program

**Table 3.** Crop yield responses, profit and agronomic efficiency (AE) to K application in China.

Crops	Trial No.	Yield (t/ha)	Yield increased			Profit (\$/ra)
			%	kg/ha	AE(kg/kg)	
Cereals	582	8.1	14	990	10.3	258
Vegetables	137	63.2	15	8500	58.0	1419
Fruit trees	51	32.5	23	6000	12.0	3548
Oil crops	87	3.0	17	433	4.8	292
Tuber crops	116	28.1	18	4000	44.0	787
Cotton	56	2.5	22	458	3.1	533
Tea	15	6.4	14	755	2.9	875

Source: IPNI China Program

from deposition, 4% from irrigation, 1% from green manure, and 1% from oilcakes (Li and Jin, 2011).

While potash consumption has greatly increased in the last 30 years, this growth is not sufficient to address the larger crop area and crop yields and their associated removal of K from soils. At the same time, China's commercial fertiliser application area increased by 14.4% (from 9.94 to 11.37 M ha between 1980 and 2008). However, the areas most associated with increasing K fertiliser application are those with cash crops, vegetables and fruit trees, which need much higher K supplies than grain crops.

Since 1980, scientists in South China, supported by the International Plant Nutrition Institute (IPNI), have carried out a number of research projects based on different soil K status, cropping patterns, interaction

between different soil nutrients, and other factors. The common aim has been to increase K application efficiency by 5-10% while maintaining a value-to-cost ratio (VCR) above 3.0. **Table 1** presents farmland soil NPK nutrient status in three provinces in south China. While the soil nitrogen (N) and phosphorus (P) balances are positive (more input than output), the soil K balance in the provinces was negative. If this continues into the future, the farmland soil K deficiency could become a challenge to future food production.

In recent years, with increased use of high yielding crop cultivars and more N and P fertiliser application, farmland soil K balance has become negative in some North China regions. Jin (2011) reported soil K<sub>2</sub>O loss in the northeast region (i.e. Heilongjiang, Jilin and Liaoning provinces) of 67 kg/ha, and in the North central region

**Table 4.** Expected crop yield, soil test values, recommended K application rates, and value-to-cost ratio (VCR).

Crop	Soil available K (mg/kg)	Recommend K <sub>2</sub> O (kg/ha)	Expected crop yield (t/ha)	VCR (\$/\$)
Rice (n=135)	<40	117	6.1	4.8
	40-60	98	6.8	3.1
	60-90	90	7.0	2.5
	90-120	77	7.8	1.8
	>120	62	8.3	1.3
Corn (n=46)	<60	170	4.7	6.2
	60-100	126	5.6	5.8
	100-130	113	6.5	3.3
	130-150	90	6.4	2.1
	>150	68	6.7	2.1
Peanut (n=26)	<50	152	2.8	8.3
	50-70	108	3.1	6.1
	70-90	100	3.4	5.7
	90-120	63	3.9	5.0
	>120	35	4.0	3.2
Rapeseed (n=67)	<50	150	1.1	3.8
	50-80	105	1.3	3.6
	80-100	92	1.4	3.1
	100-120	87	1.4	2.8
	>120	45	1.7	1.5

Source: Cooperative projects of IPNI China Programme and Soil and Fertiliser Institutes of Hunan, Hubei, Jiangxi, Zhejiang, Sichuan, Guangxi and Guangdong provinces.

(i.e. Beijing, Tianjin, Hebei, Henan, Shangdong, and Shanxi provinces) of 7 kg/ha annually (Table 2).

### Impact of potash application on main crops

Between 2001 and 2010, the IPNI China Programme conducted 1,044 field trials with different crops across the country (Table 3). These results indicated that fruit trees, cotton, tuber, and oil crops have the highest yield responses (17 to 23%) to K fertilization. Fruit trees, vegetables, and tea had the highest gains in profit (USD 875/ha to USD 3,548/ha) due to K application. Vegetables and tuber crops have the best agronomy efficiency (44 kg to 58 kg produce per kg K applied), which was significantly higher than other crops. IPNI has also summarised results from 1,041 field trials conducted over the past three decades in South China on 30 main crops. The results showed good yield responses to K fertilization in all crops. Most of the cash crops and vegetables showed better yield responses and net profits to K application than grain crops. In general, higher economic gains were found when potash was used on cash crops and vegetables first.

### Soil test-based K fertiliser recommendations for selected crops

Table 4 presents optimum, soil test-based K application rates for four main crops in South China that were developed for farmer use. Many other crops in all regions also have similar recommended K fertilization rates. Further research by the IPNI China Programme and its cooperative research network will be focused on evaluating the effect of K application with varying soil water levels, nutrient spatial distribution in fields, and K movement in the farmland ecological system and its environmental effects, if any.

## Conclusion

Potash fertilisation is very important and profitable in China's crop production. Our challenge is to use K efficiently to increase our crops needs.

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# Precision Management of Root Zone Potassium for Corn: Considerations for the Future

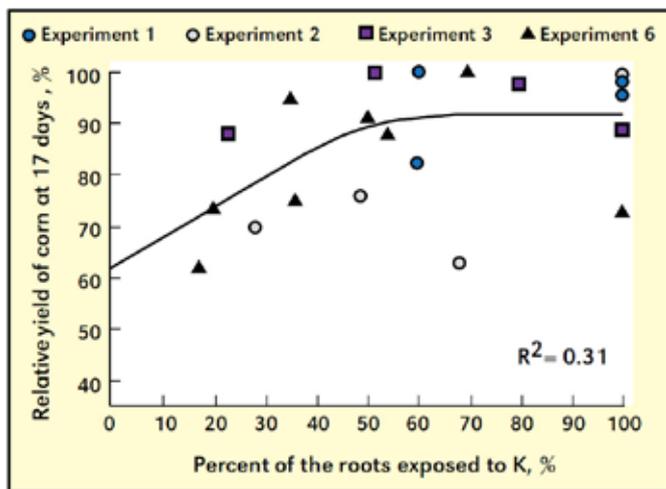
T.S. Murrell and T.J. Vyn

*Precision technologies allow fertilized soil volume to be managed over time to create zones of higher fertility, but just how this should be done for optimum short-term and long-term crop response is not well understood. Relevant considerations for K fertilizer placement include the persistence of increased fertility after banded applications as well as the redistribution of K within the soil that occurs simply under normal crop development. Research indicates that the location of prior crop rows may be even more important to soil K levels than the location of past fertilizer K bands.*

Precision guidance systems are capable of a very high level of repeatable accuracy in geo-positioning. Currently available equipment advertises 1 in. pass-to-pass accuracy. These technologies, in conjunction with geographic information system software, allow all equipment passes to be spatially referenced, recorded, and stored.

Abbreviations and notes: K = potassium; P = phosphorus; N = nitrogen; S = sulfur; ppm = parts per million.

Such capabilities provide new opportunities to manage nutrient applications, particularly those that are banded separately from (e.g. deep banding with strip tillage), or in conjunction with, crop planting operations. Instead of settling for a random array of past band applications in the field and limited knowledge of their exact location, farmers can now decide where future fertilizer should be banded in relation to past bands. If desired, farmers can place fertilizer in the same band year after year or offset

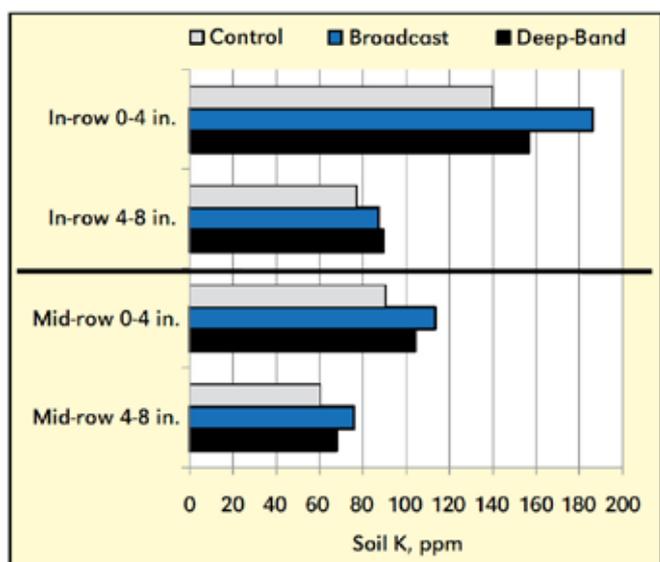


**Figure 1.** Relationship between relative yield of above-ground biomass of 17-day-old corn plants and the percent of roots exposed to K (Claassen and Barber, 1977).

bands from one year to the next at any desired distance from one another. Consequently, sub-surface fertilized soil volume can be managed more precisely than before. It is not clear, however, how bands should be managed over time to maximize profitability and productivity.

This article focuses on considerations for managing banded K applications over time for corn. Unlike N and P, localized placement of K does not cause roots to proliferate in enriched zones (Claassen and Barber, 1977). Consequently, if roots are to take full advantage of a concentrated supply of K in a band, either N, P, or both may need to be co-applied.

A question being addressed in current tillage and K placement research is how much of the soil volume needs to be fertilized to maximize corn yield. Some insight into the answer to this question was provided by Claassen and Barber (1977). In their growth chamber studies of young corn plants grown in pots, it was found that 17-day-old corn plants, on average, had maximum above-ground biomass accumulation when at least 50% of the soil volume was fertilized with K (Figure 1). Translating these results to the field, however, is not straightforward,



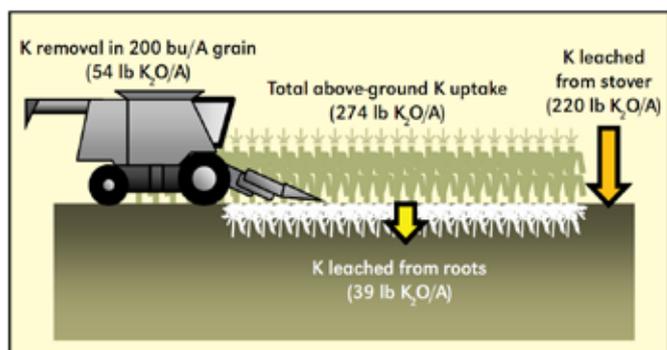
**Figure 2.** Soil K concentrations in spring 2008 following the third strip-till corn cycle for a corn-soybean rotation involving 30 in. strip-till corn and 15 in. no-till soybean.

given the variability in rooting depth and other factors in present-day high plant density environments as well as the need to evaluate the cumulative effects over the entire growing season.

The prevalence of conservation tillage systems has led to nutrient stratification in many fields, where both P and K are more concentrated near the surface than deeper in the soil profile (Robbins and Voss, 1991). Moncrief et al. (1985) showed that stratification occurs quickly in reduced tillage systems where broadcast fertilizer K is applied. In his study examining spring K applications in both no-till and spring chisel/field cultivator systems, higher ammonium acetate extractable K levels near the surface were measured 2 months after application. Differential soil test K stratification in the 0 to 2, 2 to 4, and 4 to 8 in. depths due to spring tillage systems (no-till, strip-till, and field cultivator) in the prior corn year were also observed just 12 months after both broadcast and deep banded application of 150 lb K<sub>2</sub>O/A (Yin and Vyn, 2004).

Higher soil test P and K levels near the surface in reduced tillage systems appears to be among the list of possible factors altering corn root distribution in the soil profile. In a Minnesota study (Bauder et al., 1985), root distribution was compared among several different tillage systems during the summer. In the upper 3 in. of soil, no-till and ridge-till had higher root length densities and greater calculated root lengths than where soil had been moldboard plowed or chiseled. In addition, most of the roots were located directly below the row, with very few of them 7.5 to 15 in. away. Compared to no-till, chisel tillage, and moldboard plowing, ridge-till had the greatest overall root length and the greatest penetration of roots through the soil profile. In contrast, no-till had the greatest root length density below the row at the shallowest depth and the lowest root length density in all lower layers.

Stratification of nutrients, along with changes in root distribution with various tillage systems, has led researchers to investigate if there is any advantage to increasing the volume of fertilized soil in the likely rooting zone with bands at various depths. Although banded K applications made at the start of a season initially create concentrated zones in the soil, these zones may not be detectable by the end of the season when soil sampling is conducted. Low rates of K, like those found in starter fertilizer formulations, may be too low to provide long-lasting fertility increases unless they are applied repeatedly in the same areas over time. In a study examining the effects of 25 years of N-P-K applications banded 2 in. to the side and 2 in. below the corn seed at rates ranging from 11 to 23 lb K<sub>2</sub>O/A/yr (Duiker and Beegle, 2006), only a slightly enriched zone next to the row was detected under chisel/disk tillage. Soil was sampled at 0 to 2, 2 to 4, and 4 to 6 in. depth increments along transects perpendicular to rows. In the other two tillage treatments examined, no-till and moldboard/disk, no enriched zone was detected where the starter fertilizer had been applied. This was in contrast to P, where distinct zones were found in all three tillage treatments. Instead, the most concentrated zone in the soil following grain harvest



**Figure 3.** Estimated quantities of K<sub>2</sub>O removed from the field with grain harvest as well as returned to the soil from the corn plant through leaching of K from corn stover and roots. Quantities are for 200 bu/A corn grain.

was in the corn row. In studies from Iowa, enriched K zones in the corn row were detected in both chisel-disk and no-till systems after 4 years of annually deep banded K (Mallarino and Borges, 2006). Bands were placed 5 to 7 in. deep in the spring prior to tillage and applied at a rate of 70 lb K<sub>2</sub>O/A/yr. Corn was planted directly over the bands. Enriched zones in the row were detected consistently in both tillage systems at the 2 to 6 in. depth increment. Recently collected data from Indiana in a strip-till corn followed by no-till soybean system (**Figure 2**) shows higher K concentrations in the corn row than between rows where K had been both broadcast or deep banded. Interestingly, the same effect was observed where no K had been applied (Vyn, 2010).

