BETTER CROPS
WITH PLANT FOOD

2013 Number 3

Improving Nutrient Use Efficiency in Potato: Research Examples from the U.S. and China
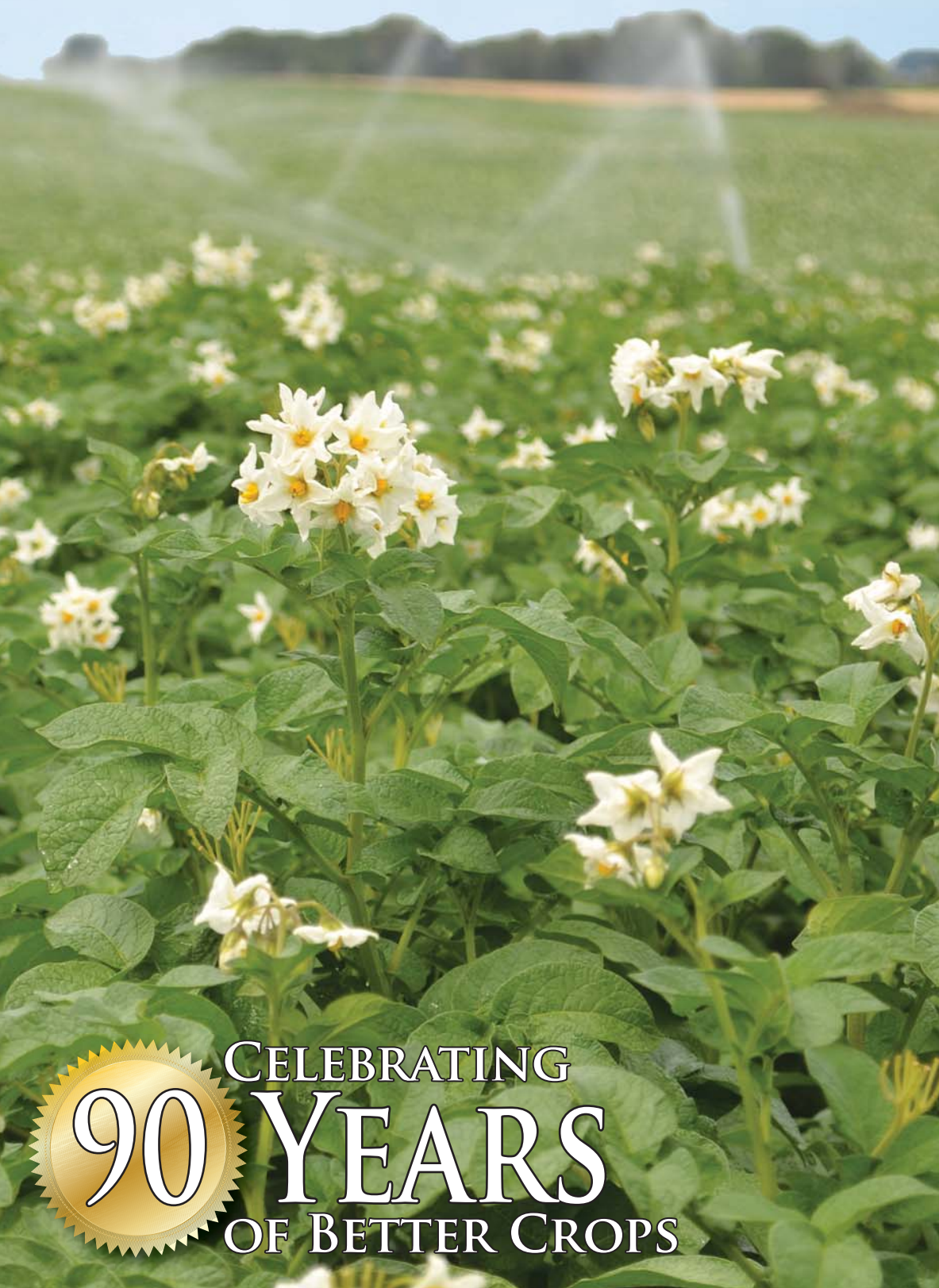
In This Issue...

Sustaining Profitability from Fertilizer in sub-Saharan Africa

Optimizing Broadcast Fertilizer Application

A Review of Global Phosphate Rock Reserves

Also:

Essentials of Selenium

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22nd International Grasslands Congress

Theme: Revitalizing Grasslands to Sustain Our Communities

The International Grasslands Congress program will explore the current issues facing grasslands around the world and share the latest industry developments and solutions.

Three main streams of programming are planned including: (1) Improving production efficiency to revitalize grasslands; (2) Improving grassland environment and resources; and (3) Grassland people, rights, policies, practices and processes.

The Congress aims to present a program which is participative, innovative, stimulating, thought-provoking and enriching by offering networking and learning opportunities to grassland scientists, extension workers, students, agri-business professionals, policy makers and leading livestock producers and farmers from all over the world. **BC**

Dates/Location: September 15-19, 2013, Sydney Australia
Program Details: http://www.igc2013.com

ASA-CSSA-SSSA International Annual Meetings

Theme: Water, Food, Energy & Innovation for a Sustainable World

The American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America will host more than 4,000 scientists, professionals, educators, and students at the 2013 International Annual Meetings. **BC**

Dates/Location: November 3-6, 2013, Tampa, Florida
Program Details: https://www.acsmeetings.org/

N2013 - 6th International Nitrogen Conference

Theme: Let us aim for just enough N: Perspectives on how to get there for "too much" and "too little" Regions'

The International Nitrogen Initiative (INI), African Nitrogen Centre, International Institute of Tropical Agriculture (IITA) and Makerere University College of Agricultural and Environmental Sciences welcome scientists, agriculturalists, environmentalists, industrialists, economists, policy implementers and other practitioners to the 6th International Nitrogen Conference (N2013).

The common objective of these conferences is the design of more productive, economic, and sustainable food and energy production systems to meet the challenges of the growing global population in a changing environment. **BC**

Dates/Location: November 18-22, 2013, Kampala, Uganda
Program Details: http://n2013.org/

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More Profitable Fertilizer Use For Poor Farmers

By Crammer Kayuki Kaizzi, Charles S. Wortmann and Jim A. Jansen

Fertilizer use is often of low profitability compared with other uses of money available to finance-constrained farmers. Fertilizer use profitability varies with crop-nutrient choice, application rate, and fertilizer costs relative to commodity values. An optimization tool integrates 15 crop-nutrient response functions for Uganda to allocate available money to crop-nutrient-rate options expected to maximize net returns on the investment. This optimization approach is applicable to finance-constrained smallholder farmers globally once the relevant crop-nutrient response functions are known.

Low fertilizer use by smallholder farmers commonly constrains productivity. Many of these farmers do not have the financial capacity to use enough fertilizer to maximize net returns per hectare. High fertilizer costs and low commodity prices, associated with costly input supply and inefficient marketing, reduce profit potential. Competing needs for money often take priority when profitability of fertilizer use is inadequate. Such farmers need high net returns on their investments in fertilizer use.

Recommendations for non-finance-constrained fertilizer use commonly strive to maximize mean net returns per hectare. These recommendation approaches are inappropriate for financially constrained fertilizer use where purchasing capacity is inadequate to apply enough fertilizer to maximize net returns per hectare. Fertilizer use by finance-constrained smallholders, however, needs to aim at maximizing net returns on small investments in fertilizer use.

This is achieved by allocating fertilizer to an optimized choice of crop-nutrient-rate combinations. The profitability of different crop-nutrient combinations varies with the relative value of crops, the costs of fertilizer nutrients, the magnitude of each crop's response to an applied nutrient, and the shape of the response curve. Nutrient application rate is a consideration when crop response is curvilinear, with greater returns on finance-constrained investment with lower versus higher rates. Underlying this approach to fertilizer rate determination are robust crop-nutrient response functions. A method of optimizing across these response functions is then needed to determine the allocation of fertilizer investment to the crop-nutrient-rate combinations that maximize net returns on investment. The approach is valid for mono-culture cropping systems where several nutrients are considered, but is especially important when cropping systems are comprised of several crops.

An Example from Uganda

Research was conducted in Uganda with funding from the Alliance of a Green Revolution in Africa. Fifteen nutrient response functions were determined from the results of 80 field trials for corn, sorghum, upland rice, drybean, soybean, and peanut; and for N, P and K as appropriate for the crop (Kaizzi et al. 2012a b c). While the study used an incomplete design, N by P interactions were evaluated and the effects were found to be not significant. Some crop-nutrient combinations were more profitable than others (**Figure 1**). Application of at least a low rate of N to upland rice or to dry bean was much more profitable than other fertilizer uses. The response functions were curvilinear and the figure also illustrates the effect of application rate on profitability. It implies a need to

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

A team of Ugandan soil scientists led by Dr. Kaizzi, center, conducted research to determine 15 crop-nutrient response functions that were then integrated by UNL collaborators into the Uganda Fertilizer Optimization Tool. Angela Nansamba, on the left, was a team member and is a graduate student supported by UNL through INTSORMIL.

determine combinations of crop-nutrient-rate that will give the best net return on the amount of fertilizer that the farmer can afford to use.

Information such as in **Figure 1** can be used to prioritize crop-nutrient-rate options, in consideration of fertilizer use costs and expected grain values. Depending on which crops the farmer wishes to plant, application of a low rate of N to upland rice and bean may be of highest priority if the financial constraint is severe. With a less severe financial constraint, the priority options include additional N applied to rice and bean, some N applied to maize and sorghum, and some P applied soybean and groundnuts. With no financial constraint, fertilizer should be applied for each crop-nutrient combination that maximizes net return per hectare for the given fertilizer cost to commodity value ratios. To fully and more accurately use the information from the 15 crop-nutrient response functions, a more complex process of consideration is needed.

The Uganda Fertilizer Optimization Tool

To enable full optimization across the 15 crop-nutrient response functions, the Excel-Solver based Uganda Fertilizer Optimization Tool was developed (Jansen et al., 2013; http://cropwatch.unl.edu/web/soils/software). The tool considers the land area that the farmer wishes to plant for each crop, expected commodity values at harvest (accounting for both the values for home consumption and market), the costs of fertilizer use, and the finance available to the farmer for fertilizer use (**Figure 2**). The output includes the recommended fertilizer
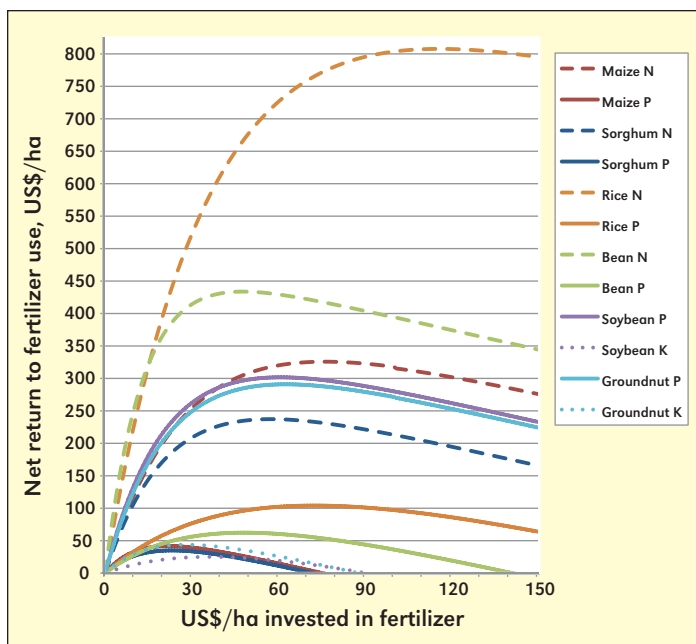
Figure 1. The profitability of fertilizer use varies greatly depending on which nutrient is applied to which crop and at what rate. Nitrogen applied to rice or dry bean were especially profitable options as shown in this figure. Profitability of crop-nutrient-rate combinations varies with per kg crop values and fertilizer costs; crops values used here were US$0.20, 0.20, 0.40, 0.50, 0.35, and 0.40 for maize, sorghum, rice, bean, soybean, and peanut, respectively; and costs of fertilizer use were US$1.50, 2.50 and 1.00, respectively for N, P and K.

rate for each crop and the expected effects on crop yields and net returns.

Using the tool when the financial constraint is moderate or severe, the estimated net returns to the investment in fertilizer use are typically greater than twice as much as when fertilizer is applied to maximize net returns per hectare. The greater potential for profitability with the tool is expected to enable finance-constrained farmers to gradually break out of poverty and increase fertilizer use to the point of maximizing net returns per hectare.

This fertilizer use optimization approach was introduced to 60 government and non-government extension staff in Uganda with training for the remaining extension staff planned. Participants learned of the approach and underlying principles, use of the tool, and working with farmers in making recommendations.

Wider Applications

This fertilizer use optimization approach is applicable to more profitable fertilizer use for finance-constrained crop production throughout sub-Saharan Africa and other continents. The tool is also useful to those who have adequate access to credit or other finance for fertilizer use as it enables them to account for the effects of fertilizer use costs and grain values as needed to determine application rates for maximized net returns to fertilizer use per hectare. The crop-nutrient response functions will need to be determined for the appropriate crops in any other agro-ecological zone where this approach is applied. In the 80 Uganda trials, soil test information did not account for variation in response curves. However, Mehlich 3 soil test P was always <12 mg/kg (ppm) and exchangeable K was always >130 mg/kg indicating high and low probabilities

Figure 2. Data input and output views of the Uganda Fertilizer Optimization Tool. Monetary values are in US$ (1US$ = 2,400 shillings).

Two participants involved in a role-playing exercise during training on the use of the Uganda Fertilizer Optimization Tool. The woman is assuming the role of an extension agent interviewing a farmer for input information and advising him of the fertilizer use recommendation.

for P and K response, respectively, for all site-seasons. In other places or for other crops, soil test information may need to be considered, either in the tool or separately. The optimization tool is now computer run but a cell phone application is being developed to improve farmer access to the optimization approach. **BC**

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Potato Response to Phosphorus Fertilizer Using a Dicarboxylic Acid Polymer

By Jeffrey C. Stark and Bryan G. Hopkins

Improving P use efficiency in some alkaline soils is difficult due to poor P solubility. A dicarboxylic acid polymer (DCAP) was added to P fertilizer to improve potato P uptake, efficiency, and yield. This five-year study consisting of nine field trials, evaluated potato response to seasonal applications of liquid or dry P fertilizer with or without DCAP on calcareous soils with low to moderate soil test P. Addition of DCAP increased total yields of premium quality "U.S. No. 1" potatoes for selected P rate/source/timing combinations in seven of the nine trials.

Maintaining an adequate P supply is critical for potato plant development, tuber growth, and enhancing tuber maturity. Phosphorus deficiencies can significantly reduce tuber yield and size. Therefore, fertilization practices must be customized for the characteristics of the cropping system and local conditions to maintain adequate P availability throughout the growing season. Concentrations of soluble P in soils of the potato-producing regions in the Pacific Northwest, USA are usually very low and must be constantly replenished from soil P sources during the growing season.

