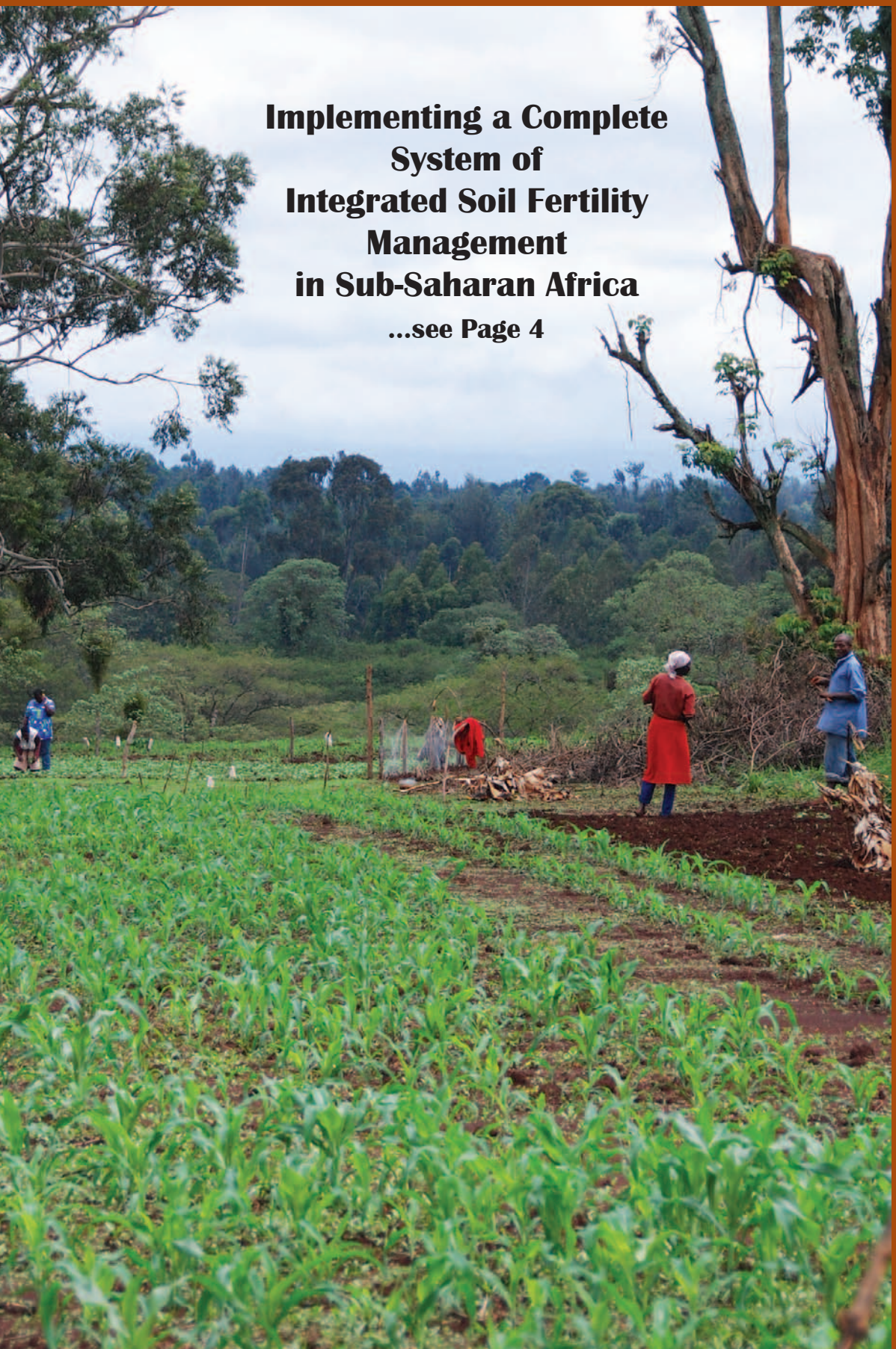
BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

2011 Number 3



Implementing a Complete System of Integrated Soil Fertility Management in Sub-Saharan Africa

...see Page 4

In This Issue...