Whether or not banded applications of K result in detectable zones of higher fertility may be influenced greatly by the growth of the corn crop itself. **Figure 3** shows estimates of the quantities of K taken up, removed by crop harvest, and returned to the soil through leaching by a 200 bu/A corn grain crop. The assumptions made were as follows: a) crop removal was 0.27 lb K<sub>2</sub>O/bu; b) total above-ground plant uptake was 1.37 lb K<sub>2</sub>O/bu; and c) leached K from the stover was the difference between total uptake and crop removal. Estimating K leached from the roots relied on estimates made by Amos and Walters for root dry matter production per plant (Amos and Walters, 2006). Grain test weight was assumed to be 56 lb/bu at 15.5% moisture. Grain yield (bu) was then converted to dry matter weight (lb). A harvest index of 0.5 was then assumed, resulting in an estimate of stover dry matter production equivalent to that of grain. This estimate included the cob weight. To subtract the cob weight, it was assumed that the cob represented 15% of the total stover dry weight. After subtracting the cob weight, the stover (minus the cob) weight was obtained. The ratio of 0.16 root:stover (minus cob) dry matter was then used to estimate total root dry weight per acre. Root K concentrations provided in Claassen and Barber (1977) were averaged and found to be 3%. This percent K was then multiplied by the total root dry weight per acre and

converted to K<sub>2</sub>O. The resulting estimates show that of the total K taken up by the above ground plant portions, most of it (approximately 80%) is returned to the soil surface through leaching from the stover. The amount of K estimated to be redistributed in the soil by the root system is 72% as much as was removed by the grain.

The quantities of K redistributed in the soil by the plant are significant compared to the quantities of K banded in the studies reported above. Consequently, it is not clear how much of the measured increases of K in the row are due to banding or simply to the redistribution of K by the corn plant itself. Some insight into this can be gained from the strip-till study from Indiana (Vyn, 2010) and an earlier no-till study from Ontario (Yin and Vyn, 2003), where higher concentrations of K were observed in the row compared to between rows, regardless of whether any K had been applied. It would seem, therefore, that redistribution of K by the plant is a major cause of higher K concentrations measured in the row and, as was the case in the Pennsylvania study (Duiker and Beegle, 2006), may make residual fertility impacts of lower, banded rates undetectable.

Precision guidance technology offers many opportunities to manage banded K applications in a number of configurations over time to create zones of higher fertility. Because the crop itself is capable of concentrating large quantities of K in the row, both at the surface and below, offsetting rows from year to year may be a viable strategy to keep K more distributed across the field over time. For instance, a second season of corn might be grown in rows placed in the middle of previous rows, with the next corn crop placed back on the original rows. The purpose of any row movement and K band movement strategy is to keep fertilized soil volumes higher over time to maximize grain yield.

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# Potassium Placement for Efficiency

T.S. Murrell

*Agronomic efficiency for potassium (K) is the increase in yield per unit of applied K. Larger, periodic K applications can have efficiencies similar to smaller, annual ones, providing farmers with flexibility in timing and placement. Band applications are typically more efficient than broadcast applications when lower rates are applied. In reduced tillage systems, bands of K deeper in the soil may provide nutritional advantages under dry growing conditions.*

Farmers have two basic placement options: broadcasting and banding. Broadcasting involves applying potassium (K) fairly uniformly over the soil surface. Broadcast K can be either left at the surface when no tillage is used or incorporated a few centimeters into the soil. Banding is the placement of fertilizer in small zones. These zones can be at the surface or below.

Which placement method is most efficient depends on the cropping system, the management practices used, the genetics employed, and the environmental conditions encountered. We will focus on maize in the temperate region of the U.S. Corn Belt, which is usually grown in rotation with soybean. Management is large scale and mechanized with typical row widths of 76 cm. Hybrid maize is usually planted in April and May and harvested in October. High rates of K uptake usually occur in June. Seeding rates average 74,000 to 86,000 seeds/ha. Potassium is typically broadcast in the fall after soybean harvest, prior to the spring when maize is planted. Land ownership varies, and owned and rented land are often present within one farming operation.

## Potassium Efficiency

When we use the word “efficiency”, we often think of “getting more for less”. There are many different ways to define efficiency; however, we examine how much additional yield is gained from a K application – termed “agronomic efficiency” (AE). It is calculated by dividing the yield response to K by the amount of K applied and is reported in units of kg grain/kg K<sub>2</sub>O.

Most often, efficiency is calculated for one season, but this doesn’t work for scenarios when single, larger rates are applied that last for several years. Larger, periodic applications can be just as efficient as smaller, annual ones. As an example, a study from Iowa (Mallarino et al., 1991) compared large broadcast applications that resulted in a total of 675 kg K<sub>2</sub>O/ha at the start of the study to annually broadcast applications of 54 to 81 kg K<sub>2</sub>O/ha

(Table 1). Maize and soybean were grown in rotation. After 10 years, both approaches had applied a cumulative amount of 675 kg K<sub>2</sub>O/ha. The AEs were nearly identical: 10.6 kg grain/kg K<sub>2</sub>O for the annual applications and 10.0 kg grain/kg K<sub>2</sub>O for the initially large applications.

A large application is often chosen when land is owned, K prices are lower, and sufficient capital exists for the larger initial purchase. Smaller, annual applications are often utilized when ground is rented and capital is limited; however their cost is more subject to price fluctuations.

## Basic Principles of Banded Applications

Band applications of K are often made to get the highest yield increase possible from a low K rate. They have a couple of key advantages over broadcast applications: 1) they can be sub-surface applied near the crop row where they are within reach of developing root systems, and 2) the K is concentrated in a zone, creating a higher quantity of plant-available K. Concentrated zones are more critical early in the season when maize roots take up K most rapidly.

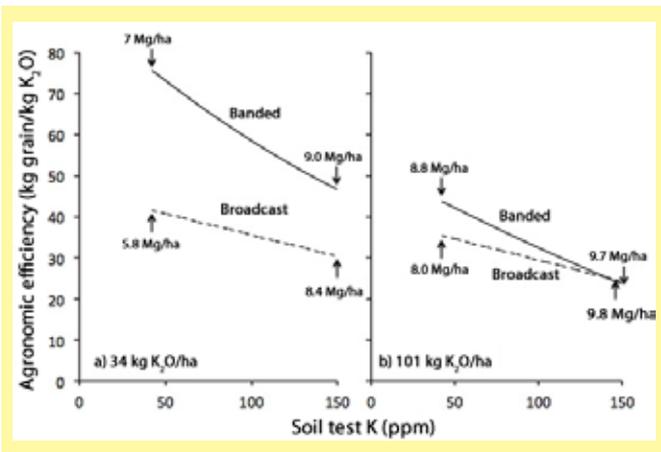
In a classic study that compared banded and broadcast applications (Parks and Walker, 1969), banded applications had a higher AE than those that were broadcast (Figure 1). A low K rate had a higher AE than a high K rate (compare Figures 1a and 1b). This was the result of a rapid increase in maize yield with the first few increments of applied K. At the highest rate applied (Figure 1b), AE was lower but overall yields were higher. This is an important point when talking about efficiency. The goal is to optimize, rather than to maximize, efficiency. Overall production, as well as several other ecosystem services, must be considered.

There is another important principle in Figure 1. At higher soil test levels, differences between band and broadcast placements diminish, especially at higher K rates. In fact, at high rates of applied K, broadcast

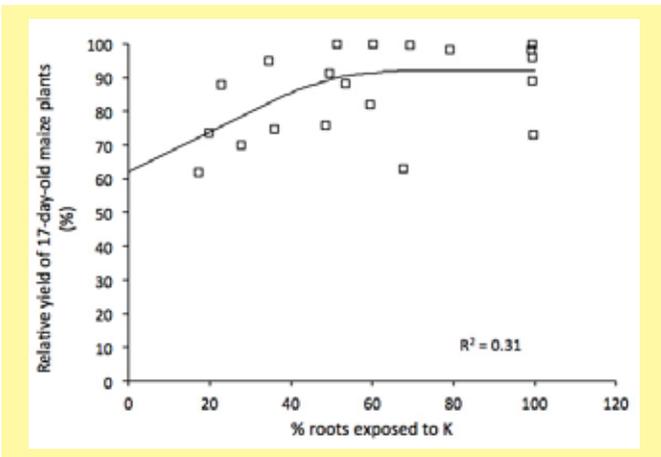
**Table 1.** A comparison, at the end of ten years, of the agronomic efficiency (AE) of 675 kg K<sub>2</sub>O/ha applied by the initiation of the experiment to the AE of annual applications of 54 to 81 kg K<sub>2</sub>O/ha applied each year (Mallarino et al., 1991).

Fertilizer rate	Total K applied after 10 years	Cumulative maize response	Cumulative soybean response	Total response	AE
	(kg K <sub>2</sub> O/ha)	----- (kg grain/ha) -----			(kg grain/kg K <sub>2</sub> O)
54 to 81 kg K <sub>2</sub> O/ha/y	675	5207	1922	7129	10.6
675 kg K <sub>2</sub> O/ha	675	5584	1183	6767	10.0

Note: responses for maize and soybean are each summed over 5 years. Maize grain yield was adjusted to 15.5% moisture but soybean grain yield was not adjusted for moisture content.



**Figure 1.** Agronomic efficiency of maize grain yield response to banded and broadcast applications of a) 34 kg K<sub>2</sub>O/ha and b) 101 kg K<sub>2</sub>O/ha at various soil test levels. Responses are from a multivariate regression model. Modeled grain yields at low and high soil test K levels are provided for each placement method (Parks and Walker, 1969).



**Figure 2.** Aboveground biomass yield of 17 day-old maize plants expressed as a percentage of maximum biomass yield for various percentages of the root volume exposed to K (Claassen and Barber, 1977).

applications are expected to outperform banded ones. Why? It has to do with how much soil volume is fertilized.

A disadvantage of a band application is that it is not well distributed throughout the soil. Earlier work with young (17 day-old) maize plants (Claassen and Barber, 1977) demonstrated that about 50% of the roots needed to be exposed to K to maximize growth (Figure 2). This work suggests that if K is placed only in bands, the bands should be applied in different positions over time to expand the volume of soil that is fertilized. What many producers have done is to combine larger, periodic broadcast applications of K with banded ones. The broadcast applications fertilize a larger soil volume while the banded applications provide concentrated zones that young root systems can access.

When banding K, it's best to co-apply either phosphorus (P), nitrogen (N), or both. Why? The answer has to do with root proliferation. When maize roots grow into a concentrated band of either N or P, hormonal feedback mechanisms within the plant signal root branching. Roots in the bands form secondary, tertiary, and higher laterals, resulting in a mass of roots in the

band. More roots aren't necessarily produced; rather, a greater proportion of the root system is in the band. Potassium doesn't evoke this response. So without N or P, plant roots will grow right through a K band. Of the two nutrients to co-apply, P doesn't move far in soils and has residence times longer than a single season, just like K; however, N bands are typically short-lived. So P and K banded together create an enriched zone that roots can explore for more than one season.

## Banding to Anticipate Dry Weather in Reduced Tillage Systems

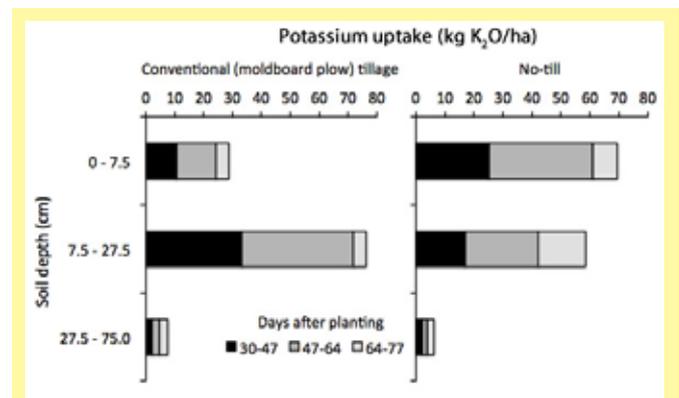
A phenomenon of reduced or no tillage is K stratification in soil. Soil at the surface contains more K than soil deeper down. Surface levels can be two to three times as concentrated in K (Karathanasis and Wells, 1990).

The change from more to less soil disturbance affects more than just the distribution of K. It also affects where in the soil maize gets its K. Back in the 1980s, a group of researchers at Purdue University compared conventional (moldboard plow) tillage to no-till (Mackay et al., 1987). They combined field measurements with a mechanistic model and came up with some interesting findings. Their results, Figure 3, show that maize grown under no-till gets more of its K from the uppermost soil layer than maize under conventional tillage. The researchers concluded that,

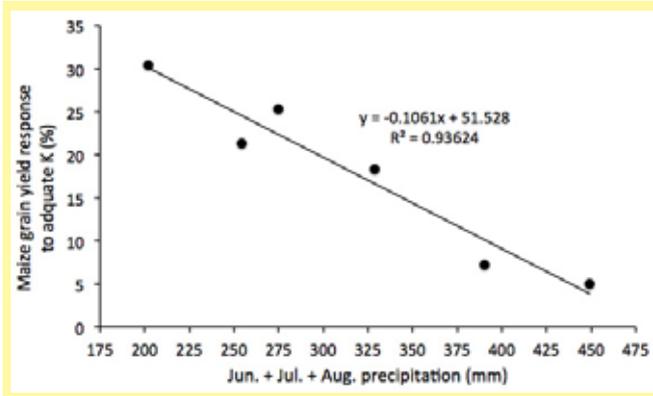
“Conservation tillage systems may be less tolerant of unfavorable growing conditions during periods of rapid nutrient uptake (late June and early July in the [U.S.] Cornbelt) because of the increased dependence on K... near the soil surface. Some deep placement of fertilizer...K may therefore be desirable after several years of no-till cropping, to provide...K to roots growing deeper in the soil and to lessen the dependence on nutrients in the soil surface layer.”

Years earlier, one of the researchers from this group had discovered that maize responded more to K when the growing season was drier (Barber, 1959). Figure 4 shows that maize yield was increased 30% under such conditions but was much lower when the season was wetter.