In these alkaline soils, the primary factors used in determining P fertilizer recommendations are soil test P concentration, amount of excess lime ($CaCO_3$), and the yield goal. Excess lime in the soil increases P sorption on $CaCO_3$ surfaces and increases P precipitation as Ca-P minerals. The combined effect of these processes is an overall reduction in P availability to plants. This is reflected in regional potato P fertilizer recommendations that adjust for excess lime content in soil.

In this region, P fertilizer for potato is typically added in the fall or in the spring as a broadcast application, as a concentrated band during bed formation, and/or as a concentrated subsurface band at planting. The effectiveness of banded P for potato has been shown to vary with P source in calcareous soil; with the acidity of the fertilizer solution being a key factor. Banding P fertilizer in the soil can be beneficial by concentrating P near the early-developing root system.

One approach to improving P use efficiency is to reduce the concentration of potentially reactive cations in the immediate vicinity of the P fertilizer when applied to the soil. A long-chain dicarboxylic acid (DCAP) copolymer (AVAIL®; SFP, Leawood, KS, USA) composed of maleic and itaconic acids has been developed to improve crop P uptake efficiency (**Figure 1**). It is highly water soluble and only slightly mobile in the soil. A coating of DCAP on monoammonium phosphate (MAP)

Daily potato P uptake requirements typically range from 0.7 to 1.8 kg P_2O_5/ha/day during the tuber-bulking phase.

fertilizer may significantly modify soil chemical characteristics in the immediate vicinity of a fertilizer granule and thereby improve P uptake and crop yield. DCAP is also formulated for inclusion in liquid P fertilizers.

The DCAP coating is reported to provide a high negative-charge density compound that dissolves rapidly in the soil. The benefit would occur when the polymer sequesters soil cations (such as Ca, Mg), thereby increasing P solubility and making P more accessible for plant uptake. There are multiple reports where DCAP has shown significant yield benefits for a variety of crops. However, there also are multiple reports where no yield benefit has been obtained from use of DCAP-treated P fertilizer compared with untreated P. The specific conditions where benefits from DCAP should be expected are still under investigation.

The objective of this study was to evaluate potato yield response to DCAP applied in the fall and spring with both dry and liquid P fertilizer on calcareous soils considered "low to moderate" in soil P concentrations for potato production. Optimum recommended soil P concentrations are higher for potatoes than for many other agronomic crops.

A total of nine irrigated field trials were conducted in southeastern Idaho, USA between 2004 and 2008. Additional experimental details are available in Hopkins (2013) and Stark and Hopkins (2013). All of the trials were conducted with the Russet Burbank potato cultivar and all were conducted on calcareous soils with pH values ranging from 7.8 to 8.3 and excess lime contents ranging from 1.0 to 9.7% (**Table 1**).
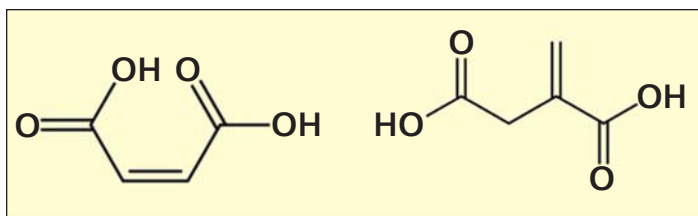

Figure 1. The dicarboxylic acid polymer is composed of a long chain of maleic acid (left) and itaconic acid (right). A dicarboxylic acid is an organic compound that contains two carboxylic acid functional groups.

Abbreviations and Notes: P = phosphorus; Ca = calcium; Mg = magnesium; v/v = volume-to-volume; ton/A = tonnes/ha x 0.446.

Table 1. Selected soil parameters for the nine potato P fertilization trials

Trial	Year	Soil Type	pH	Organic matter, %	$CaCO_3$, %	Extractable[1] soil P, mg/kg
1	2004	Sandy loam	8.0	2.1	1.0	35
2	2004	Loam	7.9	1.9	5.4	19
3	2004	Loam	8.0	1.7	3.4	18
4	2004	Sandy loam	8.1	2.4	2.9	21
5	2005	Loam	7.8	2.9	1.5	30
6	2005	Sandy loam	8.1	1.7	5.6	19
7	2006	Loam	8.1	2.8	9.7	17
8	2007	Sandy loam	8.1	1.9	6.8	18
9	2008	Sandy loam	8.3	2.1	7.2	21

[1]Olsen-P

Trials 1 through 5 (2004-2005)

The first five trials listed in **Table 1** were conducted in grower fields near the University of Idaho Research and Extension Center Aberdeen, Idaho in 2004 and 2005. Individual plot sizes were 3.6 m wide (four 0.9 m width rows) by 12 m long with 30 cm in-row seed piece spacing. Six replicates of three treatments were established in randomized complete blocks (RCBD) in each field. Treatments included an untreated check (no P fertilizer) or 67 kg P_2O_5/ha of MAP fertilizer applied with or without addition of DCAP at 1% (w/v).

The fertilizer was broadcast applied within 0 to 3 days prior to planting and incorporated with routine tillage operations. The P application rate selected was based on soil sampling to a depth of 25 cm and represented a slight excess above University of Idaho recommendations. Nitrogen was balanced in all plots with application of broadcast urea fertilizer at the same time as the pre-plant P treatments were applied. At harvest, tubers were harvested, graded, and weighed to determine total and U.S. No. 1 yield, which reflects the premium tuber quality that commands the highest market prices.

Three of the five trial sites showed significant ($p \leq 0.07$) increases in total yield in response to P fertilization (**Table 2**).

Table 2. Total and U.S. No. 1 yields of Russet Burbank potato for trials 1 through 5 as influenced by P applied as MAP or DCAP-treated MAP.

Fertilizer	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
---------------------- Total yield, t/ha ----------------------					
Check	44.0	35.5	27.6	28.4	39.6
MAP	45.8	39.1	30.4	36.7	40.8
DCAP	35.5	43.5	34.3	42.3	44.8
$LSD_{0.10}$	5.3	3.5	3.7	5.3	NS
Pr > F	0.018	0.045	0.067	0.017	0.103
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
---------------------- U.S. No. 1 yield, t/ha ----------------------					
Check	30.3	21.9	16.8	17.6	23.1
MAP	31.6	26.7	17.6	21.9	23.7
DCAP	17.3	30.7	19.1	23.8	25.1
$LSD_{0.10}$	4.5	3.8	NS	5.8	NS
Pr > F	0.012	0.033	0.218	0.038	0.246

Addition of MAP resulted in significant total yield increases over the untreated check in trials 2 and 4 but DCAP reduced total yield in trial 1, where initial soil P was relatively high. U.S. No. 1 yields were increased by P fertilization only in trial 2. The lack of response to MAP in the other trials is not surprising since these fields had relatively high soil test P concentrations. It is interesting that the two fields that responded positively to MAP fertilization were on the lower end of soil test P concentrations of the five fields used in this study (**Table 1**). Both trials that responded to MAP fertilizer (trials 2 and 4) also responded with additional yield increases when DCAP was combined with the MAP fertilizer. Although there was no response to MAP without DCAP compared to the check for trial 3, the MAP+DCAP-treated plots increased total yield over both MAP alone and the untreated check plots.

Significant differences ($p \leq 0.05$) for U.S. No. 1 yield were observed in trials 1, 2 and 4 (**Table 2**). As with total yield, the U.S. No. 1 yield in trial 2 for the MAP+DCAP-treated plots was significantly greater than MAP-treated plots. Trial 4 also had a similar response where MAP+DCAP resulted in a significant U.S. No. 1 yield increase compared to the untreated check but not compared to MAP alone. Petiole P concentration of MAP+DCAP-treated plants was significantly greater than the other treatments at mid and late season sampling dates for trials 1-5 (data not shown).

Trials 6 through 9 (2005-2008)

Trials 6, 8 and 9 were conducted at the University of Idaho Aberdeen Research and Extension Center, while trial 7 was conducted in a grower's field near Blackfoot, ID. Individual plot sizes in these trials were 3.6 m wide (four 0.9 m width rows) by 15 to 18 m long with 30 cm in-row seed piece spacing. Treatments for trials 6 and 7 included an untreated check (no P fertilizer) and different rates of MAP fertilizer applied +/- DCAP at 1% (w/v). Treatments for trials 8 and 9 also included an untreated check and different rates of MAP +/-DCAP (1% w/v) or ammonium polyphosphate (APP) applied +/-DCAP at 0.5% (v/v).

All nutrients besides P, were applied to provide for optimum yield based on soil tests taken the previous fall. Nitrogen was balanced in all plots with application of broadcast urea at the same time as the pre-plant P treatments were applied. Irrigation water was added as needed. At maturity, tubers were harvested, graded, and weighed to determine total and U.S. No. 1 yield.

Experimental designs for the trials 6 and 7 were arranged as a split plot, RCB design with fall or spring P application as the main plots and P source/rate combinations as subplots with four replications. The P rates were 0, 112 or 224 kg P_2O_5/ha.

The experimental design for trial 8 was similar to trials 6 and 7 with the exception that spring P was banded rather than broadcast applied. The P treatments included fall plus spring applications of P (0, 180 or 270 kg P_2O_5/ha), compared with single spring P applications (0, 180 or 270 kg P_2O_5/ha) applied entirely as band treatments of APP +/- DCAP. The split, fall plus spring applications were comprised of fall broadcast MAP +/- DCAP applied at 90 or 180 kg P_2O_5/ha plus 90 kg P_2O_5/ha as APP banded in the spring, +/-DCAP. A control treatment (check) received no additional P. APP treatments were banded at row formation 15 to 20 cm below the surface of the hill and

Table 3. Total and U.S. No. 1 yields of Russet Burbank potato for trials 6 and 7 as influenced by P applied in the fall or spring as MAP or MAP treated with DCAP.

Fertilizer	Fall P -- kg P$_2$O$_5$/ha --	Spring P	Trial 6 Total yield ------- t/ha	Trial 6 U.S. No. 1	Trial 7 Total yield	Trial 7 U.S. No. 1
Check	0	0	37.9	23.7	44.9	31.3
MAP	112	0	43.0	30.0	45.8	31.5
DCAP	112	0	44.1	28.1	50.5	37.6
MAP	224	0	43.9	28.8	48.3	35.6
DCAP	224	0	44.2	32.5	50.0	38.4
Check	0	0	38.9	20.8	44.8	31.5
MAP	0	112	39.9	24.3	45.6	31.7
DCAP	0	112	43.1	29.2	49.1	36.7
MAP	0	224	42.2	24.3	46.8	31.9
DCAP	0	224	42.8	24.5	46.4	34.6
Treatment Means						
MAP			42.3	26.8	46.6	32.7
DCAP			43.6	28.6	49.0	36.8
Fall			43.8	29.9	48.7	35.8
Spring			42.0	25.6	47.0	33.7
LSD$_{0.05}$			ns	2.8	1.8	2.8
PR > F			0.093	0.052	0.001	0.001

9 to 10 cm to the side of the seed row.

In trial 9, the treatments included comparisons of P applied entirely in the spring at 0, 90, 180 or 270 kg P$_2$O$_5$/ha; with the P treatments consisting of 45 or 90 kg P$_2$O$_5$/ha broadcast as MAP, +/-DCAP, and the remainder applied as APP, +/- DCAP, banded in the bed prior to planting, as previously described.

Total potato yields were significantly increased in trial 6 where P was added (p ≤ 0.10). The mean total yield for the P-fertilized treatments (42.9 t/ha) was higher than the mean check yield (38.4 t/ha) but there were no significant differences in total yield between any of the P source/rate/DCAP treatment combinations (**Table 3**).

There was a significant yield increase (p ≤ 0.05) for U.S. No. 1 tubers in response to P treatment in trial 6. All P-fertilized treatments had higher U.S. No. 1 yields than the check for both fall and spring fertilization. DCAP treatment resulted in significantly more U.S. No. 1 potatoes when added to fall-applied MAP at 224 kg P$_2$O$_5$/ha and to spring-applied MAP at 112 kg P$_2$O$_5$/ha than uncoated MAP at those same rates. However, DCAP had no effect on U.S. No. 1 yield for the other P rate/timing combinations. In addition, fall P fertilization produced higher U.S. No. 1 yields than spring P fertilization.

In trial 7, DCAP treatment resulted in significantly (p ≤ 0.05) higher total and U.S. No. 1 yields than MAP without DCAP. The benefit of DCAP on each of these yield parameters were greatest at the lower P rate (112 kg P$_2$O$_5$/ha), particularly with respect to total yield. The use of DCAP resulted in higher U.S. No. 1 yields for all P rate/timing combinations, except for the spring-applied treatment at 224 kg P$_2$O$_5$/ha where there was no benefit.

In trial 8, main effects of DCAP addition were not significant for total or U.S. No. 1 yield (**Table 4**). However, there were significant effects of P application on total and U.S. No. 1 yield and for DCAP on total yield for selected P rate/source/timing treatment combinations. For example, at the 180 kg P$_2$O$_5$/ha application rate, fall + spring P application plus DCAP produced a higher total yield than fall + spring application without DCAP. Conversely, at the 270 kg P$_2$O$_5$/ha rate, total yield for the fall + spring treatment with DCAP was lower than the fall + spring treatment without DCAP.

Trial 9 focused entirely on potato response to spring-applied P, with the applications evenly split between broadcast MAP and banded APP applied +/- DCAP. At each P application rate, the addition of DCAP produced significant increases in U.S. No. 1 tuber yield, ranging from 18 to 26% compared to untreated MAP and APP. Total yields exhibited a similar trend, but treatment effects were not significant (**Table 5**).

Petiole P concentration of MAP+DCAP-treated plants in trials 1-5 was significantly greater (p ≤ 0.10) than the other treatments at mid and late season sampling dates at all sites (**Figure 2**). However, plant P analysis for trials 6-9 revealed no significant (p ≤ 0.05) differences in stem, tuber or total plant P uptake between the P-source or the P-timing treatments, nor were there significant differences in petiole P concentrations among treatments (data not shown).

Summary

In summary, DCAP increased total and/or U.S. No. 1 yields for selected P rate/source/timing combinations in 7 of 9 trials.

Table 4. Total and U.S. No. 1 yield of Russet Burbank potato for trial 8 as influenced by P applied in the fall and spring as MAP or APP applied with or without DCAP.