Also:

...and much more

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BETTER CROPS WITH PLANT FOOD

Vol. XCV (95) 2011, No. 3

Our cover: Planting beans after maize near the Kenyan Agricultural Research Institute (KARI) at Machakos.
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BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by the International Plant Nutrition Institute (IPNI). Periodicals postage paid at Norcross, GA, and at additional mailing offices (USPS 012-713). Subscriptions free on request to qualified individuals; others $8.00 per year or $2.00 per issue. Address changes may be e-mailed to: cmees@ipni.net

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

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

The Government of Saskatchewan helps make this publication possible through its resource tax funding. We thank them for their support of this important educational project.

CONTENTS

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IPNI Board of Directors Elects New Officers

New officers of the Board of Directors of the International Plant Nutrition Institute (IPNI) were elected in May 2011. The IPNI Board Meeting took place in conjunction with the 79th Annual Conference of the International Fertilizer Industry Association (IFA) held in Montreal, Canada.

Joachim Felker, Member of the Board of Executive Directors, K+S Aktiengesellschaft, Kassel, Germany, is the new Chairman of the IPNI Board for a two-year term.

Stephen R. Wilson, Chairman, President, and Chief Executive Officer (CEO) of CF Industries Holdings, Inc., in Deerfield, Illinois, is the new Vice Chairman of the IPNI Board. Dr. Mhamed Ibnabdeljalil, Ph.D., Executive Vice President of Sales, Marketing & Raw Material Procurement at OCP Group in Morocco, was elected Chair of the Finance Committee.

Mike Wilson, President and CEO of Agrium Inc., Calgary, Alberta, concluded his term as Chairman of the IPNI Board of Directors and was recognized for outstanding leadership and service in that role since 2009. Dr. Terry L. Roberts continues as President of IPNI. BC

Mike Wilson (left) was recognized for his dedicated service as Chairman of the Board since May 2009. Mr. Wilson is President and CEO of Agrium Inc., Calgary, Alberta. IPNI President Dr. Terry Roberts (right), expressed appreciation of the other Board members and the entire organization.

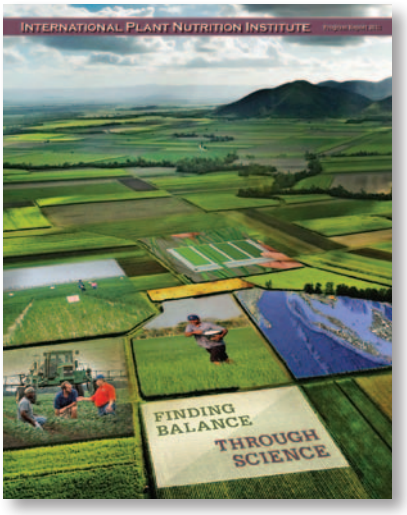
Joachim Felker, Chairman of the IPNI Board

Stephen Wilson, Vice Chairman of the IPNI Board

Dr. Mhamed Ibnabdeljalil, Chair of the Finance Committee

Annual IPNI Program Report and Research Projects Summary Now Available

The International Plant Nutrition Institute (IPNI) recently released its Program Report and Research Projects Summary, two separate booklets that highlight issues and accomplishments over the past year. The theme for the 2011 Report is *Finding Balance Through Science* – something that has always been central to IPNI activities. The collection of research examples provided in these booklets describe in both words and imagery how Staff at IPNI use science to better understand, describe, and share information on how to most efficiently and effectively use all available nutrient sources of plant nutrients to provide for the food, feed, fiber, and fuel needs of a growing human family.