All of this evidence pointed to the possibility of



**Figure 3.** Potassium uptake from three soil depths (0 to 7.5, 7.5 to 27.5, and 27.5 to 75 cm) for two tillage systems (conventional and no-till), measured at three intervals during the growing season (30 to 47, 47 to 64, and 64 to 77 days after planting) (Mackay et al., 1987).



**Figure 4.** Response of maize grain yield to adequate levels of soil K at various levels of total precipitation for the months of June, July, and August, expressed as a percentage of maximum yield (Barber, 1959).

placing K deeper in the soil to increase the fertilized soil volume and make it strategically available in reduced tillage systems, especially under dry growing conditions. This is exactly what researchers investigated almost a decade later.

In the state of Iowa in the U.S., scientists placed K in bands at a depth of 15 to 20 cm below the soil surface (Bordoli and Mallarino, 1998). The bands themselves were about 2.5 cm wide. These bands were applied and maize planted over the top of them, so that they were directly below the crop row. Trials were conducted both at research farms as well as on farmers' fields. Maize responded at some sites but not others. When responsive and non-responsive sites were all grouped together, deep bands of K increased maize yield by about 0.2 Mg/ha in trials on research farms and by about 0.6 Mg/ha in farmers' fields. These responses occurred even when soil samples taken to a depth of 15 cm indicated adequate or high K fertility.

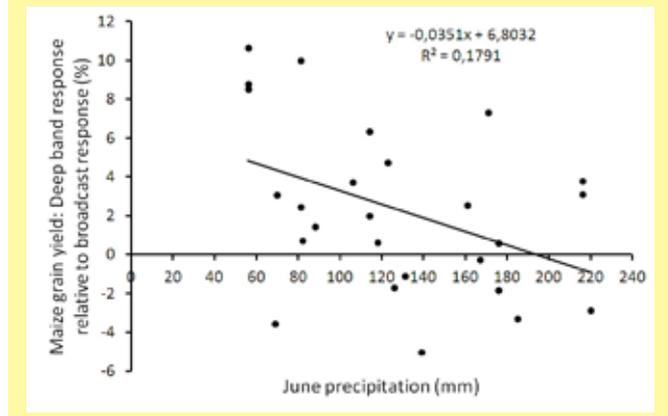
The researchers noticed that there appeared to be a relationship between maize response and weather conditions, just as the researchers from Purdue had theorized:

"It is likely that the responses to deep-banded K were related with weather conditions, particularly soil moisture....The correlations do suggest, however, that response to deep-banded K was greater when there was little rainfall in June."

Their data, which were not graphed in the original publication, are provided in Figure 5. While not strong, there is a trend toward greater yield responses with lower precipitation during June, the month when nutrient accumulation is rapid.

## Summary

Gaining the most yield from an application of K requires knowledge of the cropping system, management practices, genetics, and environmental conditions. For maize grown in the U.S. Corn Belt, farmers have flexibility in gaining the most efficiency from K



**Figure 5.** Maize grain yield response to deep banded K for various amounts of rainfall in June, expressed as a percentage of maize yield attained with broadcast K applications. Positive percentages indicate higher yields with banding (Bordoli and Mallarino, 1998).

fertilization. Periodic, larger applications appear to be just as efficient as smaller, annual ones. At lower soil test levels when only low rates of K are applied, banding has greater efficiency; however at higher rates, broadcast and banded applications may be equally effective. In reduced tillage systems, a deep band of K below the crop row may be a good strategy to minimize malnutrition problems if the growing season becomes dry during periods of rapid nutrient uptake.

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# Is Potassium Fertilizer Really Necessary?

T.S. Murrell

*Potassium is required by plants. Not applying K on soils with low indigenous supplies limits yields and production and is considered a form of land degradation. On soils with high indigenous supplies, omitting K will not reduce yields or production; however, continued withdrawal of K through successive crop harvests will eventually deplete indigenous supplies to yield-limiting levels, as has been observed in several areas around the world.*

Plants require 17 nutrients to develop properly. Potassium (K) is one of these and is taken up in large quantities. It is therefore termed a “macronutrient.” Plants get their K from the soil via their roots. Consequently, one of the most basic questions that soil fertility and plant nutrition scientists have addressed over the past several decades is, “How much of a plant’s nutrient needs can be met by what’s already in the soil?”

To determine if a soil already has enough K, scientists apply incremental amounts of K then measure the degree to which plants respond. A zero rate of K, termed a “check” provides a basis for comparison. Increases in growth and yield with K additions, when compared to the check, indicate that the soil supply alone is not sufficient to meet the plant’s requirements.

An experimental design that is often used to measure response is the “omission plot.” Omission plots are a set of treatments that examine how the lack of one nutrient affects yields and nutrient uptake when all other nutrients are at sufficient levels. As an example, a recent meta-analysis from China summarized results from a total of 522 omission plot experiments across three major wheat-growing regions (Liu et al., 2011). The average response to K additions was  $0.74 \text{ Mg ha}^{-1}$ .

Plant response has been and continues to be the basis for determining whether or not K is needed. One general type of approach, termed “plant-based” in this article, relies primarily on these types of plant measurements. The other approach, “soil-testing based” also relies on plant response but incorporates soil analysis. We discuss each of these approaches.

## Plant-Based Approaches

To determine how much of the plant’s nutrient needs can be met by the soil, plant-based approaches use measurements of K uptake. Using omission plots, the “indigenous supply” of K in the soil is found by measuring the total amount of K taken up by plants that are grown where no K has been applied but where all other nutrients are in sufficient quantities (Dobermann et al., 2003). The indigenous soil K supply is compared to the amount of K taken up by plants receiving adequate K. If both quantities are the same, then plant-available K supplies in the soil are sufficient. If K uptake by fertilized plants exceeds the indigenous K supply, then the soil supply of K is inadequate.

Because it is not feasible to put omission trials on every parcel of ground that is to be evaluated, scientists assemble data from various sites and years where such trials have been conducted and create models that help them estimate indigenous soil K supplies and total

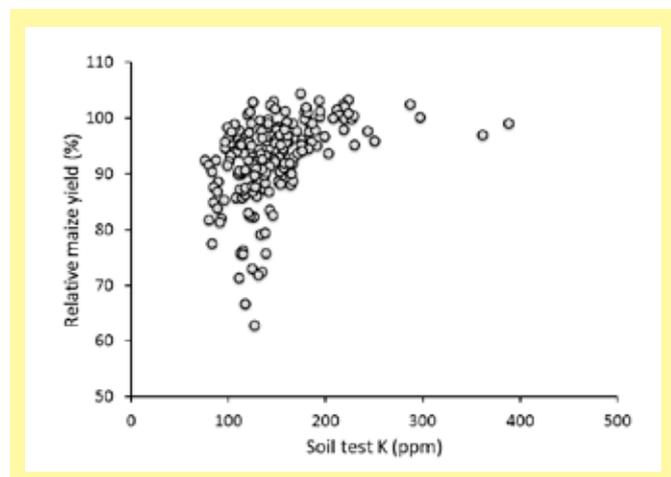
uptake requirements for areas where no data exist. An example of this approach is Nutrient Expert (Pampolino, 2012).

## Soil Testing-Based Approaches

Soil testing is another approach to determining how much of the plant’s nutrient needs can be met by the soil. It is also built around plant response, but the emphasis has most commonly been on yield response rather than on nutrient uptake.

Soil testing was developed to provide a method for predicting, before a crop is grown, whether or not soil K supplies are adequate (Bray, 1944). Soil testing usually uses chemical solutions to remove a portion of the K from soil particle surfaces that is considered to be plant-available. Because of the way these extracting solutions work, the K that is measured is termed “exchangeable K.” It is not a direct measure of the total amount of K available for plant uptake. Instead, it is simply an index that must be related to plant response to have any agronomic meaning. Creating this relationship is accomplished with a calibration study.

In a calibration study, a representative sample of the soil is taken from the experimental site and analyzed for exchangeable K. Then one of two experiments is conducted. The first option is an omission plot, like that described above, where crop yield without K (the check) is compared to crop yield fertilized with K. The second option is a K rate study, where incremental rates of K, including a check, are applied. The first approach measures yield response only. The second approach measures not only yield response but, when combined with statistical models, the quantity of K that was needed to just reach



**Figure 1.** An example of soil test calibration data (adapted from Barbagelata and Mallarino, 2013).



**Nutrient omission plots** in spring wheat at the Experimental Agricultural Enterprise "Omskiy" of the Siberian Research Institute of Agriculture, Omsk District (left to right: Dr. N.A. Voronkova and Dr. V.V. Nosov). *Photo taken by V. Nosov.*

the highest yield attainable at that site. The yield of the crop grown without K is expressed as a percentage of the yield obtained with sufficient K. This percentage, called "relative yield" indicates whether or not the indigenous supply of K is adequate. A relative yield less than 100% signals deficiency. The soil test level measured at that site is then associated with the observed relative yield. This association indicates what percent of the attainable yield can be met by the supply of indigenous soil K indexed by the soil test (Dahnke and Olson, 1990).

A recent example of such a calibration comes from Iowa State University (Barbagelata and Mallarino, 2013) and is shown in **Figure 1**. Each point in the figure comes from one study conducted in one year, what scientists call a "site-year." The figure demonstrates that when many site-years of data are combined, a generalized relationship emerges: as the soil test level of K declines, crop yields decline when left unfertilized, indicated by lower relative yields. Such a relationship forms the basis of soil testing-based approaches that predict whether or not soil supplies of plant-available K are adequate at any given location.

## Nutrient Budgets

A key component of both plant-based and soil testing-based approaches is the nutrient budget. It is calculated by subtracting the amount of K removed from a parcel of land from the quantity of K applied. Positive budgets indicate K enrichment while negative ones signal K depletion. Most often, "partial budgets" are calculated. These simplified budgets compare: 1) nutrients removed with harvested portions of plants, termed "crop removal" and 2) K applied with commercial fertilizers, manure, and/or biosolids. These budgets are partial because they do not consider all inputs and outputs.

Potassium budgets are of great interest to scientists around the world. They indicate whether agricultural practices are depleting, enriching, or maintaining indigenous K supplies. Where indigenous supplies of K are low, enrichment is appropriate. Depletion is appropriate where indigenous supplies are high, such as in more arid agricultural areas; however, there is a caveat to depletion. If it occurs long enough on soils with high

amounts of K, the indigenous supply eventually becomes inadequate for crops.

At a workshop held in Uganda, stakeholders determined that negative nutrient budgets should be used as an indicator of land degradation (Bekunda and Manzi, 2003). The stakeholders were farmers, traders, decision and policy makers, staff of extension, researchers, and development organizations. Case studies demonstrated that, "...commercial farmers appear not to be re-investing some of the sale proceeds into replacing nutrients removed in harvests..."

Thus, K applications must not only provide enough K to meet crop needs, they also need to sustain plant-available soil K supplies over the long term.

## Conclusion

Potassium is required by plants. Not applying K on soils with low indigenous supplies limits yields and production and is considered a form of land degradation. On soils with high indigenous supplies, omitting K will not reduce yields or production; however, continued withdrawal of K through successive crop harvests will eventually deplete indigenous supplies to yield-limiting levels, as has been observed in several areas around the world.

Potassium fertilizer is necessary. Both plant-based and soil testing-based approaches inform decisions about whether or not a K application is needed to provide plants with adequate nutrition and to sustain soil productivity.

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# Potassium fertilizer significantly improved potato yields in Yunnan province, China

Mei Yin, Lifang Hong and Shihua Tu

*Applications of potassium (K) fertilizer significantly increased potato yields and economic returns, but the responses of potato grown in two different types of productivity soils varied considerably. The optimal K fertilizer rates were found to be 270 kg K<sub>2</sub>O/ha in the high productivity soil and 135 kg K<sub>2</sub>O/ha in the low productivity soil. The application of potassium fertilizer should be timed to coincide with the maximum accumulation of dry matter and potassium by the crop during its fast growing stages.*

Potato is one of the most widely cultivated crops in China and it ranks third after only maize and rice in Yunnan province, southwest China; 703,000 hectares of potatoes were planted in 2012. However, potato yields are usually low even under the favorable climatic conditions in Yunnan. Low fertilizer use and imbalanced nutrient application, especially insufficient or lack of potassium fertilizer, are considered to be partially responsible for low yields and quality throughout (Duan et al., 2013). Therefore, a project was launched in 2012 to study the effects of different K rates on potato yields in two acid red soils with low and high fertility/productivity at two separate locations - Yuezhou and Dongshan in Qujing District, Yunnan - and to ultimately determine the optimal K rate for potato production in the region. The low fertility soil in Yuezhou was tested and found to be low in soil organic matter and deficient in nitrogen (N) and K, while the high fertility soil in Dongshan was sufficient in organic matter and had adequate N and K (Table 1).

The field experiments were set up in a randomized complete block design with four K rates (0, 135, 270 and 405 kg K<sub>2</sub>O/ha) and three replications. A combination of 150 kg N/ha and 90 kg P<sub>2</sub>O<sub>5</sub>/ha was added to each treatment in addition to the designated K rate. The plot size was 20 m<sup>2</sup> (4×5 m). The sources of fertilizers were urea (N 46%) for N, single superphosphate (P<sub>2</sub>O<sub>5</sub> 12%)



Potato field

for P and potassium chloride (K<sub>2</sub>O 60%) for K. Fertilizer N was split as basal (50%) and topdressing (50% at the tuber bulking stage) applications. Fertilizer K was split as a basal dose (50%) and a topdressing (50%) at the tuber bulking stage. All of fertilizer P was used as basal application. The potato variety Hezuo 88 was selected as the testing crop and seeded in March and harvested in mid-August 2012.

The potato was rainfed without irrigation throughout the growing season. Plant samples were collected at each growth stage to determine dry biomass accumulation and to analyze K uptake by shoot and tuber. At harvest, the potato shoot and tuber of each treatment were harvested, weighed and recorded separately. Plant samples were taken to analyze nutrient uptake by shoot and tuber. K use efficiency and economic analysis were conducted.