Fertilizer	Fall P, kg P$_2$O$_5$/ha	Spring P, kg P$_2$O$_5$/ha	DCAP	Total P, kg P$_2$O$_5$/ha	Total yield, t/ha	U.S. No. 1, t/ha
Check	0	0	0	0	44.3	25.7
MAP/APP	90	90	0	180	45.7	26.0
MAP/APP	90	90	+DCAP	180	49.7	26.6
MAP/APP	180	90	0	270	51.9	30.5
MAP/APP	180	90	+DCAP	270	47.7	26.6
Check	0	0	0	0	45.1	24.2
APP	0	180	0	180	48.1	29.8
APP	0	180	+DCAP	180	50.4	29.9
APP	0	270	0	270	50.1	31.3
APP	0	270	+ DCAP	270	48.2	29.3
Treatment Means						
- DCAP					49.0	29.4
+ DCAP					49.0	28.1
Fall/Spring					48.8	27.4
Spring					49.2	30.1
LSD$_{0.05}$					3.9	5.1
PR > F					0.003	0.050
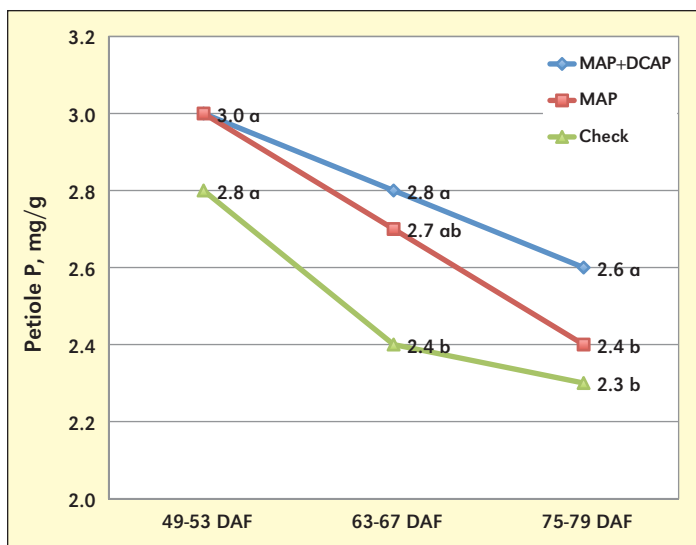
Figure 2. Petiole P concentrations for potatoes grown without fertilizer P (check), with untreated MAP, or dicarboxylic acid polymer (DCAP)-treated MAP. Data are combined for trials 1-5. DAF = days after fertilization. Data points with the same letter at a specific DAF are not significantly different at $p \leq 0.10$.

Table 5. Total and U.S. No. 1 yield of Russet Burbank potato for trial 9 as influenced by P applied in the spring as MAP or APP applied with or without DCAP.

Total P, kg P_2O_5/ha	MAP, kg P_2O_5/ha	APP, kg P_2O_5/ha	DCAP	Total yield, t/ha	U.S. No. 1, t/ha
Check	0	0	0	40.4	21.8
90	45	45	0	44.1	22.3
90	45	45	+DCAP	43.6	28.2
180	90	90	0	41.8	22.5
180	90	90	+DCAP	50.0	26.6
270	90	180	0	43.1	25.2
270	90	180	+DCAP	45.6	29.8
Treatment Means					
Fertilizer P without DCAP				43.0	23.3
Fertilizer P with DCAP				46.4	28.2
$LSD_{0.05}$				ns	4.1
PR > F				0.37	0.05

Not surprisingly, these results show that the benefit of DCAP-treated fertilizer is more likely when soil test P concentrations are low and at modest rates of fertilizer P. Evidence from these trials and the work of other researchers suggest that high rates of P overwhelm any beneficial response from DCAP.

It is clear from the range of responses reported by various researchers that many factors, including crop type, soil properties, fertilizer source, rate, placement, timing, etc., can have effects on crop response to P fertilizers blended with DCAP. However, the growing number of positive yield responses to DCAP observed for such crops as potato, rice and maize suggest that further research with this product is warranted to improve its effectiveness and the predictability of response. BC

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Proper Nectarine Nutrition Improves Fruit Quality

By R. Scott Johnson, Andres Olivos, Qin Xiaoqiong, Carlos Crisosto and Themis Michilaides

Successful stone fruit production requires attention to both fruit yield and fruit quality. Mineral nutrient shortages will result in a greater degree of fruit browning during storage. Excessive N fertilization stimulates vegetative growth, delays fruit ripening, and increases the severity of brown rot.

Fruit tree nutrition research has primarily focused on optimizing growth and yield, with less attention paid to its effect on fruit quality. The link between tree fruit nutrition and fruit quality cannot be overlooked. For example, studies on apples and plums have shown an influence of nutrient deficiencies on internal fruit breakdown. Other work has demonstrated a link between plant nutrition and fruit color. But additional research is needed on the influence of mineral nutrition on stone fruit postharvest quality and cold storage performance.

A major problem with stone fruits is their tendency to become brown during storage. Browning of fruits and vegetables occurs when a naturally occurring enzyme (polyphenol oxidase, PPO) degrades phenolic compounds to form quinones, which rapidly form brown-colored compounds (melanin) (**Figure 1**).
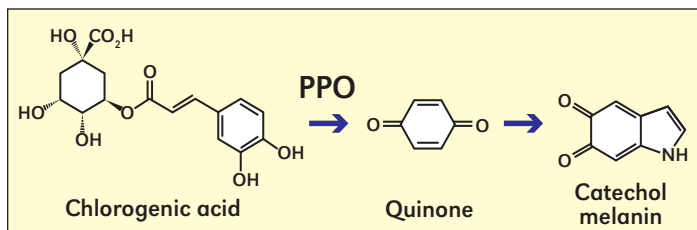
Figure 1. Generalized example of the production of melanin from polyphenolic compounds following the breakdown of fruit by the naturally occurring polyphenol oxidase (PPO) enzyme. Melanin is the cause of fruit browning.

The concentration of phenolic compounds, the activity of PPO, and the presence of oxygen are strongly related to enzymatic browning. However, the composition of the phenolic compounds and their concentration are important contributors to fruit antioxidant capacity, which is desirable because they provide benefits to human health. In addition, certain phenolic compounds can assist in enhancing resistance to brown rot (*Monilinia fructicola*) in peaches by acting directly on cutinase and preventing the penetration of this fungal infection within the fruit flesh.

It would be preferable to have fruit with high concentrations of phenolic compounds, but low postharvest fruit browning during and after cold storage. Two studies were conducted to measure the influence of nutrient supply on fruit yield and quality.

Experimental Details

1. N-P-K Study

In 2000, 60 large (10,000 L) tanks were buried in the ground at the University of California Kearney Agricultural Research Center in Parlier, CA to study the nutrition of stone fruit. Each tank was filled with sand to enable accurate control

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium.
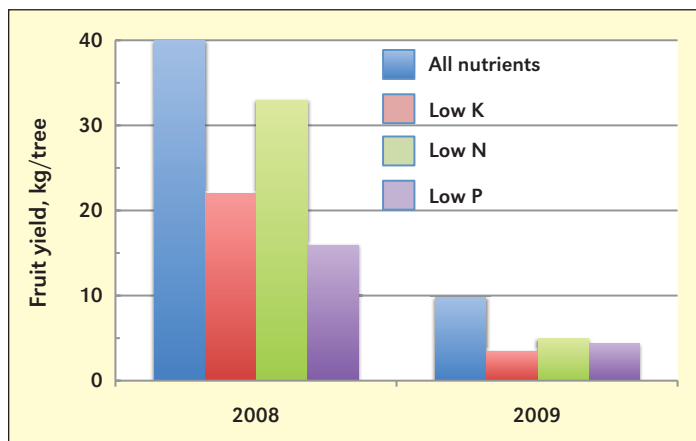
Figure 2. Nectarine yield during 2008 and 2009 for trees fertilized with low K, low N, low P, or supplied with all nutrients.

of the nutrient supply and specific mineral deficiencies.

A 'Grand Pearl' nectarine tree was placed in each tank and trained to a perpendicular V system to ensure uniform shape. Four different fertilization treatments were imposed for 8 years using a drip irrigation system with two emitters per tank. The treatments were a fully fertilized control, low N, low P, or low K with four replications per treatment.

In 2008 and 2009, fruit were collected from each tree as they reached commercial maturity based on color and firmness. Fruit size, soluble solids concentration, and titratable acidity were determined at harvest. In 2009 only, fruit was stored for 11 days at 5°C for quality evaluation. After storage, fruit was evaluated for internal breakdown symptoms and other disorders.

2. Nitrogen Rate and Brown Rot Study

'Fantasia' nectarines were grown in a 2-acre field at the Kearney Center in Parlier, CA and received 0, 100, 175, 250, or 325 lb N/A/yr since the 8th year after planting. Mature fruit was harvested in the 16th and 17th year and evaluated for various parameters of quality. The effect of N fertilization on brown rot was studied by inoculating the blossoms or green fruit with three rates of brown rot spores. The number of lesions on the mature fruit was counted at harvest.

Results

1. N-P-K Study

Fruit yield and quality. In 2008, only low K and P reduced fruit yield, whereas in 2009, low N also reduced fruit yield compared with the fully fertilized control. Individual fruit weight was especially reduced in the low K and P treatments in 2008, but not in the low N treatment, compared with the fully fertilized control (**Figure 2**). All treatments had lower yields in 2009.

Fruit nutrient concentration. The N, K and Ca concentrations measured in fruit tissues were within the ranges

Fruit browning (left) was most significantly related to low P supply; while the development of brown rot in fruit (right) was related to excessive N supply—which promotes vegetative growth but also increases the risk to fungal infections.
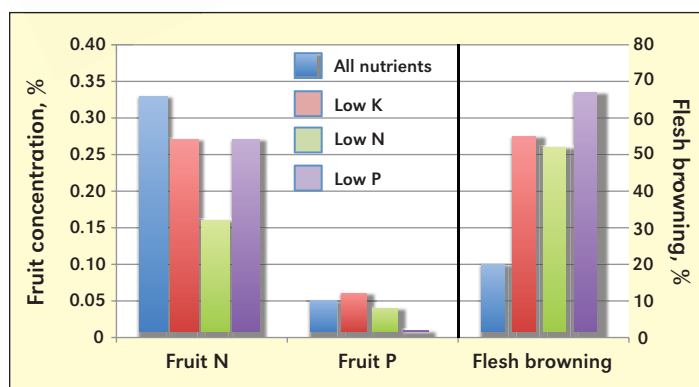
Figure 3. Effect of low K, N or P in the nutrient solution on N and P concentrations in nectarines compared with a no-deficiency control. The effect of K, N or P deficiency on flesh browning after 11 days storage at 5°C compared with a no-deficiency control.

previously published. Only fruit from the low P treatment had concentrations below those obtained from a survey of typical fruit populations. Fruit from fully fertilized trees had the highest N concentrations, followed by fruit from the low P and K treatments, whereas fruit from the low N treatment had the lowest N concentration. Phosphorus concentrations in fruit were affected significantly by the nutrient deficit treatments, with the low P treatment having the lowest concentration of P (**Figure 3**).

Potassium and Ca concentrations in fruit were unaffected by any treatment. The low K treatment did not reduce fruit K, P or Ca concentrations but reduced the N concentration (but still within the normal range). The low N treatment significantly reduced fruit N to 50% of control fruit, without affecting fruit K, P or Ca concentrations. The low P treatment reduced fruit P (~80%) and N (~20%) concentrations without reducing the K or Ca concentrations.

Fruit Browning. Fruit browning was higher in the low-P treatment than in fruit from the other treatments. The low-P fruit had 67% flesh browning in 2009 compared with only 20% in the control treatment (**Figure 3**). Fruit from all the deficient treatments had significantly more browning than fruit from the

fully fertilized treatment after 11 days of storage.

Fruit with low P concentrations had increased phenolics concentrations (620 µg/g), compared with the fully fertilized treatment (388 µg/g). The phenolic compounds act as substrates for the PPO enzyme, which produces quinones that turn fruit tissues brown.

The low N treatment also had reduced concentrations of P in the fruit, which commonly leads to increased fruit browning.

Our work demonstrated that a restricted nutrient supply (N, P or K) affects the intensity and incidence of fruit browning during cold storage, independent of which of these nutrients were deficient. However there appear to be other complex nutrient interactions, where a limited supply of two or more nutrients produced imbalances that affected the total fruit nutrient status and quality.

Only low P concentration in the fruit had a consistent effect on browning potential and its precursors during both seasons. A low fruit P concentration may have a role in excessive cell membrane permeability, allowing the phenolic substrates to be more accessible for reaction with PPO.

Contrary to what we expected, low-P fruit also had the most antioxidants, which were supposed to counteract oxidation and retard browning.

Results
2. Nitrogen Rate and Brown Rot

Although it is common for stone fruit growers to annually apply over 100 lb N/A, it is not unusual for some individuals to apply additional N in the hope of increased crop yields. However, excess N fertilization may result in overly vigorous vegetative growth, leading to a negative effect on fruit quality and also a deleterious effect on the tree's susceptibility to attack by disease and insect pests.

In this experiment, total fruit yield was not affected by the N fertilization above 100 lb N/A/yr, but the time to fruit maturity was delayed by 4 to 5 days with additional N. The lower application rates of N induced more red color on the nectarine skin. The added vegetative growth from excess N increased shade both inside and beneath the tree canopy, extending the length of the harvest period. Vegetative growth was positively correlated with N application rate.

Mature stone fruit trees in sand tanks for nutrition experiments (University of California).

Blossoms from unfertilized trees showed the lowest occurrence of brown rot infection following inoculation. When the data were combined for all infection dates, significantly more stamens were infected on blossoms from the high N treatments than on blossoms from the unfertilized and 175 lb N/A/yr treatments. The green fruit inoculation also showed a positive correlation between the incidence of infected fruit and N fertilization (**Figure 4**).

Summary

Nectarine tree fertilization practices have significant effects on fruit quality. Low fruit P consistently increased fruit browning during storage. Excessive N fertilization stimulated excessive vegetative growth and caused fruit to be more susceptible to brown rot. BC

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Additional details are available in these publications

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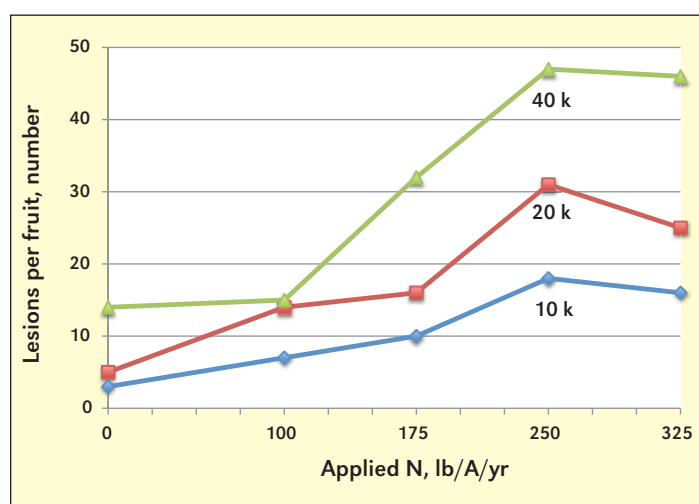

Figure 4. Effect of N fertilizer application rate and spore inoculation rate (10,000, 20,000 or 40,000 spores/ml) on brown rot infection of mature nectarines.