Both of these booklets are available from the IPNI website here http://info.ipni.net/2011PROGRAM BC

Integrated Soil Fertility Management: An Operational Definition and Consequences for Implementation and Dissemination

By Bernard Vanlauwe and Shamie Zingore

Traditional farming systems in sub-Saharan Africa (SSA) depend primarily on mining soil nutrients. The African Green Revolution aims at intensifying agriculture through dissemination of Integrated Soil Fertility Management (ISFM) strategies. This article presents a robust and operational definition of ISFM, based on detailed knowledge of African farming systems and their inherent variability and of optimal use of nutrients.

The need for sustainable intensification of agriculture in SSA has gained support, in part because of the growing recognition that farm productivity is a major entry point to break the vicious cycle underlying rural poverty. Given the low levels of fertilizer use and poor soils in SSA, fertilizer use must increase if the region is to reverse the current trends of low crop productivity and land degradation. There are renewed efforts to raise fertilizer use in SSA from the current 8 kg to 50 kg nutrients per ha by improvement of the marketing, policy, and socio-economic environment to increase fertilizer availability at prices affordable to smallholder farmers. Since fertilizer is very expensive for most smallholder farmers in SSA, the Alliance for a Green Revolution in Africa (AGRA) has adapted ISFM as a framework for boosting crop productivity through combining fertilizer use with other soil fertility management technologies, adapted to local conditions.

Various definitions for ISFM have been proposed, but most are incomplete in the sense that they fall short of defining the full set of principles that are required to sustainably increase crop productivity in smallholder farming systems in SSA. First, it is important to sketch the context under which the smallholder farmer in SSA operates. At the regional scale, overall agro-ecological and soil conditions have led to diverse population and livestock densities across SSA, and to a wide range of farming systems. Each of these systems has different crops, cropping patterns, soil management considerations, and access to inputs and commodity markets. Within farming communities, a wide diversity of farmer wealth classes, inequality, and production activities may be distinguished **(Figure 1)**. Analysis of farmer wealth classes in north-east Zimbabwe illustrates the variability that is typical of farmer communities in maize-based farming systems **(Table 1)**. Use of cattle manure and more fertilizer by the wealthier farmers results in higher farm-level productivity than on poorer farms. At the individual farm level, it is important to consider the variability between the soil fertility status of individual fields **(Figure 2)**. Variability arises due to farmer preference to apply limited fertilizers and organic nutrient resources to small areas of the farms. Any definition of ISFM must consider these attributes.

Operational definition of ISFM

We define ISFM as *'A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.'* It provides an essential basis for optimizing the use of nutrients within an ISFM framework, and should be part of a holistic evaluation of cropping sustainability. A conceptual presentation of the definition of ISFM is shown in **Figure 3**. The definition includes a number of concepts that are described below.

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

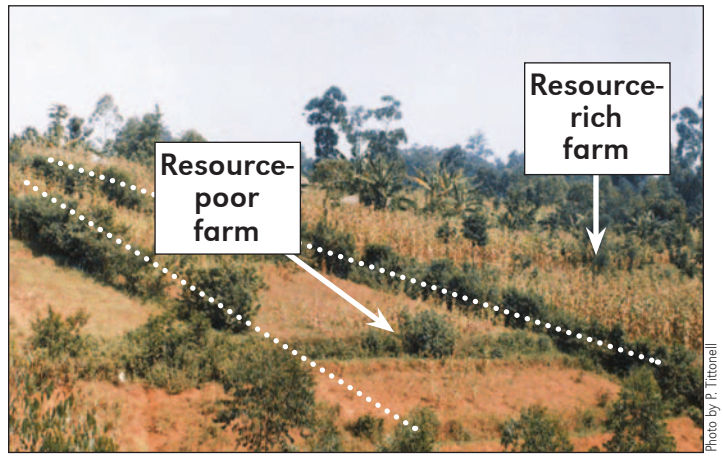


Photo by P. Tittonell

Figure 1. Photograph showing two farms of different resource endowment in Western Kenya. The farm between the two dashed white lines belongs to a resource-limited farmer and has a good maize crop on the upper slope near the homestead (not visible). The farm on the right side of the right dashed line belongs to a relatively rich farming household and has good maize across the slope.