## Effects of potassium fertilizer on potato tuber yield

Different soil fertility/productivity had a significant effect on potato yields (Table 2). Potato yields from the high fertility/productivity soil at the Dongshan site were double or more than double those in the low fertility/productivity soil at the Yuezhou site, regardless of the K rate. In the low fertility soil, potato yields increased significantly with an increase in K rates without levelling off. Yield increases ranged from 12.70% to 21.33%. In the high fertility soil at the Dongshan site, however, though potato yields significantly increased with an increase in

**Table 1.** Some of the selected properties of the soils in study.

Experiment site	pH	Organic matter (g/kg)	Alkali-hydr. N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
Yuezhou	5,1	26,2	69,9	12,9	77,8
Dongshan	5,0	44,4	108,4	12,4	105,8

**Table 2.** Potato tuber yields as affected by different K rates at two trial sites

Trial site	K rate, kg K <sub>2</sub> O/ha	Tuber yield, kg/ha	Yield increase due to K	
			kg/ha	%
Yuezhou	0	10830 c	–	–
	135	12205 b	1375	12,70
	270	12585 b	1755	16,20
	405	13140 a	2310	21,33
Dongshan	0	21135 c	–	–
	135	27225 b	6090	28,81
	270	32715 a	11580	54,79
		28050 b	6915	32,72

**Table 3.** Biomass accumulation of potato as affected by different K rates during growth periods

Trial site	K rate, kg K <sub>2</sub> O/ha	Seedling	Tuber initiation		Tuber bulking		Starch filling		Harvest	
		Shoot	Shoot	Tuber*	Shoot	Tuber	Shoot	Tuber	Shoot	Tuber
kg/ha										
Yuezhou	0	139,95	627,15	18,00	758,70	722,70	940,80	1344,00	1083,00	2166,00
	135	139,95	750,15	13,05	882,15	868,05	1115,10	1607,40	1220,55	2440,95
	270	145,05	758,40	18,00	916,20	970,20	1137,60	1698,00	1358,55	2517,00
	405	145,05	762,30	15,00	966,75	982,35	1234,95	1762,05	1314,00	2628,00
Dongshan	0	241,95	919,95	63,90	1030,20	1204,95	1398,15	3856,65	1568,10	4327,05
	135	235,95	940,05	63,90	1320,30	1249,95	1783,50	4441,65	1833,45	5545,05
	270	241,95	960,00	58,65	1458,15	1414,95	2130,45	4788,30	2233,50	6544,05
		240,00	1000,05	63,90	1407,15	1530,00	2209,05	4983,30	2283,00	5910,00

\* Here potato tuber biomass includes both tuber and root

**Table 4.** K uptake by potato at different growing stages as affected by K rates at sites

Trial site	K rate kgK <sub>2</sub> O/ha	Seedling		Tuber initiation		Tuber bulking		Starch filling		Harvest	
		kg/ha	g/ha.d	kg/ha	g/ha.d	kg/ha	g/ha.d	kg/ha	g/ha.d	kg/ha	g/ha.d
Юежоу	0	7,04	0,12	25,35	1,41	21,98	1,05	26,15	1,87	6,08	0,23
	135	7,20	0,12	33,72	1,87	26,74	1,27	35,72	2,55	1,41	0,05
	270	7,71	0,13	34,4	1,91	28,51	1,36	39,11	2,79	10,19	0,38
	405	8,1	0,14	35,31	1,96	31,57	1,50	45,50	3,25	3,35	0,12
Донгшан	0	12,17	0,22	36,61	1,74	31,89	2,13	100,67	6,71	0,12	0,01
	135	12,14	0,22	40,83	1,94	46,74	3,12	132,44	8,83	1,71	0,12
	270	12,86	0,23	41,75	1,99	53,69	3,58	155,02	10,33	1,52	0,11
	405	12,74	0,24	45,93	2,16	53,65	3,58	168,62	11,24	0,04	0

**Table 5.** The economic benefits of potato as affected by K rate at two sites

Trial site	K rate, kg K <sub>2</sub> O/ha	Tuber yield, kg/ha	Output	Cost	Net income	Income increase,
				\$/ha		%
Yuezhou	0	10830	2130,49	256,60	1873,89	-
	135	12205	2400,98	420,49	1980,25	5,68
	270	12585	2475,74	584,88	1890,86	0,91
	405	13140	2585,90	749,02	1835,90	-2,03
Dongshan	0	21135	4157,70	256,60	4144,55	-
	135	27225	5355,74	420,49	4935,00	19,07
	270	32715	6438,20	584,88	5852,88	41,22
		28050	5518,03	749,02	4769,02	15,07

K rates, the yield levelled off at 270 kg K<sub>2</sub>O/ha and then decreased with a further increase in the K rate. Yield increases ranged from 28.81% to 54.79%, much higher than those in the low fertility soil. The potato yield at 270 kg K<sub>2</sub>O/ha in the high fertility soil reached 32715 kg/ha, 160% higher than in the low fertility soil. The yield response curve of potato to different K rates in the high fertility soil was typical (Karam et al., 2009) and the curve in the low fertility soil was less common but also reported by Kelling et al. (2002) and Singh and Lal (2012). This implies that potato yields in the low fertility soil cannot be enhanced to the levels of the high fertility soil by adding K fertilizer alone. There must be other yield-limiting factors besides K which require further research. Thus, the optimal K rate was 135 kg K<sub>2</sub>O/ha in the low productivity soil, since higher K rates, despite yield increases, produced little or no economic benefit (Table 5).

### Biomass accumulation at different growing stages

The results in Table 3 showed clear trends of biomass accumulation for both shoot and tuber during the growing season at two sites. The fast biomass accumulation periods were from the tuber initiation stage to the starch filling stage for shoot and from the tuber bulking stage to the harvest stage for tuber. During the fast biomass accumulation periods, shoot and tuber weights increased with an increase in K rates. The dry matter weight of potato tissues at the Dongshan site was much higher or even double those at the Yuezhou site. According to the potato biomass accumulation patterns, K fertilizers should be applied at the seedling-tuber initiation stages to better meet its nutrient requirement for fast growth and tuber development (Guo et al., 2011).

**Table 6.** K use efficiency and agronomic efficiency as affected by different K application levels at two sites

Trial site	K rate, kg K <sub>2</sub> O/ha	K uptake by potato, kg/ha	K use efficiency, %	K agronomic efficiency, kg/kg
Yuezhou	0	87	-	-
	135	103	12,43	10,19
	270	120	12,34	6,50
	405	124	9,19	5,70
Dongshan	0	182	-	-
	135	234	38,81	45,11
	270	265	30,88	42,93
		281	24,57	17,07

### Tissue K accumulation at different growing stages

K accumulation occurred quickly from the tuber initiation stage to the starch filling stages and reached its peak values of 26.15-45.50 kg/ha at the Yuezhou site and 100.67-168.62 kg/ha at the Dongshan site at the starch filling stage (Table 4). These values were much higher than N or P accumulated in potato at the starch filling stage (data not shown), because K is the most required of the essential nutrients (Westermann, 2005). At the harvest stage, very little K was absorbed by potato plants. These results are in line with the studies of Gao et al. (2003) and Lu et al. (2013). The results imply that the stages when K is absorbed quickly are when adequate supply of K is essential for both potato yield and quality (Guo et al., 2011). The addition of K fertilizer to potato plants after the starch filling stage is of little significance; a similar report pointed out no yield or efficiency advantage for applying K later (Kelling et al., 2002).

### Economic benefits of K fertilization

At the Yuezhou site, only the 135 kg/ha K rate was economically beneficial; higher rates were of little or no economic value compared to the omission treatment (Table 5). At the Dongshan site, however, economic benefits increased with an increase in K rates and leveled off at 270 kg K<sub>2</sub>O/ha. Further increases in the K rate decreased the economic benefit. Net income due to K fertilization at the Dongshan site was more than double compared with the Yuezhou site. The results further indicate that higher K rates should be applied to potato plants in high fertility soil for higher yield increases and higher economic returns.

### K use efficiency

K use efficiency and agronomic efficiency decreased with an increase in K rates at the two sites (Table 6). Both values were much higher at the Dongshan site than at the Yuezhou site. As usual, fertilizer use efficiency of a crop is higher in low fertility soil than in high fertility soil. The experiment at the Yuezhou site produced the opposite results. This implies that there must be some other yield-limiting factors other than K which impeded potato growth as well as its response to added K. Besides, as reported by Kelling et al. (2002), yearly weather

variations may be, at least partly, responsible for the poor response of potato to added K in the low fertility soil.

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Omission K plots

# First results of research project on the improvement of K fertiliser recommendations in intensive cropping systems in Russia

S.E. Ivanova, V.A. Romanenkov, L.V. Nikitina

The level of K fertilizer use is an indicator of intensity in crop production. Unfortunately, potash fertiliser application rates in Russia have decreased in the last 10–15 years to 1–2 kg K<sub>2</sub>O per hectare of cropped area; with long-term removal of K exceeding K inputs the negative K budgets are being observed in various agricultural zones of the country from –16 to –30 kg K<sub>2</sub>O/ha (Shafran, Sychev, 2013).

Currently in Russia, potash is mainly applied as part of compound fertilisers, which do not always ensure a balanced potassium supply for plants.

The continuous removal of potassium by crop and the incomplete return of the element with fertilisers lead to a slow but permanent decrease in the content of plant-available potassium in arable soils; its mobility in soil decreases, as well as the capacity of soil to restore the initial content of plant available potassium. The final result is a loss of yield and decreased crop quality.

Moreover, the negative K balance might lead to increased soil fixing capacity, and the low rates of potassium applied as part of compound fertilisers then have almost no effect on crop yields.

It is well-known that regular potash application in agro-ecosystems is necessary for them to function effectively. Nonetheless, the issue of optimizing of the potassium status of arable soils in Russia still receives insufficient attention. This attitude is largely related to the imperfect diagnostics of arable soil fertility in terms of potassium supply, which to a large extent depends on the routine method used to measure the content of plant available K in soil. It is preferable to use a combination of different methods, which will allow more accurate predictions of crop response to potash fertilisers and determining scientifically-based application rates.

Therefore, the optimisation of potash application rates and verification of currently used routine soil K test methods are priority issues for the research project jointly organised by the International Plant Nutrition

Institute (IPNI) and the D. Pryanishnikov All-Russian Research Institute of Agrochemistry, which started in autumn 2012.

The project is focused on optimisation of potash fertiliser rates in current intensive cropping systems for crops with high demand to K (sugar beet, corn, rape and soybean), as well as checking the measurement potential of routine soil test methods depending on the regional soil properties and adjusting the current soil K test interpretation classes based on the results obtained from shortterm field experiments executed on large industrial farms. The complex approach has been used for the project design included the following issues:

- Determining crop response to potash fertilisers and their effect on crop quality and yield in high-yield crop systems;
- Determining the residual effect of potash applied to the crop with highest demand in potash;
- Evaluating the validity of routinely-used soil K test methods, and corresponding interpretation classes ;
- Assessing of crop removal and nutrient balance in trials;
- Assessing potash fertiliser economic efficiency.

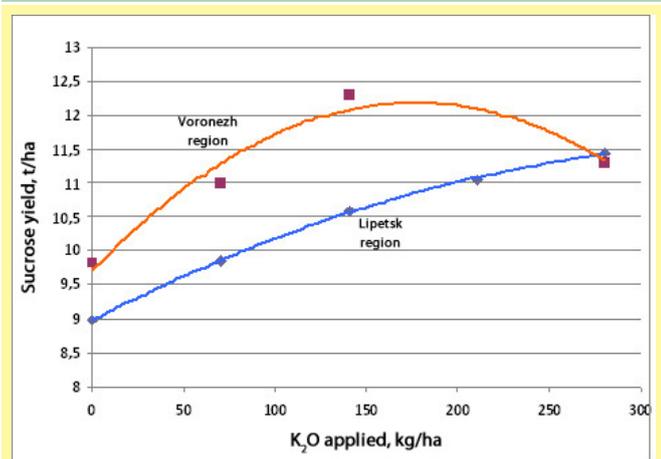
The methodological basis of the research is three-year field experiments with increasing K rates applied to crops with high demand in K such as sugar beet, grain corn, soybean and rapeseed, which are grown intensively on large industrial farm in the Central Russia and North Caucasian regions.

Experiments are being carried out in the Lipetsk, Voronezh, Belgorod, and Rostov regions by the regional centres of the Russian State Agrochemical Service. The soil types being investigated are leached chernozem (Voronezh region), typical chernozem (Belgorod and



**Table 1.** Effect of K application on sugar beet root yield and sucrose yield

	Root yield, t/ha	Sucrose yield, t/ha	Root yield, t/ha	Sucrose yield, t/ha
Region	Voronezh region		Lipetsk region	
Yield in NP treatment (background)	66.21	9.82	56.91	8.97
Maximum yield in treatments with potassium(NPK)	80.39	12.30	69.31	11.44
Maximum yield increase due to potash	14.18	2.48	12.40	2.47
LCD 0.05	9,59		1,16	



**Figure 1.** Effect of potash fertiliser application on sucrose yield in 2013 field experiments.

Voronezh regions), podzolized chernozem (Lipetsk region), calcareous ordinary chernozem (Rostov region) and dark grey forest soil (Lipetsk region).

All industrial farms that participated in the project have much higher yields than the regional average. For example, all farms chosen for the sugar beet trials have average root yields above 55 t/ha. It is important to highlight that there are currently no potash fertiliser recommendations in Russia for obtaining such high yields. Therefore, the aim of the project is to be a unique source of information targeted first and foremost at agricultural producers, enabling them to obtain high yields.

The project's first year results are very promising for all crops studied. However, this article only covers data obtained from sugar beet and grain corn trials in Central Russia after the first growing season (2012–13).

**Sugar beet.** Experimental plots in Lipetsk and Voronezh regions have been launched on chernozem soils with “increased” (higher than medium) content of plant available potassium routinely extracted by Chirikov method (0.5M CH<sub>3</sub>COOH).