Selenium: Essential for Animals, Not for Plants

By Robert Mikkelsen

Selenium (Se) is essential for many physiological functions in humans and animals, but not for plants. In humans, it is present in more than 20 proteins that are involved in roles such as cancer protection, anti-oxidants, maintaining defenses against infection, and regulating growth and development. Since Se is obtained primarily in food, its accumulation by plants is of interest.

The accumulation of Se by plants has been studied worldwide, even though it is not classified as an essential nutrient. Many regions grow crops that contain insufficient Se to meet human and animal nutritional requirements. In these locations, efforts have been made to increase plant Se concentrations. Other areas have problems with excessive Se found in vegetation. When plants contain very high Se concentrations, animals that consume these plants can be at risk of toxicity (called selenosis).

The uptake of Se by plants is governed by many soil and plant factors. The most important factors determining uptake are the chemical form and the concentration in the soil. Other important factors in determining the accumulation of Se by plants include soil properties such as pH, clay content, soil mineralogy, and the concentration of competitive ions.

The capacity of different plant species to accumulate Se also varies widely. For example, Se-accumulating plants such as some species of the genus *Astragalus* can contain up to 20,000 parts per million (ppm) Se, whereas most agricultural crops contain less than 1 ppm.

The chemical state of Se in soil is a very important factor in the ability of plants to acquire it. It is found in several different oxidation states:

Selenate (Se⁶⁺): This form (SeO_4^{2-}) is the most readily taken up by plants. It is very soluble and behaves quite similarly to sulfate (SO_4^{2-}). Selenate is most likely to be found in well-aerated, neutral pH soils. Selenate is translocated directly from the roots to the leaves and stored in the cell chloroplasts before being converted to organic compounds such as seleno-methionine. An abundance of sulfate in the soil inhibits the uptake of selenate since they both compete for uptake at the same transport sites of roots.

Selenite (Se⁴⁺): This form (SeO_3^{2-}) is more typically found in aerated soil with acid to neutral pH. Selenite is much more reactive with various soil minerals than selenate, making it
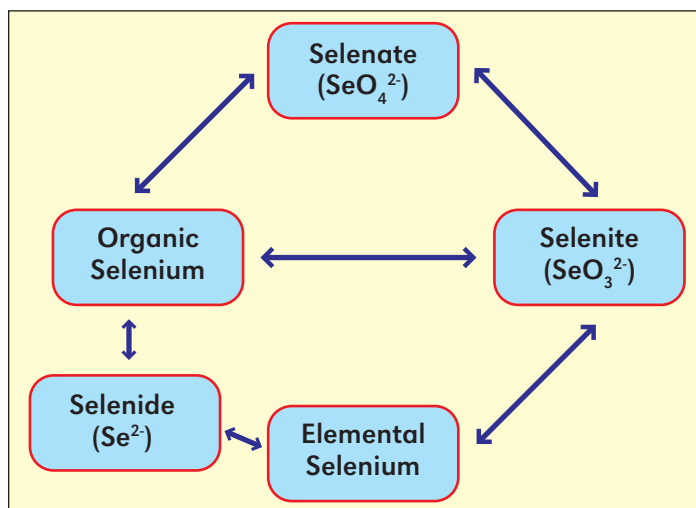
Selenium cycle in soil.

less soluble in the soil solution. When plants take up selenite, much of it is converted to organic compounds (such as seleno-methionine) before being translocated in the xylem.

Elemental Selenium (Se⁰): Metallic selenium is quite insoluble and not available for plant uptake.

Selenide (Se²⁻): This form of selenium is found primarily in soils under strongly reducing conditions (such as flooded soils). It may be present in a combination with a variety of minerals and organic compounds. It is mostly unavailable for plants in this form.

When Se concentrations in human or animal food are considered too low, Se-fortified fertilizer has been used to boost the supply. Wide-spread Se fertilization is routinely performed in Finland and New Zealand to boost the Se concentration in forages and cereal crops. There are other areas of the world where the Se concentration is low and fertilizer fortification with Se may be useful.

The range between Se deficiency and toxicity for humans and animals is fairly small. Careful study should be done before a program is initiated to boost the Se concentration of crops to avoid excess accumulation and potential toxicity. **BC**

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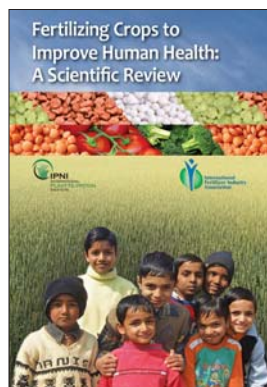
Recent Publications on Micronutrients and Human Health

Fertilizing Crops to Improve Human Health: A Scientific Review
Bruulsema, T.W., Heffer, P., Welch, M.R., Cakmak, I. and K. Moran. IPNI, IFA, October 2012. 290 pp.

Fertilizing Crops to Improve Human Health: Infographics, May 2013.

For details see IPNI Website: http://info.ipni.net/FCIHH or IFA Website: http://www.fertilizer.org/ifa/HomePage/SUSTAINABILITY/Nutrition

Optimizing Nutrient Stewardship Using Broadcast Fertilizer Application Methods

By John Fulton, Timothy McDonald, C. Wesley Wood, Oladiran Fasina and Simerjeet Virk

Research from Auburn University suggests continued advancement in the capacity of spinning disk broadcast spreaders in order to increase the efficiency of the field operation has likely enhanced the risk for well known issues related to obtaining good uniformity in product spread patterns for common granular fertilizer blends. Recommendations are provided in order to increase awareness of this risk and ensure optimal results can be obtained from this popular fertilizer application method.

Nutrient stewardship continues to be at the forefront for growers as they attempt to better manage costs and efficiently utilize inputs. Nutrient management is just one area of focus for growers, but can be a difficult task at the farm level to ensure that soil supply of nutrients meets crop demands. Precision agriculture practices such as precision soil sampling coupled with variable-rate fertilizer application technology has afforded growers the ability to spatially manage soil fertility levels; thereby better matching soil fertility levels with crop yield potential to maximize profitability. A primary benefit of precision agriculture is the ability to more accurately place fertilizers, which has been confirmed by science and practitioners under the assumption that equipment and technology are operating at peak performance.

Illustration of pan layout prior to a spreader traversing the test area. Tarps are used to collect fertilizer in order to eliminate environmental risks at the test site.

In the U.S., spinner disc spreaders continue to be the primary means to apply granular fertilizers. Over the past 10 years, spinner spreader manufacturers have developed spreader beds and the associated hardware components to spread wider and independently meter and apply multiple products. They have also increased bed capacity to carry more material. Today, a majority of spreader manufacturers offer beds with stated spread widths between 80 and 100 ft. for fertilizer. Occasionally, a 120-ft spread width has been used for beds mounted on high clearance sprayer frames. In this same time period, the use of guidance technology on spinner spreaders has significantly increased, allowing the same paths to be traveled each time during field application. These advancements in both spreader design along with the use of precision ag technology have been a response to meet field capacity (A/hr) requirements of these machines to ensure timely application for efficient crop production.

While fertilizers can be applied as individual constituents or as a blend, blended fertilizer products are common in order to meet specified agronomic requirements while reducing spreading costs (e.g., minimizing trips across the field). We also know that design of spreader components (i.e., divider, discs, and vanes) influences material flow behavior and thereby distribution. However, the nature of blended fertilizers can make it difficult to spread uniformly due to varying physical properties of the N, P and K raw constituents, which can lead to segregation during application. Research has noted that particle size is the major contributing parameter impacting segregation (Bradley and Farnish, 2005; Bridle et al., 2004; Miserque et al., 2008; Smith et al., 2005) and spread distance of fertilizer. Research documents the potential for fertilizer segregation and its negative effect on production distribution (Miserque at al., 2008; Yule and Pemberton, 2009). The main point is that times have changed in the U.S. with the need to spread wider and use blended fertilizers to help manage costs. The idea of fertilizer segregation coupled with repeatable field traverses using guidance technologies, physical size of modern spreaders, and varying application rates increases the opportunity for cumulative application errors generating nutrient "streaking" within fields.
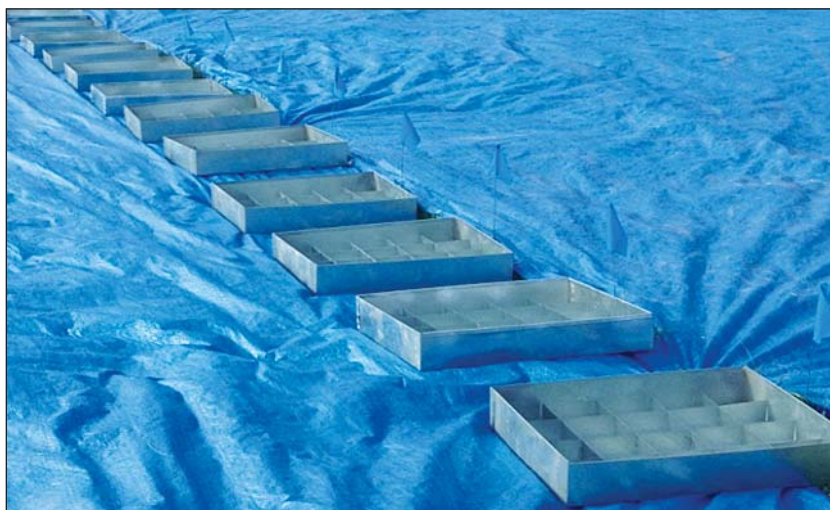
A study was conducted at Auburn University over the past two years to better understand the potential for blended fertilizer segregation as impacted by spreader hardware and fertilizer physical characteristics for spinner-disc spreaders. Two unique spreader setups were used to determine how hardware could impact segregation with a focus on how fertilizer interacted with the vanes and discs. These included different divider and vane designs.

Different fertilizer blends, which were readily available and used in central Alabama were investigated. The first blend has a grade of 17-17-17 with ammonium nitrate, DAP and potassium chloride (KCl) as the base constituents. The second blend was a 10-26-26 that included only DAP and KCl. Additional treatments included application rates of 200 and 400 lb/A and different spinner-disc speeds. Standard pan testing procedures (following ASABE Standard S341.3) were conducted to document distribution patterns. Field tests included

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; DAP = diammonium phosphate. IPNI Project #AL-21.

Table 1. Mean physical characterization for the different fertilizer components and blended products.

	Product	Grade, %	Mean d_{50}[a], mm	GSI[b]
Blend 1	Ammonium Nitrate	34 - 0 - 0	2.16	25
	DAP	18 - 46 - 0	3.22	17
	Potash	0 - 0 - 60	3.05	29
	Blend 1	17 - 17 - 17	2.87	32
Blend 2	DAP	18 - 46 - 0	3.17	14
	Potash	0 - 0 - 60	3.00	25
	Blend 2	10 – 26 – 26	2.97	19

a) d_{50} is the median particle size for the fertilizer.
b) GSI represents Granulometric Spread Index

Table 2. ANOVA results for comparison of nutrient mass fractions across the swath based on pan testing.

Source	DF	Mean	Coefficient of Variation, %	Mean Square Error	p-Value
N	14	17.9	4.0	3.0	0.4726
P_2O_5	14	16.8	25.0	56.4	<0.0001
K_2O	14	14.7	26.0	59.1	0.0037

capturing applied material with randomly placed collection pans across fields during a variable-rate application using the 17-17-17. Samples were also collected from the hopper and conveyor to establish that significant product segregation had not occurred prior to pan and field-testing. Analysis included both physical and chemical characterization using standard laboratory procedures while weighing material captured in pans to compute rate applied at a specific location. High-speed video was also utilized to evaluate particle behavior on the spinner-discs and vanes. This video was able to establish the amount of material being controlled on the vanes versus uncontrolled particles that ricocheted.

Pan and field tests indicated that fertilizer segregation is possible when applied in blended forms using spinner-disc spreaders. While segregation can occur due to loading and vibration during field application, our grab samples from the hopper and conveyer indicated than the level of segregation off the conveyor was minor and insignificant. Particle size analysis (**Table 1**) supported the notion that segregation occurred mainly due to size variability between the constituents.

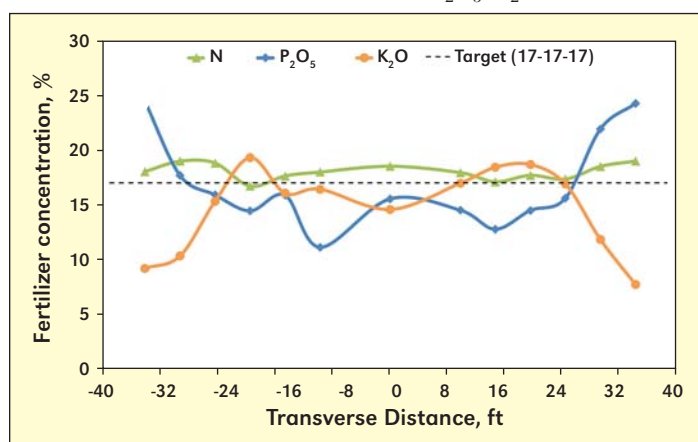**Figure 1** provides the applied N-P_2O_5-K_2O mass fractions

Figure 1. Example nutrient concentration across the spread width for Blend 1 (17-17-17) with a spreader setup at a 70 ft. spread width. Reported data are the mean of three pan tests.

across the swath for Blend 1 (17-17-17). The N mass fraction was consistent across the swath (p=0.4726; **Table 2**), but is a result of both ammonium nitrate and DAP contributing a source of N in Blend 1. These results are important to note

as the reason for uniform N across the swath. Observations of material collected in pans suggested that ammonium nitrate in the center transverse pan locations (-8 to 8 ft.) tended to be pulverized more than the larger N particles beyond these transverse distances. For pans on the pattern periphery (>25 ft. from the centerline), the source of N was primarily from DAP. Conversely, there existed a significant difference between the applied P_2O_5 and K_2O mass fractions (p<0.05; **Table 2**). DAP tended to be applied towards the end locations of the pattern with concentrations reaching 25%. DAP concentration was also higher at the center portion of the pattern generating a W-shaped pattern. Potash peaked on either side (20 ft. transverse locations) of the spreader centerline generating an M-Pattern. The point of these data is that segregation can become an error that is not detected by operators.