1. Focus on agronomic use efficiency

The definition focuses on maximizing the use efficiency of fertilizer and organic inputs since these are both scarce resources in the areas where agricultural intensification is needed. Agronomic efficiency (AE) is defined as incremental return to applied inputs or:

$$AE\ (kg/kg) = (Y_F - Y_C) / (F_{appl})\ [1]$$

where Y_F and Y_C refer to yields (kg/ha) in the treatment where nutrients have been applied and in the control plot, respectively, and F_{appl} is the amount of fertilizer and/or organic nutrients applied (kg/ha).

2. Fertilizer and improved germplasm

In terms of response to management, two general classes of soils are distinguished: (i) soils that show acceptable responses to fertilizer (Path A, **Figure 3**) and (ii) soils that show minimal or no response to fertilizer due to other constraints besides the nutrients contained in the fertilizer (Path B, **Figure 3**). In some cases, where land is newly opened, or where fields are close to homesteads and receive large amounts of organic inputs each year, a third category of soil exists where crops respond little to fertilizer as the soils are fertile. These soils

Figure 2. Photographs of a 3-week old maize crop in two different plots within the same farm (about 200 m apart) in Western Kenya. Both maize crops were planted at the same time. The left photograph shows a responsive plot near the homestead while the right photograph shows a less-responsive plot with high densities of 'couch grass' [*Elymus repens* (L.) Gould subsp. repens], a noxious weed (see insert in the center). Adapted from Vanlauwe et al, 2010.

need only maintenance fertilization and are termed 'fertile, less responsive soils'. The ISFM definition proposes that application of fertilizer to improved germplasm on responsive soils will boost crop yield and improve the AE relative to current farmer practice, characterized by traditional varieties receiving too little and insufficiently managed nutrient inputs (Path A). Major requirements for achieving production gains on 'responsive fields' within Path A include: (i) the use of disease-resistant and improved germplasm, (ii) crop and water management practices, and (iii) application of 4R Nutrient Stewardship – a science-based framework that focuses on applying the right fertilizer source at the right rate, at the right time during the growing season, and in the right place. These 4R's provides an essential basis for optimizing the use of nutrients within an ISFM framework.

3. Combined application of organic and mineral inputs

Organic inputs contain nutrients that are released at a rate determined in part by their chemical characteristics or organic resource quality. However, organic inputs applied at low rates commonly used by smallholder farmers in Africa seldom release sufficient nutrients for optimum crop yield. Combining organic and mineral inputs has been advocated as a sound management principle for smallholder farming in the tropics because neither of the two inputs is usually available in sufficient quantities and because both inputs are needed in the long-term to sustain soil fertility and crop production. Two other issues arise within the context of ISFM: 1) Does fertilizer application generate the required crop residues that are needed to optimize the AE of fertilizer for a specific situation? and 2) Can organic resources be used to rehabilitate 'less-responsive soils' and make these responsive to fertilizer? (Path C).

The first issue is supported by data obtained in Niger by Bationo et al. (1998). Where fertilizer was applied to millet, sufficient residue was produced to meet both farm household demands for feed and food as well as the management needs of the soil in terms of organic inputs and surface protection of the soil from wind erosion. Evidence also supports the second rehabilitation issue. In Zimbabwe, applying farmyard manure for 3 years to sandy soils at relatively high rates enabled a clear response to fertilizer where such response was not visible before rehabilitation (Zingore et al., 2007).

4. Adaptation to local conditions

As previously stated, farming systems are highly variable at different scales and a challenge before the African Green Revolution is adjusting for site-specific soil conditions. Firstly, soil fertility status can vary considerably within short distances. A good proxy for soil fertility status is often the soil organic matter (SOM) content, provided that this parameter is not over-extrapolated across dissimilar soils. Soil organic matter contributes positively to specific soil properties or processes fostering crop growth, such as cation exchange capacity, soil moisture and aeration, or nutrient stocks. On land where these constraints limit crop growth, a higher SOM content

Table 1. Variability of resource endowment and maize productivity for a farming community in northeast Zimbabwe.