The treatments included:

- Absolute control (without fertilisers);
- Background treatment — nitrogen and

phosphate treatment with optimal rates to planned high yield according to the each farm practice (NP);

- NP+ K70 (NPK1);
- NP+ K140 (NPK2);
- NP + K210 (NPK3);
- NP + K280 (NPK4).

Potash fertilisers have been applied in the form of potassium chloride (KCl). The rates of K fertilisers to be applied were calculated taking into account the possible residual effect on the two subsequent crops. Each trial utilised crop management technology.

In the sugar beet trials the aim was to obtain a high sugar beet root yield with an acceptable sucrose concentration in the roots (not less than 14%).

In the experiment conducted in the Voronezh region, the application of K fertilisers led to very high yields (more than 80 t/ha) combined with an acceptable concentration of sucrose in the roots (more than 14%). The highest yield of sugar beet roots and sucrose was achieved when applying 140 kg K<sub>2</sub>O/ha (NPK2). Yields therefore increased by 21% or 14 t/ha due to the application of potash compared to the background treatment. Moreover, potash fertilisers increased not only root yields but the sucrose concentration in roots as well. As a result, the sucrose yield increased by 2.5 t/ha, equivalent to 25% (**Table.1, Fig. 1**). The same rate provided the best economic efficiency of K application.

An evaluation of economic efficiency of potassium fertiliser application showed that for the treatment (NPK2) with the highest achieved yield (80 t/ha) the maximum increase in profitability due to K was 23%, which resulted in a net profit increase due to K of 22,000 roubles per ha and a decrease in production cost by 130 roubles per tonne of root yield (**Table 2**).

In the Lipetsk region, the sugar beet root yield was slightly lower than in the Voronezh region at approximately 57 t/ha. However, yield increase due to the application of different K rates was observed in all treatment categories. The maximum root yield was achieved by applying 280 kg K<sub>2</sub>O/ha (NPK4). At this rate, the root yield increase was 12.4 t/ha or 22% higher than in the background treatment. The sucrose yield

**Table 2.** Economic efficiency of potassium fertiliser application in comparison with the background treatment (NP)\*

Treatment	Profitability increase due to K, %	Profit increase due to K, roubles/ha	Profitability increase due to K, %	Profit increase due to K, roubles/ha
Voronezh region, sugar beet		Lipetsk region, sugar beet		
NPK1	14	10 619	10	5 298
NPK2	34	22 297	16	8 757
NPK3	16	11 874	20	10 774
NPK4	17	12 701	23	12 401
Belgorod region, grain corn		Voronezh region, grain corn		
NPK1	10	2 344	2	2 111
NPK2	7	2 763	27	7 974
NPK3	5	3 182	-9	3 184
NPK4	1	3 335	-37	-534

\* Costs were calculated based on the price of potassium fertilisers of 7,700 roubles per metric tonne of KCl.

Treatment	Date of measurement			
	7 Aug 13	27 Aug 13	11 Sept 13	26 Sept 13
Control	15.1	16.1	14.0	14.3
Background (NP)	15.6	16.6	13.5	14.7
Background+K140	14.6	16.8	13.7	14.9
Background+K280	15.7	17.5	12.2	14.6

Treatment	K <sub>2</sub> O rate, kg/ ha	Yield, t/ha	Yield increase due to K, t/ha
Control	-	9.1	-
NP	-	9.8	-
NPK1	60	10.2	0.4
NPK2	120	11.2	1.4
NPK3	180	10.6	0.8
NPK4	240	10.2	0.4
LCD 0.05		0,93	

increased by 2.5 t/ha, equivalent to a more substantial yield increase of 28%. The same rate provided the best economic efficiency.

An evaluation of economic efficiency of potassium fertilisers application showed that for the NPK4 treatment with the highest achieved yield (57 t/ha) the increase in profitability due to K was 23%, which resulted in a net profit increase of 12,000 roubles/ha and a decrease in production cost by 142 roubles/t root yield (Table 2).

As part of the sugar beet experiment in the Voronezh region, the dynamics of sugar accumulation in the roots were studied during the vegetation period until harvesting in autumn 2013. This period was characterised by intensive rainfall (for the majority of September) which resulted in delays to sugar beet harvesting. Sucrose concentration in the roots was measured starting from 7 August 2013. Analysis of the sugar accumulation dynamics (Table 3) showed that the sucrose concentration in roots in treatments with potassium chloride (KCI) increased by 0.2–0.9% at the end of August compared to the background treatment and then decreased substantially by 1.9–2.9%. Sucrose concentration in the roots was still above the acceptable level of 14% (Table 3). This decrease in sugar content in September was a result of the intense growth of the sugar beet plants during the period of abundant

Treatment	K <sub>2</sub> O rate, kg/ ha	Yield, t/ha	Yield increase due to K, t/ha
Control	-	6.4	-
NP	-	7.5	-
NPK1	70	8.4	0.9
NPK2	140	8.7	1.2
NPK3	210	9.1	1.6
NPK4	280	9.4	1.9
LCD 0.05		1,2	



**Рис. 2.** Сахарная свекла, производственный опыт, Воронеж, 2013.

rainfall.

The highest values were observed on 27 August for the K280 treatment. The growth of sugar beet plants led to a reduction in the difference in sugar accumulation between the treatments, which explains the maximum sucrose concentration being achieved with the K140 treatment at harvesting (beginning of October).

These results demonstrate that it is possible to increase sugar concentration in the roots to more than 16% by applying potash fertilisers at the same time as achieving high yields. Therefore, both weather conditions and the harvesting timing are important factors that influence the accumulation of sugar in the roots and sucrose yield. This must be taken into account for crop management planning.

Grain corn. In the grain corn experiment, the following treatments were used:

Absolute control (without fertilisers);

Background treatment –NP at optimal levels to achieve high yields;

Background +4 increasing K rates (K60–K280).

Potash fertilizers have been applied as potassium chloride. The rates of K fertilisers were calculated taking into account the possible residual effect on the two subsequent crops.

In the field experiment in the Voronezh region, the maximum grain yield was achieved at K120, a yield increase of 1.4 t/ha, or 14% compared to the background treatment alone (Table 4). Therefore, every 1 kg K<sub>2</sub>O resulted additional 12 kg of grain. The same level of application provided the best economic efficiency. The net profit increase amounted to 7,974 rubles per hectare, profitability increased by 27% and production costs decreased by 70 rubles per tonne of grain (Table 2).

In the field experiment on grain corn in the Belgorod region, the maximum grain yield (9.4 t/ ha) was achieved at a K<sub>2</sub>O rate 280 kg/ha. In this treatment, yields increased by 1.9 t/ha, or 25% compared to the background treatment alone (Table 5).

Potash application led to an additional 7 kg of grain production per 1 kg of K<sub>2</sub>O. The same level of application provided the best economic efficiency. The net profit increase amounted to 3,300 rubles per hectare, profitability increased by 10% and production costs decreased by 100 rubles per tonne

of grain (Table 2).

Based on the project's first-year results with regard to sugar beet and grain corn, one can conclude that the substantial yield increases at all levels of potash fertiliser application in comparison to the background treatment show that there can be significant yield losses when potash fertiliser is not applied, even on soils with

increased and high content of plant available K.

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# Potassium Budgets: Mapping Potassium Balances Across Different States of India

S. Dutta, K. Majumdar, G. Sulewski, T. Satyanarayana, A. Johnston

*Potassium input-output balances in different states of India were estimated and mapped using the IPNI NuGIS approach. Results showed negative K balances in most of the states suggesting deficit potassium application as compared to crop K uptake. Deficit application of K contributes to nutrient mining from soil, results in the depletion of soil fertility and may significantly limit future crop yields.*

Agricultural systems in India have been intensified significantly after independence, with better irrigation facilities, introduction of high-yielding (HYV) and hybrid crop varieties with far higher yield potentials than local varieties, and of course, a concomitant increase in fertilizer nutrient use in crops. Food grain production increased five-fold, from 51 million tonnes (Mt) in 1950-51 to over 250 Mt at present, while fertilizer nutrient (N + P<sub>2</sub>O<sub>5</sub> + K<sub>2</sub>O) consumption increased by nearly 400 times during the same period. However, such increase in nutrient consumption was not in balanced proportion among N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O leading to nutrient input – output imbalance. This is especially true for K<sub>2</sub>O because historically K application to crops in India has remained inadequate although the K requirements of many crops are equal to or more than their N requirements.

Several studies have highlighted the disparity between nutrient input-output balances in Indian soils and widespread deficit of plant nutrients in soils. It was also reported that out of the net negative NPK balance or annual depletion of 9.7 Mt, N and P depletions were 19 and 12 %, respectively, while 69% of the depletion was attributed to K. Therefore, K application in Indian soils is much less than K uptake by crops, thereby leading to mining of native soil K. The general assumption that most Indian soils are well supplied with K and do not require any K application may not hold true for intensive cropping systems presently practiced in the country. A soil well supplied with K for a yield level of 1–2 t/ha may turn out to be deficient in K as the yield target moves up due to the availability of better seeds, management options, etc. This clearly indicates the necessity of assessing K balance periodically in intensively cropped areas to avoid unwanted decline in soil fertility levels. The present study utilized standard data sources and methodologies to assess the changes in K balance across different states of India over a four-year interval (i.e., from 2007 to 2011).

## Determination of Potassium Balances

The study analyzed the amount of potash fertilizer received by agricultural soils through inorganic and organic sources and the removal of K by different agricultural crops. Data on fertilizer use and the total amount of recoverable manure used in different states were obtained from the Agriculture Census Division, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India website (<http://inputsurvey.dacnet.nic.in/districttables.aspx>), and from the Fertiliser Association of India. Information on district-wise K<sub>2</sub>O consumption, through inorganic sources and recoverable manure, were accessed from the above two sources; the amount of manure consumed in each district was multiplied by a certain factor, based on average K content in recoverable manure, to estimate K<sub>2</sub>O contribution from organic sources.

The total K<sub>2</sub>O removal by crops was calculated by multiplying the total production with K<sub>2</sub>O removal

Crop	K <sub>2</sub> O Removal (kg/ton)*
Wheat	24.00
Rice	19.08
Maize	20.88
Barley (grain)	7.30
Chick pea	25.81
Pigeon pea	62.50
Lentil (Vigna radiata)	25.81
Lentil (Lens culinaris)	18.35
Moth bean (Vigna aconitifolia)	25.81
Groundnut (in shell)	8.51
Sesame	2.54
Mustard	9.21
Linseed	11.62
Cotton	14.80
Sugarcane	1.44

\*Sources for the removal values for different crops are listed at: <http://nugis-india.paqinteractive.com/About%20NuGIS/>

Common abbreviations and notes: K = potassium, N = nitrogen; P = phosphorus; t = tonnes.





maintenance of soil health.

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# Soil Potassium in Uruguay: Current Situation and Future Prospects

Mónica Barbazán, Carlos Baudes, Licy Beux, J. Martin Bordoli, Alvaro Califra, Juan D. Cano, Amabelia del Pino, Oswaldo Ernst, Adriana García, Fernando García, Sebastián Mazzilli, and Andres Quincke

*Recent field research in Uruguay has revealed K deficiencies in the main field crops of the country. A preliminary survey indicates that almost 5 million ha would be deficient in K. A critical soil test K level (STK) of 0.34 meq/100g (133 ppm), has been estimated from 50 field trials.*

Efforts to understand K dynamics in soils of Uruguay have been scarce compared with those for understanding N and P dynamics, which have been studied in different situations and cropping systems. Earlier studies in K response to fertilization were done for crops that have high-K requirements such as sugarcane, sugar beet, potato, onion, and cotton, for which some guidelines for fertilizer recommendations based on soil type were established. In grain crops, the first K studies were made in the 60's, and K responses were observed in wheat grown in soils developed from cretaceous sandstones. Two decades later, a few studies in soybean showed little or no K response in northeastern soils. The lack of K studies

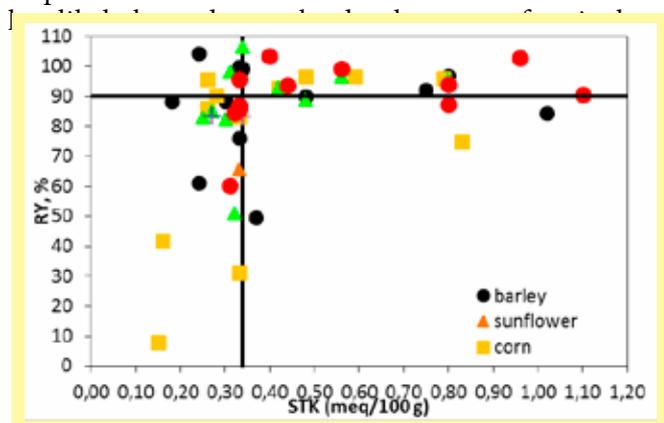
in high K soils, under conventional tillage and crop rotations that included pastures, resulting in no K fertilizer recommendations. Potassium fertilization was recommended only below 0.30 meq/100g (117 ppm), following the references of US Corn Belt, which reported low K response probability with STK over 0.23-0.33 meq/100g (90-130 ppm) in soybean and maize under conventional tillage.

More recently, field research by the faculty of Agronomy (UdelaR), INIA, and other organizations reported some cases of K deficiency symptoms in soils with low STK in maize and *Lotus corniculatus* L. Moreover, the increasingly occurrence of visual K deficiency symptoms, lead to more specific studies, which showed K response in several crops. A summary of 50 recent studies (which had the same tillage system, and similar experimental design, rate, and K source), found a critical STK level of 0.34 meq/100g (133 ppm; 0- 20 cm depth) (Barbazán et al., 2010; 2011), representing a breakthrough in K research in Uruguay (Fig. 1).