There were notable observations that fines, mainly from the ammonium nitrate, occurred at a disc speed of 800 rpm for Blend 1. Ammonium nitrate is not as dense as KCl or DAP so as the disc speed increased, this N source tended to explode into dust particles upon contact with the vanes. These dust particles, in the absence of wind, are applied along the centerline of the spreader causing a sharp peak in the distribution pattern. The 700 rpm results indicated only a slight trend to this effect, but were not significantly different from the 600 rpm results. The relevance of this result is that spinner disc speed and associated swath width should be considered when using an N source such as ammonium nitrate or urea in a blend. Results of this research suggest keeping the application width below 60 ft. unless pan tests indicate otherwise, or avoid using a triple blend. This recommendation is most critical when timing and uniformity of spread is especially important such as under high yielding conditions.

Blend 2 also generated similar concentration results for P and K across the spread width (**Figure 2**). These data indicated a consistent M-pattern for the P and a W-pattern for K at spinner disc speeds of 600, 700 and 800 rpm for this spreader and blended product. At the disc speeds tested for Blend 2, little or no fines were measured at the spreader center or on either side (10 ft.) indicating these disc speeds were not causing particles to explode. However, while not significant, the 800 rpm results did generate some fines suggesting that even higher disc speeds might cause an issue as found with Blend 1. While fertilizer segregation can occur due to various factors (i.e., loading, particle size variation, vibration, etc.), the presence of peaks and valleys across the swath width during pan tests indicate that distribution using spinner-discs and vanes can be a large contributor.

Field-testing using one spreader and Blend 1 under variable-rate application demonstrated how the issue of segregation could impact concentration uniformity. Applied nutrients were found to vary significantly from the expected rates in the fields

except for N, which had a mean concentration of 17% and a CV less than 8.5%. The applied P_2O_5 and K_2O concentrations varied significantly with mean concentrations of 15% and 17%, respectively. While the overall mean concentration was near the target of 17%, the uniformity of spread (CV) ranged from 19.7% to 37.2% for P_2O_5 and 16.8% to 30.2% for K_2O.

An important finding of this study was that level of segregation can be impacted by vane design and spinner-disc speed. Vane design can greatly impact segregation in two possible ways; 1) level of ricocheting and thereby uncontrolled material flow off the vanes and 2) the exit point and final particle velocity controlling the distance traveled (e.g., larger particles travel further). To increase spread width, one must increase spinner disc speed; however, this study established that risk of segregation also increased with
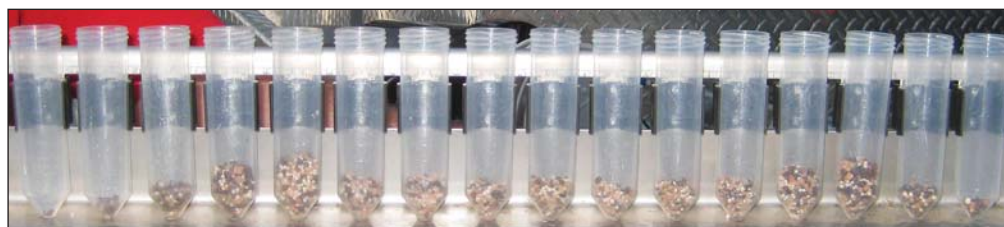
Visual illustration of the resulting distribution from an individual pan test using Blend 1 (17-17-17). Note that the DAP particles (larger in diameter) were applied further out than the KCl (pink particles) and ammonium nitrate (white particles). While not clearly visible, the center three tubes contain the highest percentage of dust particles, which were mainly ammonium nitrate.
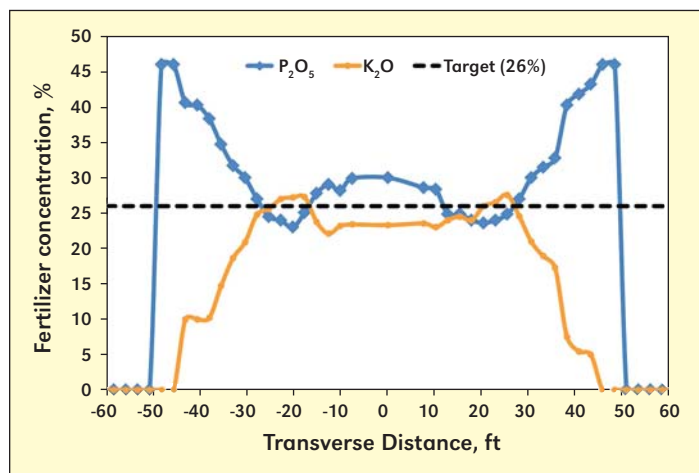

Figure 2. Nutrient concentration across the spread width for Blend 2 (0-26-26) with a spreader setup at a 70 ft. spread width. Reported data are the mean of three pan tests.

disc speed. Some of this risk was associated with ricocheting of fertilizer particles off the vanes during initial contact. Fertilizer ricocheting represents an uncontrolled aspect of material flow, which negatively impacts the spread distribution since ricocheted particles land around the center of the spreader. Ricocheting is primarily due to vane design and not the spinner-disc based on this study with the top edge of the vane (e.g., first potential contact point for particles) significantly influencing level of ricocheting. Tests showed that 35% of the material flow off the conveyer could be ricocheted at 800 rpm with a vane design having a top edge that is forward facing and angled upwards. The level of ricocheting can be reduced in half or more by making the top edge, level or tapered backwards.

Summary

This study showed that segregation of blended fertilizers occurs, especially as spinner disc speeds or spread widths increase. Spreader hardware such as vane design can impact the level of segregation. However, this study documented this problem with only two different spreader setups, and may

not exist with other setups or hardware configurations. One remaining concern is that repeated applications following the same spreader paths (e.g., use of GPS-based guidance) could result in soil fertility zones or streaks within fields. Therefore, variable-rate application of blended fertilizer could pose challenges in terms of accuracy and uniformity to meet target prescription rates. Three case studies that we reviewed in 2011 and 2012 established the issue of segregation by spreaders causing nutrient streaking in corn.

Adjustments were required to address this problem and uniformly apply granular fertilizers. Recommendations from this study would be: 1) due to the importance of similar particle size and density for blend constituents, avoid blending an N source with potash or phosphate sources unless spread width is sufficiently limited so as to prevent segregation—usually less than 50 ft., 2) use P and K sources with consistent particles sizes throughout the pile with no dust, and 3) double check through pan testing that 800 rpm or higher disc speeds are not causing significant product segregation or dust generation through particle ballistics. Spreader setup, maintenance, and calibration along with selection of the appropriate product to coincide with these parameters are as critical as ever to ensure uniform distribution as we seek to improve machinery and input efficiency. BC

Acknowledgements

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World Reserves of Phosphate Rock…
a Dynamic and Unfolding Story

By Steven J. Van Kauwenbergh, Mike Stewart and Robert Mikkelsen

Phosphorus is essential for life, and the input of P fertilizer is critical to the production of sufficient food, feed, fiber, and fuel to support a growing world population. Most modern P fertilizer is made from phosphate rock (PR), a nonrenewable natural resource. Over the past decade or so there has been concern that the world would soon deplete its PR resources, and face a catastrophic P shortage; however, recent and thorough estimates of world PR supply indicate that a P crisis is not imminent, and that the we will not soon run out of PR.

P ractically all of today's inorganic P fertilizers are produced from PR. Phosphate rock is an imprecise term that describes naturally occurring geologic materials (minerals) that contain a relatively high concentration of P. The term PR is used to describe raw (unbeneficiated) phosphate ores, but may also be applied to beneficiated or concentrated products.

Phosphate rock occurs in both sedimentary and igneous deposits across the world (**Figure 1**). Most (80 to 90%) of PR used to produce fertilizer is sedimentary in origin, and was deposited in ancient marine continental shelf environments. Sedimentary deposits, sometimes called phosphorites, occur throughout geologic time. Most PR is mined by open pit techniques, but a significant amount of deposits in China, Russia and other countries are extracted by underground mining. Apatite, a calcium phosphate mineral, is the principle P bearing component of PR.

The origin of the modern P fertilizer industry can be traced back to the mid-1800s when the first patents were granted for treating "phosphoritic substances" such as apatite and bones with sulfuric acid to produce "superphosphate". In 1842 patents were granted in England to both John Bennet Lawes and James Murray for the manufacture of P fertilizer by the process of acidulation. Although others, including Justus von Liebig, had been studying the process, Lawes and Murray have been credited as "the laymen who put the idea into permanent commercial practice" (Jacob, 1964). Practically all P fertilizers today are made by this "wet process" of treating PR with acid (e.g., sulfuric, nitric, or phosphoric) to produce phosphoric acid or triple superphosphate (TSP). Phosphoric acid is then used to produce both granular and fluid P fertilizers.

Phosphorus is essential for life, and the input of P fertilizer is critical to the production of sufficient food, feed, fiber, and fuel to support a growing world population. Considering these facts, and that PR is a finite and non-renewable natural resource, it is reasonable to question just how much PR there is in the world, and how long we can continue to extract it. This is a question that has generated considerable interest, discussion, and even some controversy. Following is a com-
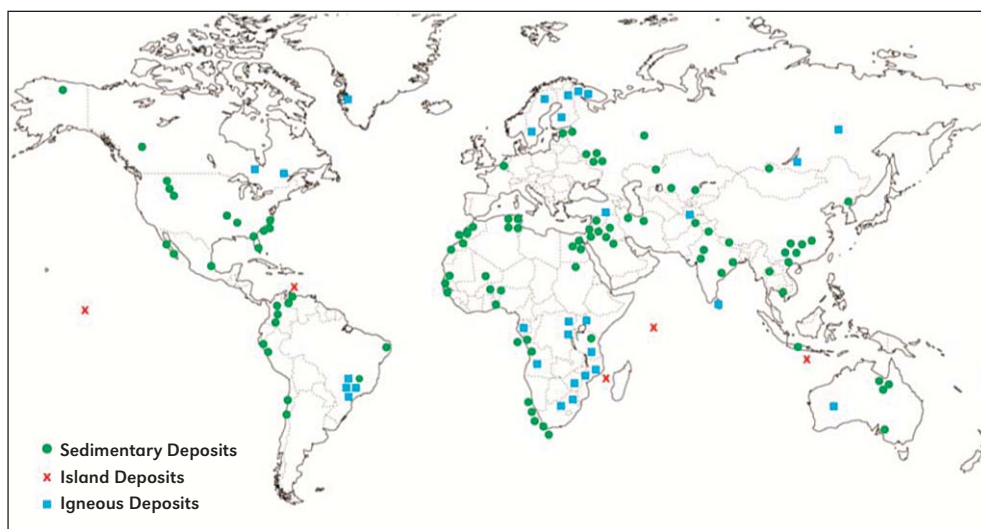
Figure 1. World phosphate rock resources (Source: IFDC).

pressed narrative of some relevant history and current status of world PR supply.

Reserves and Resources

There are two terms that must be defined prior to discussion of world PR supplies. Van Kauwenbergh (2010) simply defined reserves and resources as:

Reserves: PR that can be economically produced at the time of the determination using existing technology

Resources: PR of any grade, including reserves, that may be produced at some time in the future

Relevant History

Commercial production of PR increased by a factor of about 1,000 from the mid 1860s to the mid 1970s (**Table 1**). With increased exploitation came more attention to PR as a finite natural resource. In the early 1970s the Institute of Ecology (1971) published results of a workshop where it was suggested that the known world reserves of PR might be exhausted within 90 to 130 years. Some believe this published projection is what fueled a period of expanded interest in estimating PR reserves and resources. Through the 1970s and 1980s there was a vast amount of

Table 1.. Early progression of world PR production (Source: IFDC).

Year	PR production tons
1847	500
1850	5,000
1853	10,000
1865	100,000
1885	1,000,000
1928	10,000,000
1974	100,000,000
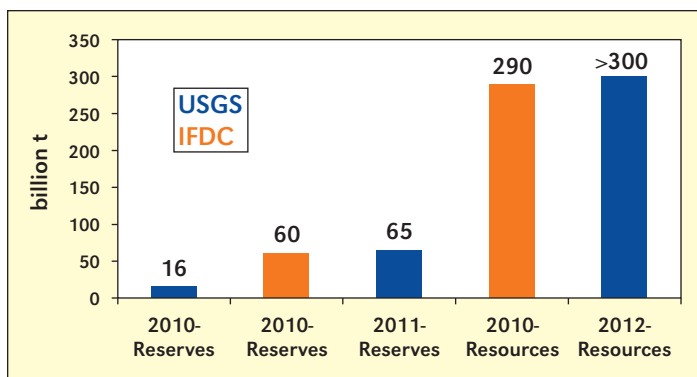
Figure 2. Phosphate rock reserve estimates reported by the USGS and IFDC (Sources: USGS and Van Kauwenbergh, 2010).

Table 2. Reserve estimates for the world's top 10 PR reserve holders and their percent of world reserves held (Source: USGS Mineral Commodity Summary, 2013).

Country	Reserves, 2012 million t	World total %
Morocco and Western Sahara	50,000	75
China	3,700	6
Algeria	2,200	3
Syria	1,800	3
Jordan	1,500	2
South Africa	1,500	2
United States	1,400	2
Russia	1,300	2
Peru	820	1
Saudi Arabia	750	1
Others	2,268	3
World total (rounded)	67,000	100

research done in this area. Chief among the groups involved in these efforts was the U.S. Bureau of Mines (USBM) and the United States Geologic Survey (USGS). However, in the mid 1990s significant funding and human resources that were once directed at PR research were diverted in other directions. The U.S. Congress voted to defund the USBM in 1995, and by the end of 1996 it was closed. Since the USBM closure, the USGS has had sole responsibility for reporting PR statistics in the U.S. through the Mineral Commodity Summaries. Since the early to mid 1990s there has generally been a limited amount of detailed publicly available information on PR reserves and resources both from the USGS and other worldwide sources.

Beginning in about the mid to late 2000s several articles and postings appeared suggesting that the world was facing a looming shortage of PR. Most of these were based on USGS reserve estimates of the time. Among the most notable of these articles was one by Cordell et al. (2009) that stated "current global reserves may be depleted in 50-100 years." Various other articles propagated mainly through the internet and news articles featured anxious headlines such as "phosphorus famine", "the disappearing nutrient", and "no phosphorus-no food". Many of these articles came on the heels of the world food crisis of 2007-08 when, as commodity prices escalated, images of food riots appeared in news releases across the world. These factors combined to set an alarmist tone and apocalyptic outlook regarding the world PR supply situation for the future.

Current Status

In response to this keen interest, the International Fertilizer Development Center (IFDC) launched an effort to update the estimates of world PR reserves and resources. The effort included a review of publically available information, such as government and industry reports and statistics, scientific literature, proceedings publications, conference presentations, etc. The review was published by IFDC as World Phosphate Rock Reserves and Resources (Van Kauwenbergh, 2010).

This IFDC report revealed significantly more PR reserves than had previously been estimated by the USGS. The USGS figure for PR reserves reported in the 2010 Mineral Commodity Summary

was 16 billion t, but the IFDC report released later the same year estimated 60 billion t of reserves. By 2011 the USGS had revised its estimate upward by a factor of about four, from 16 to 65 billion t (**Figure 2**). The official USGS estimates have stayed in about the 60 to 70 billion t range since 2010.