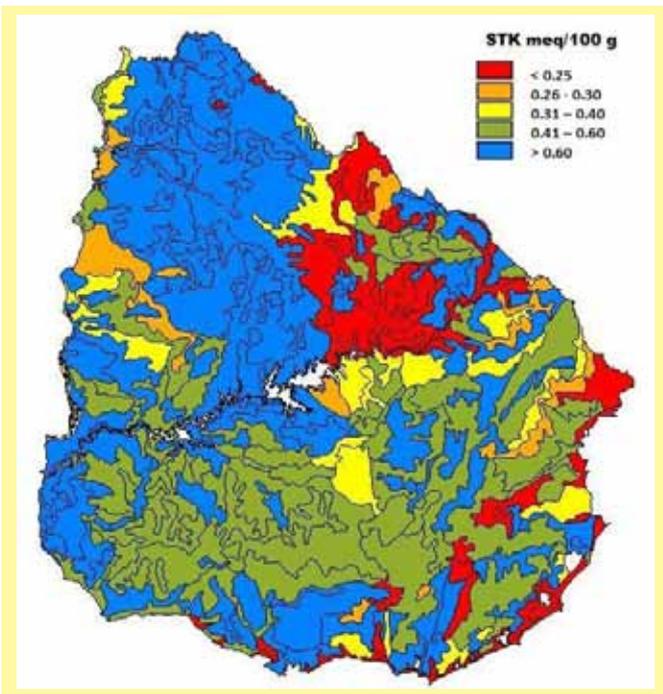
## Soil K levels: Distribution and nutrient balances for Uruguay

Soils of Uruguay present a wide range of STK (Fig. 2). According to the Soil Survey Guide of Uruguay, soil units covering approximately 5 million ha would have low K availability. In the typical agricultural area of western Uruguay, STK is medium to high.

However, agriculture scenarios of Uruguay have



**Fig. 1.** Relationship between relative crop yield (RY) and soil test K (STK; 0-20 cm) in Uruguay. Based on data of 50 field experiments. RY expressed as the percent ratio between averaged yields of Check and Fertilized plots (100-200 kg/ha of KCl). Source: Barbazán et al. (2010, 2011).

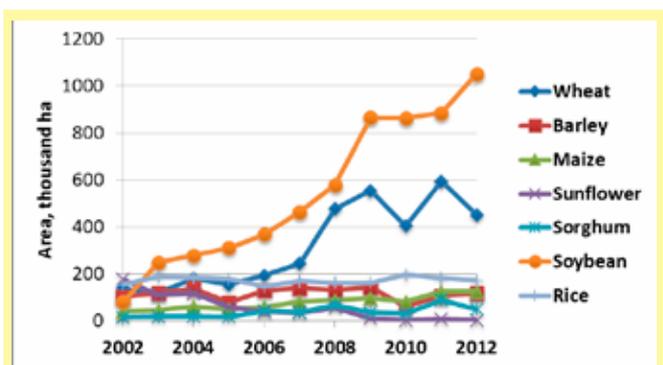


**Fig. 2.** Soil test K (STK; 0-20 cm) according to the soil recognition guide of Uruguay. Scale: 1:1,000,000. From Califra y Barbazán (unpublished).

changed during the last two decades: cropping systems have been intensified, showing a current index of 1.5 crops per year (DIEA, 2015), resulting in soil K depletion. In this sense, it has been reported that STK in soils under agriculture at Department of Soriano, in the western agricultural area, have decreased 40% and 44% at 0-7.5 cm and 7.5-15 cm, respectively, from the levels observed in the same soils without agriculture history. In addition, agriculture has expanded to marginal regions, where low STK soils are common.

The K balances in Uruguay (application minus removal), have historically been negative due to the absence of K fertilization (Mancassola and Casanova, 2015). Moreover, as soybean has increased in area (Fig. 3), due to its high K requirements, K balance has become more negative; i.e., soybean production for 2012 was of 2.76 M t, implying a K removal of approximately 55,000 t of  $K_2O$  considering an average grain content of K.

Understanding soil K dynamics is a priority to define research areas that produce useful information for K management, considering the large agricultural area, and the dependence of imported K fertilizer, moreover



**Fig. 3.** Cropped area by the seven main crops in Uruguay during the 2002-2012 period. Based on DIEA (2015).





of their current prices in Uruguay. Agronomists and farmers are already concerned about STK in the different regions, as reflected by the increasing soil K analysis demand.

Soil K removal has grown with soybean production, which currently covers approximately 1 million hectares through a wide range of soils with different availability and stocks of K. Quality and management of crop residues, may affect K distribution with soil depth, and it should be considered by soil survey/sampling and fertilizer recommendations.

Current research and experimentation focus on the relationship of K dynamics with soil mineralogy and physical properties, and changes in cropping systems and soil management history in the medium and long term. These studies would be useful to develop K fertilization guidelines. Potassium use efficiency depends on understanding of K dynamics in the soil-plant system, as well as crop and soil responses to soil fertility management. Long-term studies would greatly contribute to finding solutions to existing and anticipated problems.

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## Balancing K use in Cereals through Nutrient Expert®: Improved Yield, Higher Profit, and Reduced GHG Emission

Sudarshan Kumar Dutta, Kaushik Majumdar and T. Satyanarayana

*Inadequate and imbalanced application of nutrients, especially of K, by the cereal growers of India leads to less crop productivity and foodgrain production of the country. One of the major reasons of this drawback is associated with the lack of recommendation protocol suitable for small-scale resource challenged farmers. Nutrient Expert® (NE) provides balanced fertilizer recommendation suitable for varied yield target and farmer resource availability. The recommendation from NE guides farmers to apply the required amount of K along with other nutrients to increase productivity, enhance economic benefit and reduce green house gas emission from farm fields.*

The fertilizer consumption in India has increased significantly since last four decades. The Total NPK (N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O) consumption increased twelve times, from nearly 2 million to 25.5 million tonnes between 1969-1970 and 2011-2012 (FAI, 2014). However, there was a disproportion of the consumption ratio among these nutrients. Nitrogenous fertilizer

accounted for nearly 66 per cent of total nutrient consumption in the country (Majumdar et al., 2014); while P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O shares were only 26 and 8 per cent, respectively (FAI, 2014). This is a serious concern particularly in cereal-based cropping systems where removal of K is equal to or more than N. Inadequate K application results in a negative input-output budget

of K that ultimately leads to the mining of soil K reserve (Dutta et al., 2013), adversely affecting crop productivity.

Imbalanced fertilizer application or more specifically less K application in crops is identified as one of the major reasons for decreasing crop response to fertilizer application and the consequent lower crop production growth rate in India. There are enough scientific evidences that highlight the role of K in the yield improvement. Large number of on-farm trials across the Indo-Gangetic Plains showed that no application of potassium reduced average grain yield of rice, wheat and maize by 621, 723 and 699 kg/ha, respectively (Majumdar et al., 2012). Significant yield improvements (up to 2 t/ha yield increase) were also reported in a rice-wheat cropping system by addition of potassium across Indo-Gangetic plain (Majumdar et al., 2014).

Despite the proven economic, social, and environmental benefits of balanced fertilization, the application of potassic fertilizers is yet to gain the momentum as expected among the cereal growers. This could be attributed to the unavailability of a wide scale recommendation mechanism that is suitable for fertilizer prescription to the small-scale farmers and can be used by the frontline extension professionals.

In smallholder systems of India, farmers cultivate small pieces of land, and crop management varies widely depending on farmer awareness and resource availability. Such variable management decisions create large spatial and temporal variability in soil nutrient availability between farm fields. Ideally the fertilizer management in such smallholder landscape should vary and be location-specific to avoid over- or under-use of nutrients. Among several existing fertilizer use practices in India, farmers' fertilization strategies generally lack the necessary integration of information on soil nutrient supply and crop nutrient requirement. State fertilizer recommendations are based on response studies that are extrapolated to large areas, and the spatial and temporal variability in soil nutrient supply between farms is not addressed adequately. In both cases, potassium remained the neglected element, which caused economic loss due to unrealized crop yields (Singh et al., 2013, 2014).

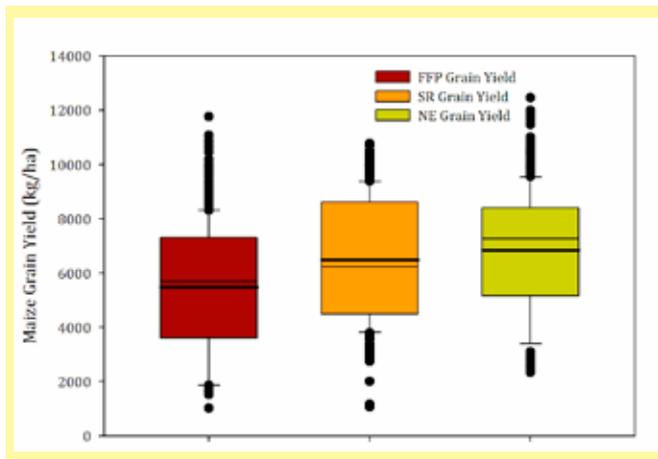
Researchers have successfully used the Site-Specific Nutrient Management (SSNM) principles to ascertain the balanced application rate of nutrients to achieve high yields in cereals in on-farm situations (Witt et al., 1999; Setiyono et al., 2010; Chuan et al., 2013). However, large-scale implementation of SSNM strategies in farmers' fields remained a challenge. IPNI recognized that the lack of an appropriate tool to help farmers and their advisors to quickly develop field-specific recommendations is the major hindrance in on-farm implementation of SSNM. This led to the synthesis of historical and current on-farm nutrient response data by IPNI to develop a fertilizer decision support tool that is easy-to-use and can work with or without soil test results. IPNI was supported in this effort by the International Fertilizer Industry Association (IFA), International Maize and Wheat Improvement Center

(CIMMYT), and a large number of national partners, ranging from National Research and Extension Institutes, Agricultural Universities, State Agriculture Departments, Fertilizer and Seed Industries, and other Non Governmental Organizations (NGO). The outcome of this effort is a dynamic nutrient management tool, the Nutrient Expert® (NE), that can generate farm-specific fertilizer recommendation for major cereals such as maize, wheat, and rice, based on the principles of SSNM (Pampolino et al., 2012). This tool utilizes information of the growing environment to provide balanced fertilizer recommendations that are tailored for a particular location, cropping system and farmer resource availability. The NE tool advocates external application of nutrients, based on indigenous soil nutrient supply and crop nutrient requirement, to achieve a target yield suitable for an individual farmer. Expected outcome from the NE-based balanced and location-specific fertilizer recommendation could be several including improved yield, higher nutrient use efficiency or saving of fertilizer and consequent improved economics of production, and environmental stewardship of applied nutrients.

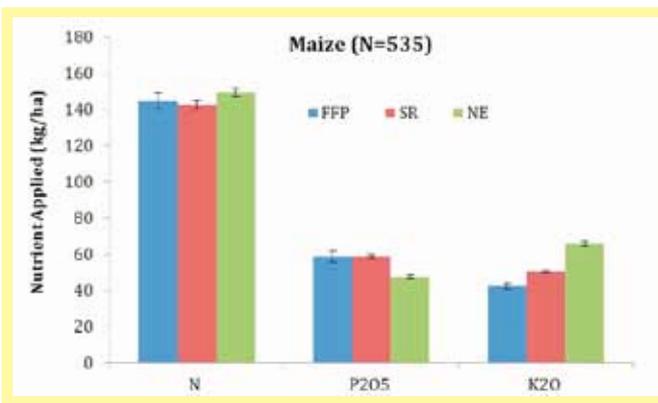
The preliminary target crops for NE development were cereals considering that more than three fourth of the cultivated land in India are under the three major cereals, rice, wheat and maize. These three crops are the major contributors to the total fertilizer consumption in India. At present, NE for wheat and hybrid maize is developed, validated, and released for free public use, while NE for rice is under nation-wide validation with government research and extension organizations. Cotton, sugarcane and soybean are the other three target crops for developing NE in near future.

The NE is a MS Access based computer application that consists of four or five different working modules depending upon the crop; for maize there are five modules while for wheat and rice there are four modules. Through the different modules, and based on farmers' inputs to simple questions, the NE tool estimates the indigenous nutrient supplying capacity of the farmer's field (i.e. contribution from crop residue recycling, addition of organic manures, residual benefit from the previous crop), determines yield responses to application of major NPK nutrients and finally arrives at the most appropriate nutrient recommendation adequate for obtaining the targeted attainable yield. There is an option within this dynamic tool to lower down the yield target considering the resource availability and input purchasing ability of the farmer, and the recommendations are generated on the new lower targeted yield. The nutrient recommendation for a particular field is transformed into fertilizer sources available at farmer's doorstep and finally a 4R compliant (Right Source, Right Rate, Right Time and Right Place) recommendation report is provided to the farmer. A cost analysis associated with the SSNM and the farmers' practice suggests whether or not the fertilizer recommendation intervention would be profitable.

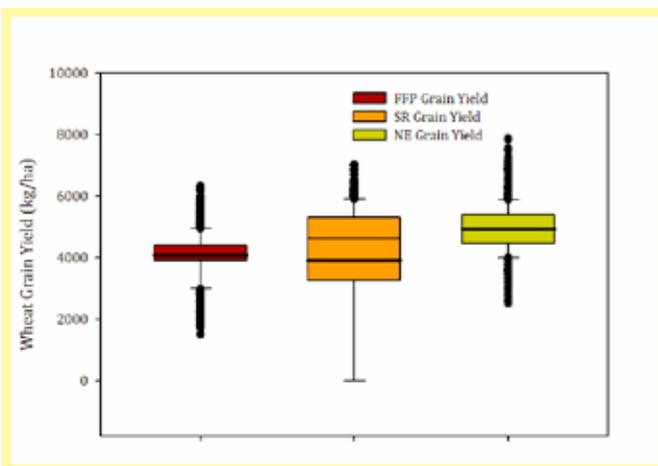
Validation trials of NE – Maize and NE – Wheat were



**Fig. 1.** Average maize grain yield in Nutrient Expert® validation trials (n=535) in India.



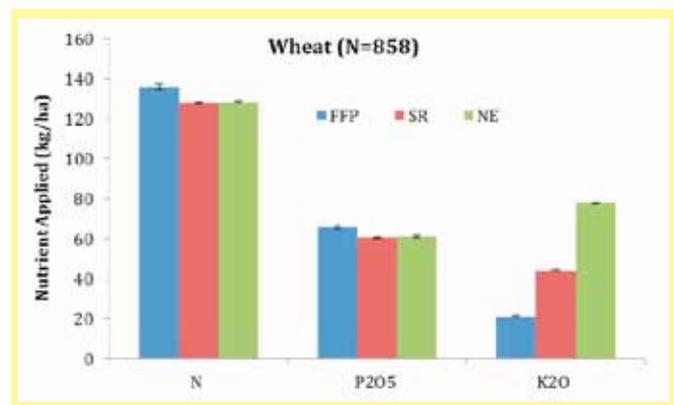
**Fig. 2.** Comparative nutrient application rates in farmers' fertilisation practices (FFP), state recommendations (SR) and Nutrient Expert®-Maize tool-based recommendations (NE) in validation trials.



**Fig. 3.** Average wheat grain yield in Nutrient Expert® validation trials (n=858) in India.

conducted across the major wheat and maize growing areas of India. The NE-based recommendations were compared to the existing fertiliser recommendation practices such as farmers' fertilisation practices (FFP) and state recommendations (SR) in these trials. The three treatments were implemented side-by-side in the same farmer's field where each plot size was  $\geq 100$  m<sup>2</sup>.

The NE - Maize based fertilizer recommendation significantly improved grain yield as compared to FFP and SR across 535 different locations of India

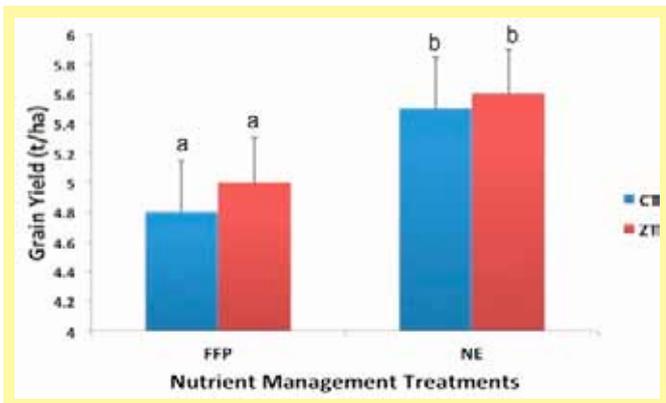


**Fig. 4.** Comparative nutrient application rates in farmers' fertilisation practices (FFP), state recommendations (SR) and Nutrient Expert®-Wheat tool-based recommendations (NE) in validation trials.

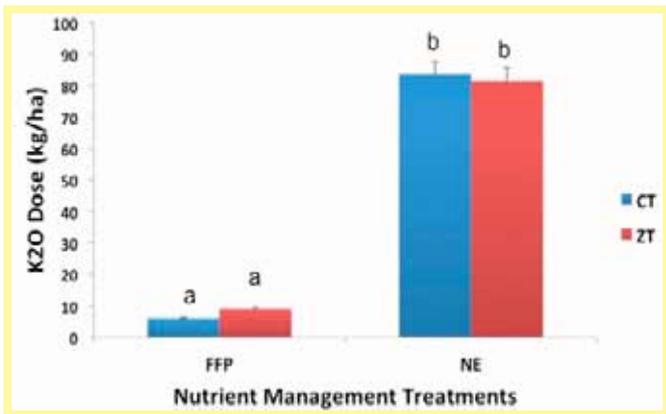
(Figure 1). The nutrients recommended by NE slightly increased N application and decreased P rates over the existing practices. However, NE recommended significantly higher amount of K than FFP or SR; 24 kg/ha over FFP and 15 kg/ha over SR (data not shown). The Nutrient Expert® tool assesses the cropping system nutrient balance based on nutrient application in previous crop (fertilizer + organic manure) and yield of previous crop, and recommends fertilizer rates based on target yield of the current crop. In most situations across 535 sites, the NE tool estimated less than required potassium application in FFP and SR in the cropping system and recommended higher K<sub>2</sub>O rates. The results outlined the lack of K application by existing fertilizer management practices even in a crop like maize that removes large amount of K from the soil. The lack of K application has been flagged earlier as one of the main reasons for decline in maize yield in major production zones of Bangladesh (Timsina et al., 2013).

In the case of wheat, average grain yield was highest (4927 kg/ha) in the NE-based recommendation as compared to FFP (4079 kg/ha) and SR (3897 kg/ha) in the farmers' field validation trials (n = 858) (Fig. 3). The effect of adequate K application on wheat grain is clearly shown in Figure 4. Across all sites, the N and P2O5 rates recommended by NE are either equivalent or less than FFP and SR. However, NE recommended additional 57 and 34 kg/ha of K<sub>2</sub>O than the FFP and SR recommendations. This highlights significant imbalance in wheat nutrient management adopted by farmers and balancing application rates with required amount of potassium increased grain yield by about 1 t/ha. Most of the validation trials in wheat were done in the Trans-Gangetic Plain region of India including the states of Punjab and Haryana. The farmers in this region typically apply inadequate amounts of K to crops because of the perception that the soils in this region has adequate available potassium due to its illitic mineralogy and high K addition through irrigation water. However, the results of our study clearly indicate significant yield advantage in wheat with balanced and adequate K application.

Dutta et al., (2014) reported on-farm validation trials (n = 109) of NE-Wheat that assessed the



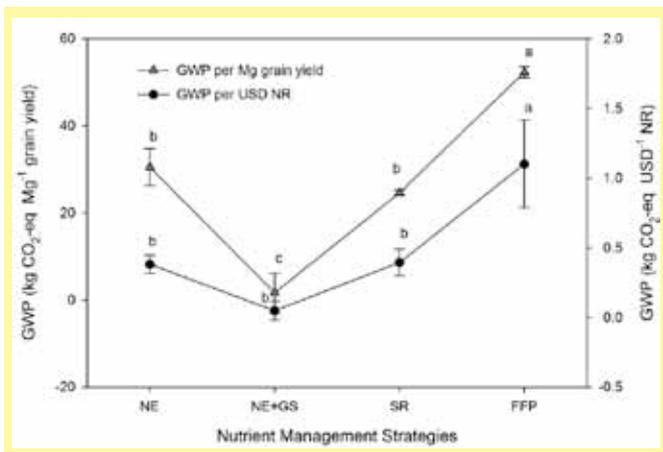
**Fig. 5.** Grain yield of wheat across different nutrient management and tillage practices. Yield with different letters are significantly ( $p \leq 0.01$ ) different



**Fig. 6.** Fertilizer K<sub>2</sub>O rates across different treatments while considering all the locations. Dose with different letters are significantly ( $p \leq 0.05$ ) different.

suitability of the Nutrient Expert® tool to provide recommendation for conventional and zero-till wheat. Establishment of wheat under zero-till conditions is gaining popularity to reduce the turn-over time between rainy season rice and winter wheat. Several new innovations in machinery now allow smallholder farmers to plant wheat on standing residue of the previous rice crop. The reported study assessed 65 on-farm trials under conventional tillage (CT) and 44 trials under zero tillage (ZT) condition, and compared the results of farmers' fertilizer practices with NE-based recommendations. Results showed a significant ( $p \leq 0.01$ ) increase in wheat yield through NE recommendations over FFP (Figure 5). It was also observed that there were significant increase in K application through NE based recommendation over FFP under both ZT and CT situation (Figure 6). The B:C ratio of NE treatment was four fold higher than that of FFP (Dutta et al., 2014).

Apart from yield improvement and improving economics, the NE-based recommendations also reduced the Greenhouse Gas (GHG) emission from farm fields in Northwestern India. A recent study (Sapkota et al., 2014) in wheat highlighted that NE recommendation reduced the emission of the GHGs that leads to less Global Warming Potential (GWP). The study showed that the estimated GWP per unit wheat grain yield as well as per USD net return was significantly ( $P < 0.01$ ) affected by nutrient management strategies. Farmers' fertilization practices



**Fig. 7.** Total Global Warming Potential (GWP) per Mg grain yield and per USD net return (NR) under different nutrient management strategies in no-till based wheat production in Haryana. NE: nutrient expert, NE+GS: nutrient expert supplemented with GreenSeeker, SR: state recommendation and FFP: farmers' fertilizer practice.

resulted in higher GWP per Mg of wheat yield while NE-based recommendation, in conjunction with "Green Seeker"(GS) based N application, resulted in the lowest GWP per Mg of wheat (Figure 7). NE in combination with GS helps in better nutrient use efficiency from in-season precision N application i.e. rate and number of splits matching physiological demand of the crops. This probably reduced the residual NO<sub>3</sub>-N in soil profile thereby minimizing the N loss as N<sub>2</sub>O emission. In addition, the adequate K application recommended by NE helps in better utilization of other nutrients, particularly N, that improves N utilization by the crops and reduces the possibility of volatilization loss of the nutrient.

Overall, Nutrient Expert® (NE) based fertilizer recommendation helped the farmers to increase the yield and improve economics through site-specific balanced application of nutrients. The on-farm results clearly highlighted the critical role played by K in improving cereal productivity in India. Balanced and adequate application of potassic fertilizer not only helped in yield improvement but may also reduce K mining from soils. Therefore, wide scale adoption of Nutrient Expert® could be the way forward towards balanced fertilizer application in smallholder systems in India for sustainable food security.

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## Soil K increases from cash crops in China

Ping He, Fang Chen, Shutian Li, Shihua Tu, Adrian M. Johnston

Understanding soil K status is important when developing appropriate K nutrient management. Reports have indicated that K deficiency is a worldwide problem. However, with the development of agricultural mechanization and implementation of policies by the Chinese central government promoting the return of crop straw to fields after harvest, and increased use of organic (compost) fertilizers, soils have been shown to have increased soil K levels. However, some contradictory reports on soil available K changes have raised concerns of scientists and the fertilizer industry. These contradictory results may be attributed

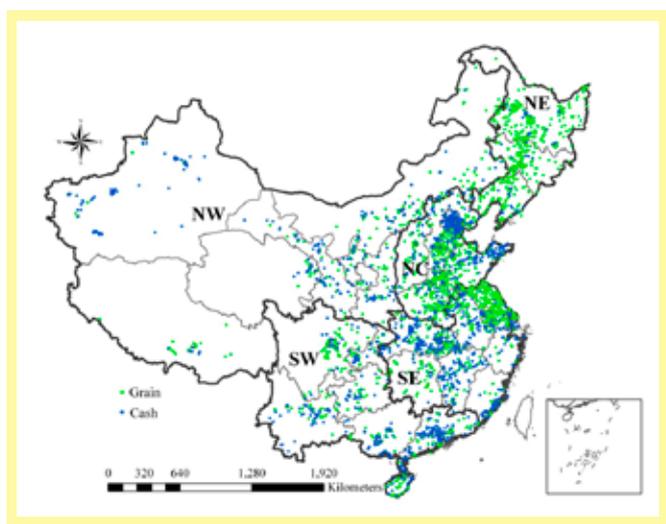
to differences in soil sampling points, number of samples, time of sampling, and analytical methods. Up to now, the effects of K fertilizer use have not attracted concerns like N and P. The historic national soil survey conducted in the early 1980s in China could not reflect current soil K status in reality. The current soil K balance in China is influenced by the imbalance of K relative to N and P fertilizers, and crop K removal by new and high-yielding genotypes. This lack of understanding needs to be evaluated.

The objectives of this study were to evaluate the temporal and spatial variation of soil available K and crop yield response to K fertilizer in China from 1990 to 2012.

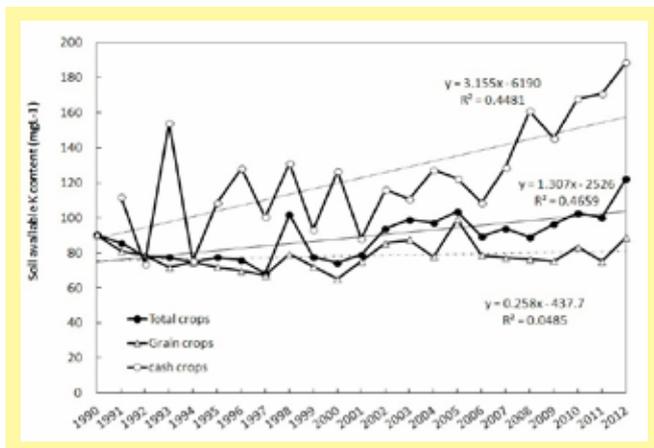
### Materials and Methods

Datasets for soil available K and crop yield were compiled from published and unpublished data sources in 1990-2012 from the International Plant Nutrition Institute (IPNI) China Program database. In total, 58,559 soil available K records (Fig.1) and 2055 yield records were collected from this database. These experiments were conducted in farmers' fields, and crop yield was obtained from the first season harvested crops from N, P and K application plots (NPK, the rates of N, P, and K fertilizers were recommended based on soil testing) and only N and P treatment (NP, no K fertilizer was applied based on NPK treatment).

To evaluate spatial variation of soil available K in China, five agricultural regions were grouped based on geographical locations and China's administrative



**Fig. 1.** Distribution of experimental sites for five production regions of China from 1990 to 2002. The green and blue dots represent grain and cash crops, respectively.



**Fig. 2.** Trends in soil available K in China from 1990 to 2012.

divisions, consisting of Northeast (NE), North Central (NC) Northwest (NW), Southeast (SE) and Southwest (SW).

In addition, each agricultural region was further divided into two sub-groups based on soil utilization pattern (grain crop and cash crop systems). In grain crop systems, soils were used for wheat, maize, rice, potato, and soybean. In cash crop systems, vegetables, fruit trees, rapeseed, sunflower, cotton, and sugar crops with higher fertilizer loadings and higher economic outputs were planted based on classification by China Agriculture Yearbook (2012). The geographical distribution of the data was shown in Fig.1.