Most of the PR reserves that were added in the 2011 USGS report came from Morocco. **Figure 3** shows USGS/USBM PR reserve estimates from 1989 through 2011 for several key countries. Morocco hovered at about 6 billion t until 2011 when estimated PR reserves were revised to over 50 billion t.

Notice also in **Figure 3** that prior to 2003 China was thought to be a relatively small PR reserve holder, but in 2003 it suddenly had more PR reserves than any other country. This happened because 2003 was the first year that the Chinese government released official PR data. Since that time, their reserve estimates have been revised downward by the USGS. Both the Morocco and China revisions show how reserve estimates are fluid and subject to dramatic change based on discovery and best available information.

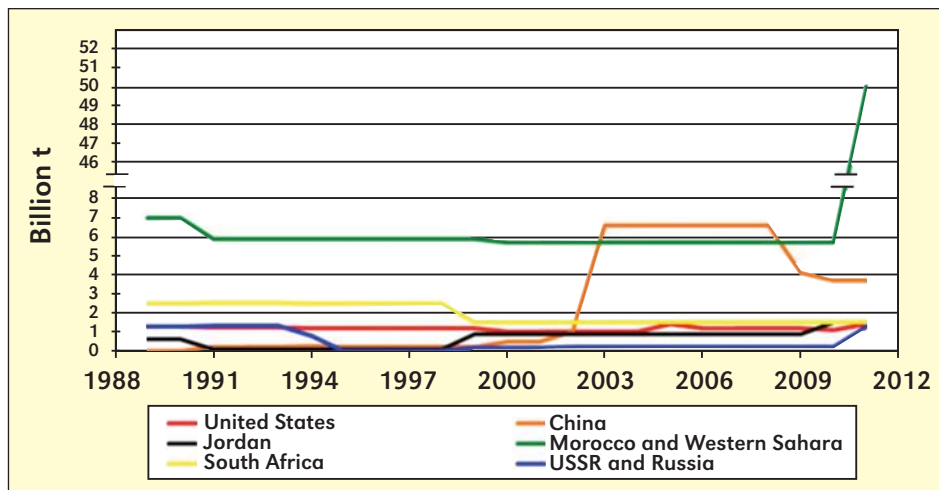**Table 2** shows the latest USGS estimates for world PR

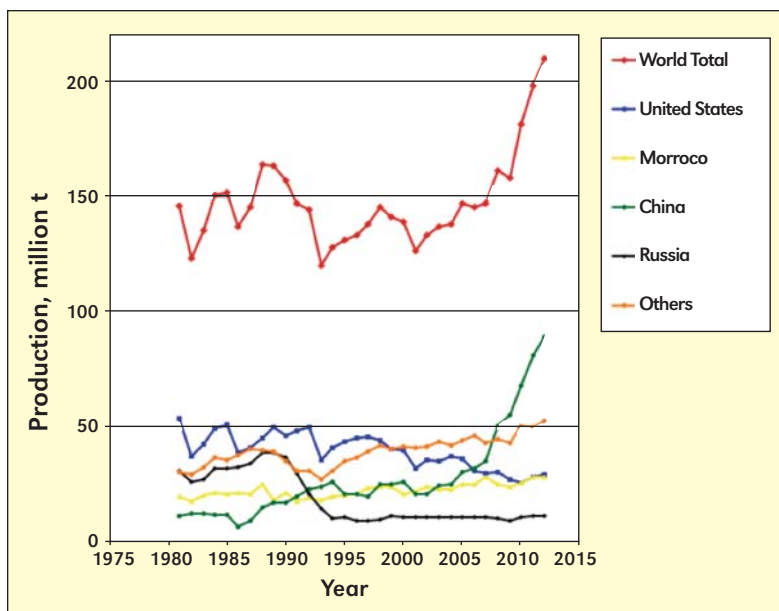**Figure 3.** Phosphate rock reserve estimates for select countries from 1989 to 2011 (Source: USGS).

Figure 4. Phosphate rock production (1981 to 2012) for the world and selected countries (Source: USBM and USGS).

according to the latest USGS report is at 210 million t. This same report suggests that within the next year, world PR production capacity could go from 220 to 256 million t, with the largest expansion project occurring in Morocco.

A simple calculation of PR reserve longevity using current reserve and production figures indicates that the world has over 300 years of reserves and over 1,400 years of resources. Thus the world will not soon face a PR crisis. It should again be emphasized that estimates for PR reserves are subject to change with updated information and discovery, and with changes in economics and technology. In the last 5 years, several new deposits have been discovered and the resources of previously located deposits are being studied to quantify more reserves. As mining and processing technology develops and improves, today's resources can become tomorrow's reserves. Nonetheless, PR is a non-renewable natural resource and, from production to end use, should be stewarded as efficiently as possible. BC

reserves for the top 10 holders. Morocco is estimated to have about 75% of the worlds PR reserves, while China is a distant second with 6%. The United States is estimated to hold about 2% of world PR reserves. Based on data found in the IFDC report, the Unites States was thought to hold about 76% of the world's recoverable phosphate product (~30% P_2O_5) in the late 1970s. As the 2010 IFDC report indicated, world phosphate rock reserves and resources are dynamic due to a wide variety of factors.

Figure 4 shows PR production for the world and selected countries from 1981 to 2012. World PR production varies considerably over this time frame, but is trending upward in recent years. Production has increased sharply since 2009 and

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Nominations for IPNI Science Award Close September 30

Each year, IPNI offers its Science Award to recognize and promote distinguished contributions by scientists involved with global ecological intensification—defined as development of high-yield crop production systems that protect soil and environmental quality and conserve natural resources. Characteristics of ecological intensification include yields near their potential, high efficiency of nutrient use, and appropriate management of soil nutrient stocks and organic matter. Such systems improve net returns, lower unit costs of production, and maintain or improve environmental quality.

The Award is to be presented each year to one agronomic scientist. The recipient receives a plaque and a monetary award of US$5,000.

Nominations must be submitted in English and completed nomination forms (no self-nominations) including all support

letters must be received at IPNI headquarters by September 30, 2013 to be eligible. Announcement of Award recipient will be on December 1, 2013.

Nomination forms are available from the IPNI Award website www.ipni.net/awards

Send completed nomination, including attachments, to:
   IPNI Science Award Committee
   International Plant Nutrition Institute
   3500 Parkway Lane, Suite 550
   Norcross, Georgia 30092-2844

Past Winners
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   2011: Dr. M.J. McLaughlin, Commonwealth Scientific and Industrial Research Organisation (CSIRO)
   2010: Dr. A.N. Sharpley, University of Arkansas
   2009: Dr. J.K. Ladha, International Rice Research Institute (IRRI)
   2008: Dr. John Ryan, International Center for Agricultural Research in Dry Areas (ICARDA)
   2007: Dr. Milkha Singh Aulakh, Punjab Agricultural University (PAU)

Zinc Application Method Impacts Winter Triticale in Western Siberia

By Igor A. Bobrenko, Natalya V. Goman and Elena Yu. Pavlova

Field experiments revealed that winter triticale responds significantly to Zn fertilizer applied to soil low in available Zn. Both yield and quality of grain were improved with Zn application. Soil application of Zn was generally more effective compared to seed treatment. The optimum Zn rates for soil application and seed treatment were found to be 8 kg Zn/ha and 100 g $ZnSO_4$/100 kg seed, respectively.

Nowadays, studies on new foodgrain resources and technologies to enhance crop productivity have a great practical significance. Improving grain quality of cereals and increasing production of plant protein are considered as the most important goals for Russian agriculture. Mineral fertilizers play a key role in achieving these goals including micronutrient fertilizers that are effective in increasing both grain yield and quality of cereals according to numerous research studies (Bobrenko et al., 2011a; 2011b). Micronutrients need to be applied at lower rates compared to macronutrients, but have higher requirements regarding their uniformity of application.

Winter triticale is a very promising cereal crop for Russia. Triticale grain has higher level of lysine than winter wheat. Lysine is an essential amino acid in human nutrition and plant proteins usually have insufficient levels of lysine. Baking properties of triticale are not as good as soft wheat, but its characteristics may be successfully used for baking of so-called "white rye" bread and pastries made from unleavened dough—when gluten quality is less important than nutritional value (Sechnyak and Sulima, 1984).

Omsk Oblast is a second largest agricultural region in Western Siberia, after Altai Krai. Arable soils in Omsk Oblast are very often deficient in available Zn according to soil fertility surveys. A low level of available Zn was revealed in 2.9 million ha, or 99% of the arable land comprised by the regional soil survey. Meadow-chernozem soils (Gleyic Chernozems) generally have insufficient levels of available P; however, high rates of P fertilizers may contribute to Zn deficiency if soil available Zn is low. A balanced application of Zn fertilizers to cereal crops is of high importance to optimize plant nutrition and, hence, to obtain higher yield and quality of grain (Krasnitskiy, 2002). Developing strategies to increase the effectiveness of Zn fertilizer use to winter triticale may be considered as a

Zinc fertilizer has a significant effect on both grain yield and quality of winter triticale grown on meadow-chernozem soil.

significant goal to enhance crop productivity in the Southern forest-steppe zone of Western Siberia (Krasnitskiy, 1999; Orlova, 2007).

The purpose of this study was to develop the most effective methods and rates of Zn fertilizer application to winter triticale in Omsk Oblast (Southern forest-steppe). This region is characterized by average annual rainfalls of 135 mm during the growth period. Research experiments were conducted during 2007-2011 in experimental fields of the Siberian Research Institute of Agriculture. The region's meadow-chernozem was a clay loam with medium OM content (6 to 9%). Average initial contents of nitrate-N (NO_3-N) and available P (0 to 30 cm soil layer) were medium at 8.0 ppm NO_3-N and 4.0 ppm P, respectively. The average level of available K was 49 ppm, which falls within the "high" interpretation class. Nitrate, available P and K were extracted with 2% acetic acid (CH_3COOH) solution (Ermokhin, 1995). It is important to indicate that available soil Zn extracted with ammonium acetate buffer solution (pH 4.8) was only 0.6 ppm Zn, which falls within the "low" category. Plots were 16 m^2 and were replicated three times. Winter triticale (variety Sibirskiy) was preceded by bare fallow. Fertilizer applications included basal rates of N and K applied as ammonium nitrate and potassium chloride before tillage and a seed-placed P fertilizer as triple superphosphate.

Table 1. Effect of basal Zn application on grain yield and quality of winter triticale grown on meadow-chernozem soil.

Treatment, kg/ha		Grain yield, t/ha					Yield increase		Test weight, g/l	Glassiness, %	Protein, %	Falling No., sec.
P_2O_5	Zn	2008	2009	2010	2011	Average	t/ha	%				
0	0	2.58	1.30	2.03	3.15	2.27	-	-	604	50	16.3	63
0	4	2.71	1.47	2.41	3.75	2.59	0.32	14	637	50	16.5	63
0	8	2.79	1.37	2.70	3.86	2.68	0.41	18	639	50	16.9	63
60	0	2.94	2.29	2.13	4.28	2.91	-	-	635	50	16.4	64
60	4	3.23	2.38	2.59	4.33	3.13	0.22	8	638	50	16.6	63
60	8	3.05	2.87	2.93	4.33	3.30	0.39	13	641	49	16.8	63
$LSD_{0.05}$		0.16	0.13	0.13	0.11							

Note: Four-year averages are given for grain quality parameters. All treatments received 30 kg N/ha.

We studied two methods of zinc sulfate ($ZnSO_4$) fertilizer application: 1) basal application before tillage and 2) powdered seed treatment.

Results

During four experimental years, grain yield of winter triticale varied from 1.30 to 3.15 t/ha (2.27 t/ha average) in the treatment receiving N fertilizer only (N_{30}) (**Table 1**). The effect of Zn fertilizer on grain yield was most dependent upon annual weather conditions and Zn rates used. Soil applied Zn rates in addition to N fertilizer improved crop productivity and a significant yield increase was revealed during all experimental years. An average yield increase due to basal Zn application at rates of 4 and 8 kg Zn/ha was 0.32 and 0.41 t/ha or 14 and 18%, respectively.

Improved P nutrition resulted in a significant yield increase of winter triticale because soil at the site had a medium soil test P. Phosphorus application at 60 kg P_2O_5/ha gave an average yield increase of 0.64 t/ha or 28% compared to N fertilizer alone. During the 2008-2009 vegetative season that had both excessive rainfall and cool weather, P application was most effective and generated a considerable yield increase of 0.99 t/ha or 76%. Basal application of Zn fertilizer at rates of 4 and 8 kg Zn/ha in treatments receiving both N and P increased the average grain yield by 0.22 and 0.39 t/ha or by 8 and 13%, respectively. In our experiments, the highest average grain yield of 3.30 t/ha was obtained in the treatment receiving $N_{30}P_{60}Zn_8$. Therefore, the highest grain productivity

of winter triticale under these environments can be achieved only through balanced application of N, P and Zn.

During the last two years of study, two more treatments were added to combine a higher basal Zn rate of 12 kg Zn/ha with both N_{30} and $N_{30}P_{60}$. However, these failed to increase grain yield beyond that achieved with 8 kg Zn/ha (data not shown). Hence, the optimum rate for basal Zn application to winter triticale grown on meadow-chernozem soil may be recommended as 8 kg Zn/ha.

Soil applied Zn fertilizer in addition to N_{30} had the highest positive effect on grain quality of winter triticale (**Table 1**). Grain test weight increased from 604 to 639 g/l and grain protein content increased from 16.3 to 16.9% (four-year average) due to basal Zn application at a rate of 8 kg Zn/ha. Improving P nutrition lessened the effect of basal Zn application on grain quality. Low Falling Numbers (63-64 sec.) for winter triticale variety Sibirskiy generally indicate the high activity of α-amylase enzyme and the accumulation of starch breakdown products in grain that makes bread sticky.

Seed treatment with $ZnSO_4$ powder at rates of 50 and 100 g $ZnSO_4$/100 kg seed was generally less effective compared to soil application of Zn. Seeds covered with $ZnSO_4$ within the $N_{30}P_{60}$ and $N_{30}P_{60}K_{60}$ treatments generated average yield increases of 2 to 9% and 6 to 8%, respectively (**Table 2**). A high effectiveness of seed treatment was found in the 2008-2009 growing season with prevailing cool weather and excessive rainfall. For example, $N_{30}P_{60}K_{60}$ combined with 50 and 100 g $ZnSO_4$/100 kg seed resulted in 0.38 and 0.55 t/ha or 16 and

Table 2. Effect of Zn seed treatment on grain yield and quality of winter triticale grown on meadow-chernozem soil.