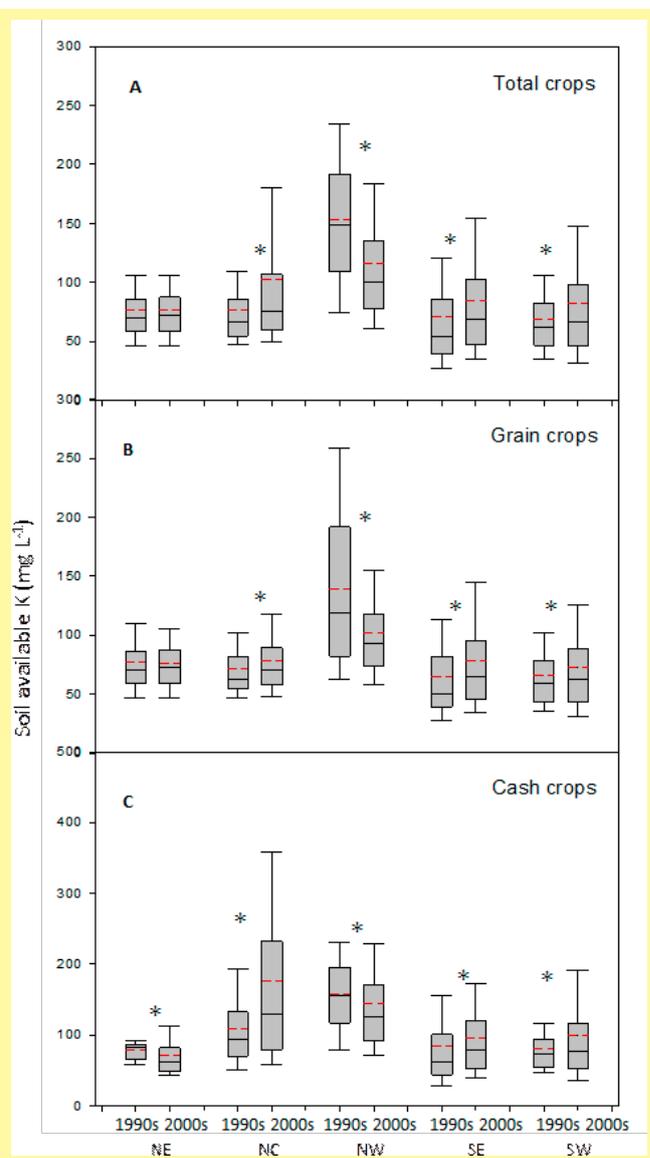
## Results

### Changes of soil available K in farmland from 1990 to 2012

From 1990 to 2012, the soil available K content from experiments with all crops in China showed an increasing trend (Fig.2). For further analysis of the driving forces of this increasing trend of soil available K, we separated the soil samples into two categories based on crops planted: grain crops and cash crops. The soil K values for both grain crops and cash crops increased with the time going from 1990 to 2012. For grain crops, soil available K content fluctuated annually, but was found to show no obvious increase. However, for cash crops, the value increased dramatically over the period. Fertilizer application rate for grain crops averaged  $110 \text{ kg K}_2\text{O ha}^{-1}$  (ranging from 30 to  $360 \text{ kg K}_2\text{O ha}^{-1}$ ), and that for cash crops averaged  $255 \text{ kg K}_2\text{O ha}^{-1}$  (ranging from 15 to  $1867 \text{ kg K}_2\text{O ha}^{-1}$ ) (data not shown). These results indicated that high K concentrations in soils planted with cash crop from high fertilizer K input drove the increased trend of soil available K in China from 1990 to 2012.

### Spatial and temporal variation of soil available K

Balanced fertilization was introduced to China in 1980s, with a major focus on use of K fertilization in China since the 1990s. However, great variation existed across different regions with mean values for soil test K of 76.8, 99.8, 118.0, 83.9 and  $81.3 \text{ mg L}^{-1}$  for Northeast (NE), North Central (NC), Northwest (NW), Southeast (SE) and Southwest (SW), respectively. To evaluate changes of soil available K in different regions of China



**Fig. 3.** Comparison of soil available K between 1990s and 2000s. (A) Total crops; (B) Grain crops; (C) Cash crops. The star \* between the two boxes indicates soil available K between 1990s (left box) and 2000s (right box) significant different at  $P < 0.05$ . The black and red lines, lower and upper edges, bars represent median and mean values, 25th and 75th, 5th and 95th percentiles of all data, respectively.

from 1990 to 2012, we compared the soil available K across different periods, the 1990s (1990-1999) and 2000s (2000-2012). Our data shows that on average, soil available K increased from  $79.8 \text{ mg L}^{-1}$  in the 1990s, to  $93.4 \text{ mg L}^{-1}$  in the 2000s. Soil available K showed no difference in the NE between the 1990s and 2000s. However, the soil available K increased by 34.8% ( $76.4$  to  $103.0 \text{ mg L}^{-1}$ ), 17.9% ( $71.5$  to  $84.3 \text{ mg L}^{-1}$ ) and 30.2% ( $68.8$  to  $82.7 \text{ mg L}^{-1}$ ) from the 1990s to 2000s for NC, SE and SW respectively, and decreased by 75.9% ( $153.5$  to  $116.5 \text{ mg L}^{-1}$ ) from the 1990s to 2000s for NW (Fig.3A).

Further analysis demonstrated that soil available K in grain crops only followed the same trends as those shown in total crops, but the changes varied among regions (Fig.3B). For the NC, SE and SW regions, the soil available K increased by 8.7%, 21.0% and 8.7% respectively in the 2000s from baselines of 72.2, 65.1 and  $66.4 \text{ mg L}^{-1}$  in the 1990s. However, for the NW, soil

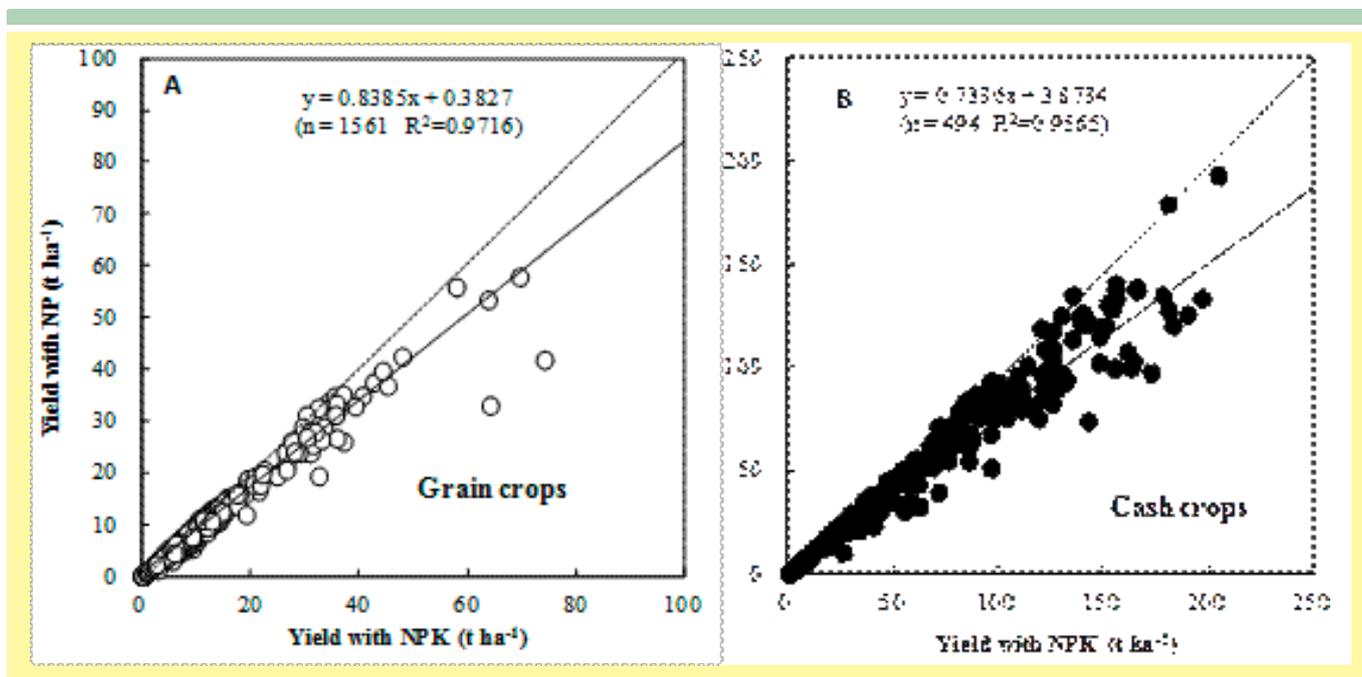


Fig. 4. Yield with NP and yield with NPK for cash crops and grain crops. (A) Grain crops; (B) Cash crops. The dash line is 1:1 line.

available K in the 2000s decreased by 73.5% compared with the 1990s (Fig.3B).

The soil available K in the 2000s for cash crops only increased by 59.7%, 12.4% and 22.2% for NC, SE and SW respectively, as compared with that in the 1990s, but declined to only 92.5% and 91.7% of that in the 1990s for NE and NW. It was indicated that the increased soil available K in the NC and SW mainly relied on the large increase in soil available K in cash crops, while the increased values in the SE was mainly attributed to larger increases in grain crops. The decrease in soil available K in the NW was mainly from the large decline in grain crops (Fig.3C).

### Discussion and conclusion

Results in this study indicated that soil available K showed a minor increased in soils planted to grain crops, but increased significantly in those soils planted to cash crops between 1990 and 2012. The trends of increased soil K for cash crops was in accordance to the high fertilizer K application rate. The K fertilizer application rates for cash crops averaged 164, 231, 205, 240 and 391 kg K<sub>2</sub>O ha<sup>-1</sup>, 1.7, 2.1, 1.7, 2.1 and 2.8 times those for grain crops for NE, NC, NW, SE and SW, respectively (Data not shown). However, the soil K for grain crops in 2000s were lower than 80 mg L<sup>-1</sup> (the critical value for K deficiency) except in NW China. Therefore, more K fertilizer was needed for soils planted with grain crops since soil K level for grain crops were below the critical levels and no increase in soil indigenous K supply has been measured. The results can be supported by relative yield and a great number of site-to-site reports as well. Although with the development of agricultural mechanization and more crop residues being returned back to soils, reports indicated that straw returning alone is not sufficient to maintain the soil K balance and chemical K fertilizer application is essential to maintain both high yield and soil K balance.

Although soil K values in cash crops were observed to be higher than those in grain crops, the relative yield of cash crops were lower than grain crops indicating that yield reduction with NP treatment, or without K application, was larger for cash crops than grain crops as compared with NPK treatment (Data not shown). This observation was also supported by the larger response to K application for cash crops than that for grain crops (Fig.4). These results indicate that the contribution of soil indigenous K supply to the yield was higher for grain crops than for cash crops and more K is needed to achieve the optimal yield of cash crops with larger yield response to K as compared with that for grain crops. In addition, the K nutrient removal by cash crops was larger than that for grain crops.

In summary, soil available K in China kept increasing from 1990 to 2012 and these increases came from the increased soil K in cash crop soils due to higher K fertilizer application. Therefore, K fertilizer application is required not only for grain crops with lower soil K levels, but also for cash crops with large yield response to K application as well. The strategies used to address this challenge need to be regional, and site-specific. The information from the current study also guides the future research orientation, such as research on soil K critical values for individual cash crops, K nutrient cycling and 4R nutrient management strategies under agricultural mechanization.

### References (Omitted)

More detail please refer to He et al published in *Field Crops Research* (2015, 173: 49-56) or <http://dx.doi.org/10.1016/j.fcr.2015.01.003>.

# Visual Indicators of Potassium Deficiency: Selected Crops



Alfalfa



Alfalfa



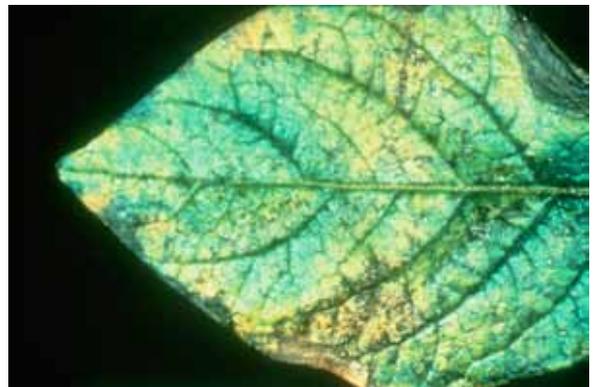
Pumpkin



Potato



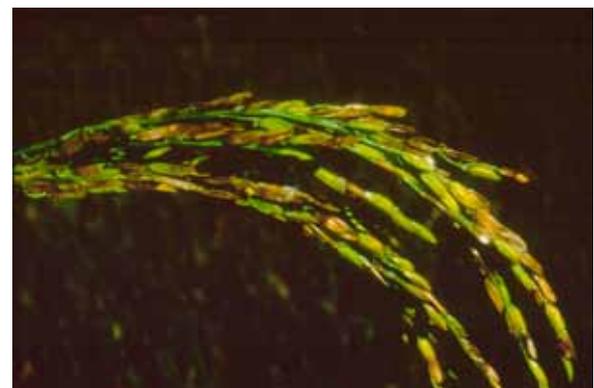
Potato



Potato



Rice



Rice



Rice



Rice



Soybean



Soybean



Soybean



Soybean



Wheat



Sugar beet



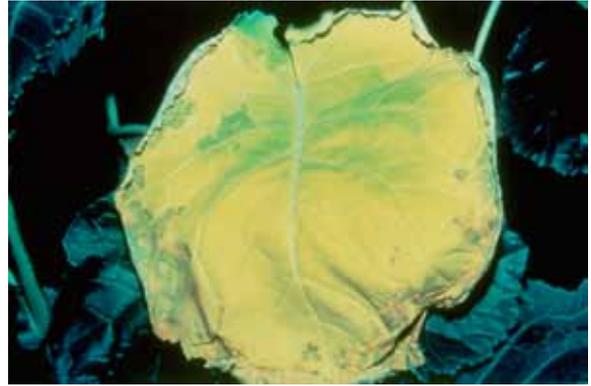
Apple



Apple



Canola



Canola



Canola



Canola



Clover



Wheat



Maize



Maize



Maize



Barley



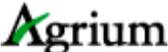
Maize



Radish



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