Treatment		Grain yield, t/ha					Yield increase		Test weight, g/l	Glassiness, %	Protein, %	Falling No., sec.
K_2O	Zn	2008	2009	2010	2011	Average	t/ha	%				
0	0	2.94	2.29	2.13	4.28	2.91	-	-	635	50	16.6	64
0	50	2.99	2.48	2.19	4.26	2.98	0.07	2	640	49	16.6	63
0	100	3.64	2.60	2.31	4.10	3.16	0.25	9	641	50	17.0	63
60	0	3.04	2.33	2.04	4.30	2.93	-	-	638	50	16.7	63
60	50	3.14	2.71	2.25	4.32	3.11	0.18	6	640	50	16.7	63
60	100	2.94	2.88	2.47	4.36	3.16	0.23	8	641	50	17.1	63
$LSD_{0.05}$		0.14	0.13	0.11	0.13							

Note: Four-year averages are given for grain quality parameters. All treatments received 30 kg N/ha and 60 kg P_2O_5/ha.
Rates for K_2O are kg/ha while rates for Zn are g $ZnSO_4$/100 kg seed.

24% yield gains, respectively.

During the last two years we included an increased Zn rate of 150 g $ZnSO_4$/100 kg seed into the study for both the $N_{30}P_{60}$ and $N_{30}P_{60}K_{60}$ treatments; however, no further yield increase was found with this high Zn rate (data not shown). The optimal Zn rate for seed dressing, therefore, may be recommended as 100 g $ZnSO_4$/100 kg seed.

Comparing the average yields in treatments receiving $N_{30}P_{60}$ and $N_{30}P_{60}K_{60}$ it can be concluded that K fertilizer has practically no any effect when applied to winter triticale. A positive effect of K fertilizer on grain yield was, nevertheless, revealed in the 2007-2008 season that was characterized by a low snowfall in winter and inadequate precipitation during several months.

Seed dressing with $ZnSO_4$ powder in treatments receiving $N_{30}P_{60}$ and $N_{30}P_{60}K_{60}$ had a small positive effect on grain quality of winter triticale (**Table 2**). Nevertheless, the maximum grain protein (17.1%) was formed in the $N_{30}P_{60}K_{60}$ treatment with Zn seed covering at a rate of 100 g $ZnSO_4$/100 kg seed.

Summary

In conclusion, our results indicate that Zn fertilizer has a significant positive effect on both grain yield and quality of winter triticale grown on meadow-chernozem soil in the Southern forest-steppe zone of Western Siberia. It was revealed that soil applied Zn fertilizer under these environments generally is more effective in increasing grain yield compared to seed treatment. The optimum Zn rates for soil application and seed treatment were found to be 8 kg Zn/ha and 100 g $ZnSO_4$/100 kg seed, respectively. **BC**

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Omsk State Agrarian University, Omsk. The authors acknowledge Dr. V. Nosov, Director, IPNI Southern and Eastern Russia Region, for his comments and help during the preparation of this article.

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InfoAg Conference Update

Interest in the implementation of precision ag technologies was highly evident at the 2013 edition of The InfoAg Conference, which drew a record number of 1,100 participants this past July 16-18, in Springfield, Illinois.

The International Plant Nutrition Institute (IPNI) partnered with Crop Life Media Group and PAQ Interactive to provide the "premier precision ag event of the year" designed to share expertise amongst practitioners, vendors, and researchers, and showcase new developments within the precision ag industry.

"InfoAg was designed to be a leading edge source for information on technology in crop production, data management, and communication and it continues to deliver," said Dr. Terry Roberts, IPNI President. "I was impressed with the enthusiasm and excitement of the audience and the quality of the presentations."

In his opening address to the plenary session titled "Connecting the Dots", Dr. Steve Phillips, IPNI Southeast U.S. Region Director, and InfoAg Conference Co-Chair summarized, "You can see how this conference has grown and the depth of

the relationships and the partnerships that we're able to form by bringing all levels of precision agriculture together at this one event." He also emphasized the increasing role of precision ag in 4R Nutrient Stewardship (i.e., using the right nutrient source at the right rate, right time, and right place) throughout the world, in both developed and developing countries. "It's going to take all of us working together, and it's going to be the precision ag industry that's going to move 4R Nutrient Stewardship forward."

As a reflection of the growth of the conference and a desire to build on the momentum generated from the event, InfoAg is moving from its traditional biennial schedule to become an annual event. The event will take place on July 29-31 at Union Station, St. Louis, Missouri in 2014. **BC**

Additional links: InfoAg Conference Newsletter: http://infoag.org/subscribe; InfoAg on Twitter: @InfoAg

Response of Potato to Fertilizer Application and Nutrient Use Efficiency in Inner Mongolia

By Yu Duan, De-bao Tuo, Pei-yi Zhao, Huan-chun Li and Shutian Li

Potato production in Inner Mongolia is limited by unbalanced nutrition and inadequate water supplies. Field trials find balanced fertilization can significantly increase tuber yield for both rainfed and irrigated potato. Crop uptake of N, P and K increased rapidly at 25 to 57 days after emergence (DAE) under both rainfed and irrigated conditions. The economic benefit from fertilizer application was higher in irrigated versus rainfed potato.
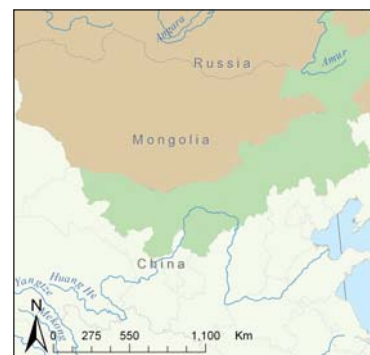
The Inner Mongolia Autonomous Region (IMAR) is one of the major potato production areas in China with a potato planting of about 760,000 ha and a total production of 9.55 million t. However, potato yields in the region are restricted both by water shortage and by unbalanced fertilizer application. Understanding the response of potato to fertilizer application and NUE are important for efficient nutrient management and high potato yields in the IMAR.

From 2002 to 2011, field trials were conducted on rainfed and irrigated potato across Inner Mongolia. Some chemical properties of the experimental soils are listed in **Table 1**. All the trials had four treatments including a balanced fertilization or OPT treatment, which was determined by soil analysis using the ASI procedure (Portch and Hunter, 2005; Bai et al., 2007), and three nutrient omission plots (i.e., OPT-N, OPT-P, OPT-K). The recommended rates for rainfed potato were 45-150 kg N/ha, 30-60 kg P_2O_5/ha, and 30-90 kg K_2O/ha with a mean of 83-44-50 kg N-P_2O_5-K_2O/ha; while rates in irrigated potato were 120-300 kg N/ha, 60-150 kg P_2O_5/ha, and 90-225 kg K_2O/ha with a mean of 190-97-137 kg N-P_2O_5-K_2O/ha (**Table 2**).

Yield Response and Nutrient Use Efficiency

Rainfed Sites

Ten experiments with rainfed potato produced tuber yields between 9.6 to 21.4 t/ha (14.9 t/ha average) with OPT treatments (**Table 2**). An average of 3.2 t/ha (27%), 2.4 t/ha (22%), and 2.2 t/ha (19%) more tuber was produced in balanced OPT plots than in N, P and K omission plots, respectively. Potato gave significant responses to N, P and K applications in 8, 9 and 8 of the 10 site-years, respectively. The average agronomic efficiencies (AE) of N, P and K were 41 kg tuber/kg N, 55 kg tuber/kg P_2O_5, and 43.2 kg tuber/kg K_2O. The average recovery efficiencies (RE) of N, P and K fertilizers were 33, 17 and 50%, respectively. An average of 5.89 kg N, 1.44 kg P_2O_5, and 5.52 kg K_2O was required to produce 1 t of tuber at the 14.9 t/ha yield level.

Irrigated Sites

Fifteen experiments with irrigated potato found OPT treatments able to increase tuber yields over N, P and K omission treatments by an average of 7.1 t/ha (26%), 6.5 t/ha (23%), and 5.8 t/ha (20%), respectively (**Table 2**). Significant responses to N, P and K fertilizer application were noted in 15, 12 and 10 of the 15 site-years. Thus N was the most limiting nutrient for the region's area under irrigated potato followed by P, then K. The average AE for N, P and K was 37.9 kg tuber/kg N, 65.6 kg tuber/kg P_2O_5, and 41.1 kg tuber/kg K_2O. The average RE for N, P

Table 1. Selected chemical properties of experimental soils, Inner Mongolia.							
Year	County	Water regime	pH	OM, %	Mineral N, mg/l	Olsen P, mg/l	Exchangeable K, mg/l
2002	WUC*	Rainfed	7.8	0.8	13	15	66
2003	WUC	Rainfed	8.6	1.2	13	13	77
2004	WUC	Rainfed	8.4	1.0	75	14	70
2004	WUC	Rainfed	8.5	1.0	48	18	78
2005	WUC	Rainfed	8.2	1.3	32	12	55
2006	WUC	Rainfed	7.8	1.0	8	16	145
2007	WUC	Rainfed	8.3	0.9	35	14	68
2007	WUC	Rainfed	8.4	1.0	75	14	70
2008	WUC	Rainfed	8.5	0.8	27	11	62
2011	WUC	Rainfed	8.3	1.0	20	19	89
2002	WUC	Flood Irrigation	8.3	0.7	9	15	76
2003	WUC	Flood Irrigation	8.4	1.1	10	18	83
2004	WUC	Flood Irrigation	8.4	1.2	8	10	55
2005	WUC	Flood Irrigation	8.4	1.4	30	10	66
2006	CHYZ**	Flood Irrigation	7.9	0.4	8	21	59
2007	CHYZ	Flood Irrigation	8.4	1.4	41	25	109
2008	WUC	Flood Irrigation	8.5	1.3	24	19	124
2008	WUC	Flood Irrigation	8.7	0.7	33	6	79
2008	CHYZ	Sprinkler Irrigation	8.9	0.3	51	12	99
2009	CHYZ	Flood Irrigation	8.4	1.3	19	27	137
2009	WUC	Flood Irrigation	8.5	2.5	24	8	138
2009	WUC	Sprinkler Irrigation	8.5	1.3	43	38	90
2010	WUC	Flood Irrigation	8.4	0.8	34	20	81
2010	WUC	Sprinkler Irrigation	8.4	0.4	26	14	54
2011	WUC	Drip Irrigation	8.1	1.3	20	14	80
MAX			8.9	2.5	75	38	145
MIN			7.8	0.3	8	6	54
MEAN			8.4	1.0	29	16	84

*WUC = Wuchuan County; **CHYZ = ChaYouZhong County.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; NUE = nutrient use efficiency.

Table 2. Yield response to fertilizer application and NUE in rainfed and irrigated potato, Inner Mongolia.

Year	Nutrient applied, kg/ha			Tuber yields, t/ha				AE, kg/kg			RE, %			Nutrient requirement, kg/t		
	N	P_2O_5	K_2O	OPT*	OPT-N	OPT-P	OPT-K	N	P_2O5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rainfed																
MAX	150	60	90.0	21.4	15.7	17.3	18.5	90.3	117	62.0	51.3	21.2	92.6	7.36	2.35	7.71
MIN	45	30	30.0	9.60	7.50	5.90	7.30	9.30	21.1	26.7	22.3	13.1	23.6	4.09	1.02	3.36
MEAN	82.8	43.5	49.5	14.9	11.7	12.5	12.6	41.0	55.0	43.2	33.1	16.8	50.1	5.89	1.44	5.52
Irrigated																
MAX	300	150	225	60.2	47.8	44.2	47.2	70.3	133.3	93.7	50.4	20.6	65.4	9.05	2.51	9.44
MIN	120	60	90	12.9	9.90	10.2	10.1	20.0	13.3	8.60	28.5	9.20	38.3	4.04	0.94	4.38
MEAN	190.1	97.1	137.0	35.7	28.6	29.2	29.9	37.9	65.6	41.1	35.6	14.9	49.9	5.56	1.48	6.21

*OPT = balanced fertilization treatment determined by soil testing based recommendation of ASI procedures (Portch and Hunter, 2005; Bai et al., 2007).
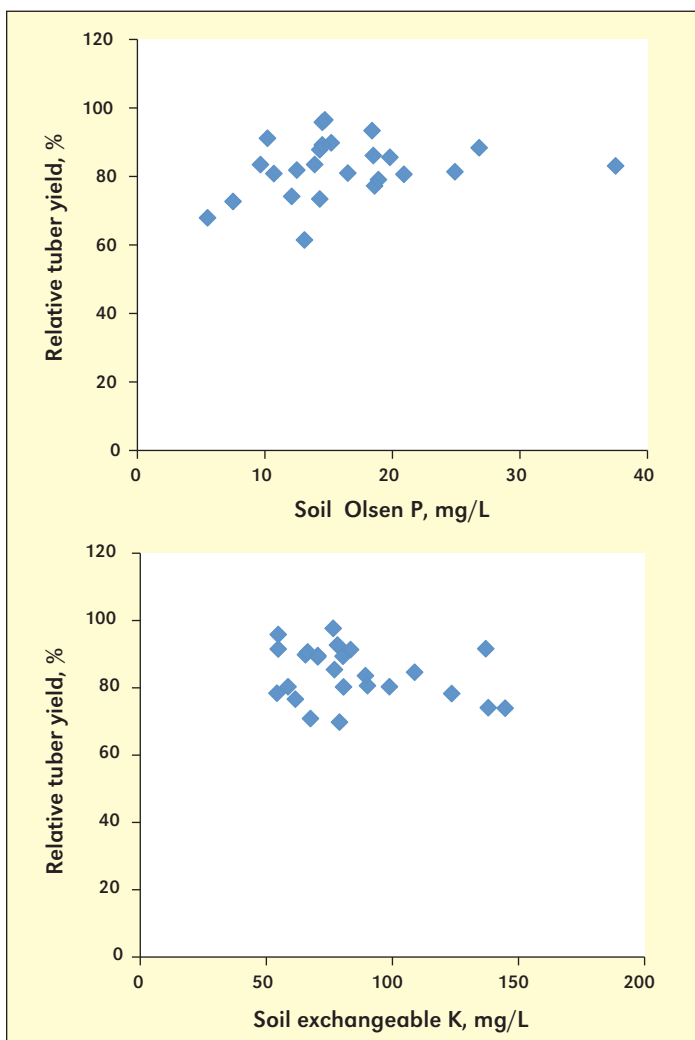

Figure 1. Relationship between the relative yield of potato tuber in OPT-P and OPT-K plots (i.e., the ratio of tuber yield in OPT-P or OPT-K plot to the tuber yield in the OPT plot) with available soil P (top) and exchangeable soil K (bottom) for 25 site-years.

and K fertilizers were 36, 15 and 50%. An average of 5.56 kg N, 1.48 kg P_2O_5, and 6.21 kg K_2O was required to produce 1 t of tuber at the 35.7 t/ha yield level.

It is clear that the recommended rates of nutrients for irrigated potato were 2.2 to 2.8 times that recommended for rainfed potato. Similarly, the tuber yield for irrigated potato was, on

Irrigated potato research site in Inner Mongolia.

average, 140% higher than the yield for rainfed potato. However, nutrient use efficiencies (AE and RE) were comparable between both systems. Similarly, mean N and P requirements to produce 1 t of tuber were similar for rainfed and irrigated potato, while more K was required under irrigated conditions.

Relationship between Relative Yields and Soil Test Values

No significant relationship existed between the relative yields of potato in OPT-P and OPT-K plots (i.e., the ratio of yield in either the OPT-P or OPT-K plot to the yield in the OPT plot) and soil test P and K values (**Figure 1**). For P, although most of the soil Olsen P was above the critical level of 12 mg/L, low temperatures (annual average temperature of 2.5°C) decreased P availability, especially at the seedling stage in the early spring, so additional P fertilizer was needed for crop production. For K, although 11 of the 25 experimental sites had exchangeable K above the critical value of 80 mg/L, applying K fertilizer still increased tuber yield. One reason could be the higher K requirement of potato plants, while another reason may be related with soil moisture conditions. Drying conditions may limit soil K availability, while in irrigated conditions more K is required by the potato plant to produce more tuber yield.

Nutrient Accumulation and Distribution

Nutrient accumulation was tested in different plant parts at different growth stages of rainfed and irrigated potato in 2011 in Wuchuan County. In irrigated potato, 85 to 100% of N, 76

to 100% of P, and 72 to 100% of K were accumulated in leaves and vines before 40 DAE (**Figure 2**). After 40 DAE, nutrient accumulations in tubers increased much above that in leaves and vines. About 71, 89 and 76% of the plant N, P and K, respectively, were accumulated in potato tubers at harvest.

In rainfed potato, most of N, P and K accumulation in the leaves and vines occurred before 25 DAE, thereafter nutrient accumulation in tubers increased rapidly (**Figure 2**). About 80, 91 and 91% of N, P and K, respectively, were accumulated in potato tubers at harvest. Greater portions of N and K were accumulated in rainfed tubers compared to irrigated tubers. There was a rapid uptake of N, P and K in the period between 25 to 57 DAE under both rainfed and irrigated conditions. This implies that N, P and K should be in sufficient supply before that period.

Table 3. Economic analysis of fertilizer application in rainfed and irrigated potato, Inner Mongolia.

Year	Gross income, $/ha				Net income, $/ha				Economic benefit, $/ha		
	OPT	OPT-N	OPT-P	OPT-K	OPT	OPT-N	OPT-P	OPT-K	N	P_2O_5	K_2O
Rainfed											
MAX	3,424	2,512	2,768	2,960	2,080	1,304	1,463	1,742	1,453	649	744
MIN	1,536	1,200	944	1,168	250	-40	-314	-135	99	75	108
MEAN	2,384	1,872	2,000	2,016	1,087	640	727	762	447	360	325
Irrigated											
MAX	9,632	7,648	7,072	7,552	6,890	5,127	4,399	4,905	1,906	2,491	1,985
MIN	2,064	1,584	1,632	1,616	1,259	355	309	567	470	127	61
MEAN	5,712	4,576	4,672	4,784	3,323	2,253	2,296	2,426	1,070	1,027	898

Prices: N: $0.75/kg, P_2O_5: $0.74/kg, K_2O: 0.70/kg, commercial potato: $0.16/kg.
Rainfed costs: seed potato and seeding: $632/ha, management including pesticide/herbicide: $169/ha, machine harvest: $363/ha. Irrigated costs: seed potato and seeding: $968/ha, management including pesticide/herbicide: $460/ha, irrigation: $242/ha, machine harvest: $726/ha.

Benefit from Fertilizer Application

Economic analysis showed that N, P and K fertilizer in rainfed potato increased farmer's income by US$99 to 1,453, $75 to 649, and $108 to 744/ha, with a mean of $447, $360 and $325/ha, respectively (**Table 3**). Application of N, P and K was more profitable in irrigated potato with respective increases of $470 to 1,906, $127 to 2,491, and $61 to 1,985/ha—averages of $1,070, $1,027 and $898/ha.

Conclusion

Potato tuber yields in both rainfed and irrigated conditions were significantly increased by balanced fertilization in Inner Mongolia. Potato required similar amounts of N and P in rainfed and irrigated conditions, but required more K under irrigated conditions. Sufficient nutrient supply is critical at 25 to 57 DAE. Application of N, P and K increased farmer's income significantly in both systems, but was more beneficial within irrigated systems. BC

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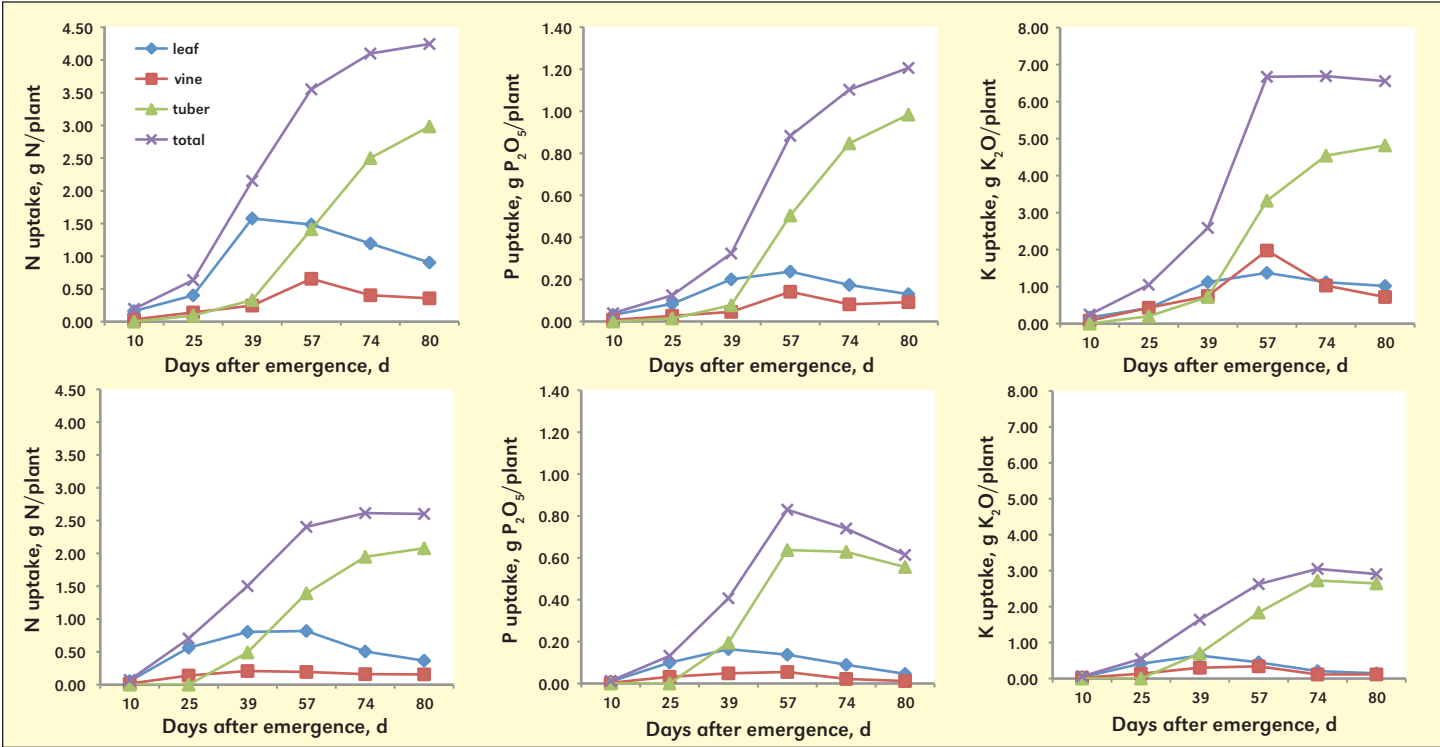
Figure 2. Accumulation of N, P and K by irrigated (top) and rainfed (bottom) potato in Inner Mongolia.

2013 IPNI Crop Nutrient Deficiency Photo Contest Announced

The 2013 edition of IPNI's annual photo contest on crop nutrient deficiencies is now accepting entries. Anyone from around the world is invited to submit their well-documented examples in four nutrient-based categories: Nitrogen (N), Phosphorus (P), Potassium (K), and Other (including secondary and micronutrients). Participants will have the chance to win cash prizes and their efforts will be highlighted in the first issue of *Better Crops with Plant Food* released in 2014.

As in past contests, some specific supporting information is required for all entries, including:
- The entrant's name, affiliation, and contact information.
- The crop and growth stage, location, and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors, and additional details that may be related to the deficiency.

Preference will be given to those photos representing real field-grown plants, that provide both soil and tissue analyses, include some record of the current fertilization (i.e., source, rate, time, and place), and which do not show just single leaves or plant parts.

Entrants are limited to one entry per category (i.e., one individual is able to have only one entry in each of the four categories). The winner in each category will receive a cash prize of US$150, while second place receives US$75. A Grand Prize of US$200 will be offered for the best overall photo entry. Selection of winners will be determined by a committee of IPNI scientific staff.

Photos and supporting information can be submitted until December 12, 2013 (5 pm EDT). Entries should only be submitted electronically as original, high-resolution digital files. Please see the contest site >www.ipni.net/photocontest< for all details. BC

Conversion Factors for U.S. System and Metric

Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others…depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields in Illinois would use units of pounds per acre (lb/A) for fertilizer rates and bushels (bu) for yields; an article on rice production in Southeast Asia would use kilograms (kg), hectares (ha), and other metric units.

Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

To convert Col. 1 into Col. 2, multiply by:	Column 1	Column 2	To convert Col. 2 into Col. 1, multiply by:
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
	Area		
2.471	hectare, ha	acre, A	0.405
	Volume		
1.057	liter, L	quart (liquid), qt	0.946
	Mass		
1.102	tonne[1] (metric, 1,000 kg)	short ton (U.S. 2,000 lb)	0.9072
0.035	gram, g	ounce	28.35
	Yield or Rate		
0.446	tonne/ha	ton/A	2.242
0.891	kg/ha	lb/A	1.12
0.0159	kg/ha	bu/A, corn (grain)	62.7
0.0149	kg/ha	bu/A, wheat or soybeans	67.2

[1]The spelling as "tonne" indicates metric ton (1,000 kg). Spelling as "ton" indicates the U.S. short ton (2,000 lb). When used as a unit of measure, tonne or ton may be abbreviated, as in 9 t/ha. A metric expression assumes t=tonne; a U.S. expression assumes t=ton.

As scientists, IPNI encourages farmers and advisers to seek out evidence when assessing options such as new fertilizer products or formulations. In a presentation, a graph or table may be shown with a comment like "….it is clear from this that…." and proceed to describe how the data supports the argument or point to be made.

But the truth is not always that clear. We are all very good at fitting patterns to the things we see to fit them into the scheme of things we understand—or think we understand. In fact the human mind is very adept at pattern recognition—just think how subtle are the differences in the faces we pass in the street—but how clearly we can recognize a friend when they appear.

Pattern recognition has its shortcomings though—such as when you mistakenly greet an old friend who infact is a stranger who you thought you recognized.
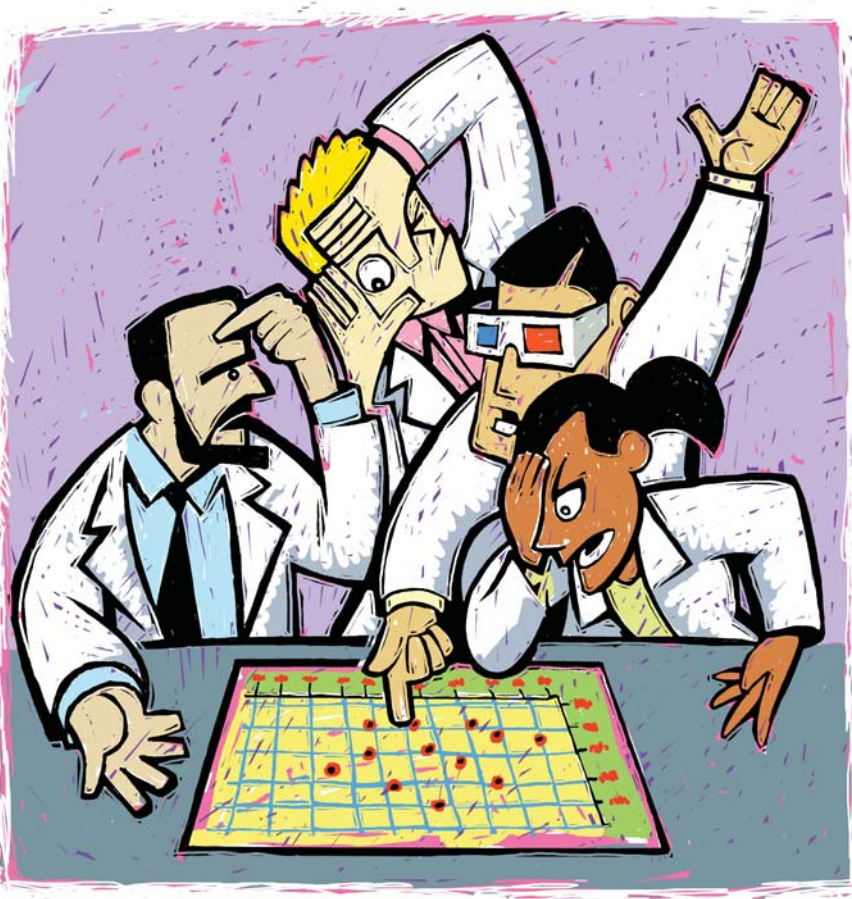
This same problem can be a trap when evaluating evidence. We often try to fit the data into patterns we recognize even though we try to be objective. Statistics can help by fitting trend lines or regressions between an independent variable such as yield and a dependent variable such as fertilizer applied. It is easy to jump to a conclusion that what was changed caused the effect measured.

It takes good experimentation to separate associative effects from caused effects—such as making sure there are appropriate controls and that we are sure that we have confidence in knowing the factor that was altered in the experiment. But more than that, we look to experiments to test our ideas and expand our thinking—not just to justify what we already believe.

A line on a graph or a 95% probability function is not proof even if from a well designed experiment. There needs to be a reasoned argument for the response or lack of it.

That is where science diverges from belief—scientists will change their opinion based on evidence. As John Maynard Keynes—one of the foremost economists in the last century said when challenged as to why his opinion had altered. His response was "When the facts change, I change my mind. What do you do, sir?"

While we need to be skeptical of junk science, we also need to keep our minds open so we can capture the new, novel and innovative. Our task of feeding the world demands we do so.

Dr. Robert Norton
IPNI Australia and New Zealand Program Director