Farm type	% of farms	Household size	Farm size, ha	No. of Cattle	Fertilizer N use, kg/farm	Cattle manure use, t/year	Farm-level maize productivity, t/ha
Richest farmers	16	7	3.1	12	110	10	3.0
Relatively rich farmers	28	5	2.5	7	65	6	2.2
Relatively poor farmers	24	6	2.2	0	42	0	0.4
Poorest farmers	32	4	1.0	0	19	0	0.4

Adapted from Zingore et al., 2011

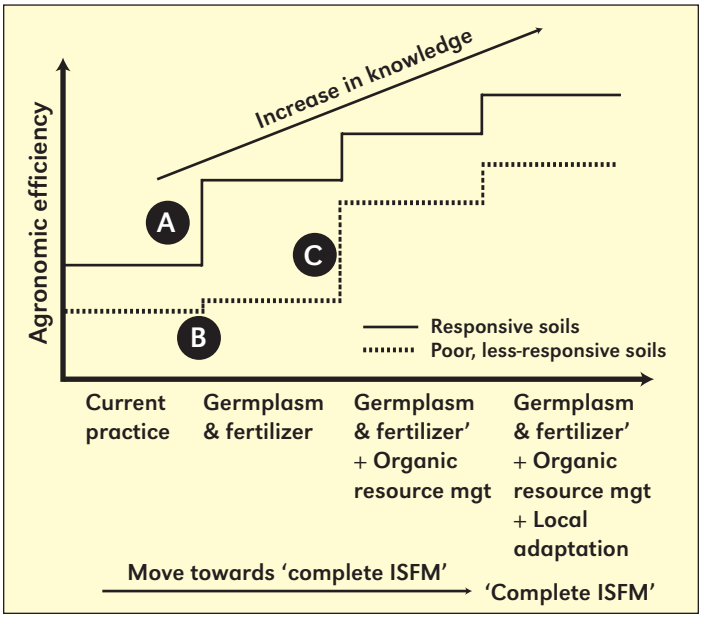


Figure 3. Conceptual relationship between the agronomic efficiency (AE) of fertilizers and organic resource and the implementation of various components of ISFM, culminating in complete ISFM towards the right side of the graph. Soils that are responsive to NPK-based fertilizer and those that are poor and less-responsive are distinguished. The 'current practice' step assumes the use of the current average fertilizer application rate in SSA of 8 kg fertilizer nutrients per ha. The meaning of the various steps is explained in detail in the text. At constant fertilizer application rates, yield is linearly related to AE. Adapted from Vanlauwe et al, 2010.

may enhance the demand by the crop for N and consequently increase the fertilizer N use efficiency. On the other hand, SOM also releases available N that may be better synchronized with the demand for N by the plant than fertilizer N. Consequently a larger SOM pool may result in lower N fertilizer AEs. Evidence from Western Kenya shows that for fertile soils, AE for plant nutrients is less than that for less intensively managed outfields (Vanlauwe et al., 2006).

5. A move towards 'complete ISFM'

Several intermediary phases are identified that assist the practitioner's move towards complete ISFM from the current 8 kg/ha fertilizer nutrient application with local varieties. Each step is expected to provide the management skills that result in yield and improvements in AE **(Figure 3)**. Complete ISFM comprises the use of improved germplasm, fertilizer, appropriate organic resource management, and local adaptation. **Figure 3** is not necessarily intended to prioritize interventions but rather suggests a need for sequencing towards complete ISFM. It does however depict key components that lead to better soil fertility management. For less-responsive soils, investment in soil fertility rehabilitation will be required before fertilizer AE will be enhanced.

Integration of ISFM principles in farming systems

Principles embedded within the definition of ISFM need to be applied within existing farming systems. Two examples clearly illustrated the integration of ISFM principles in existing cropping systems: (i) dual purpose grain legume – maize rotations with P fertilizer targeted at the legume phase and N fertilizer targeted at the cereal phase in the moist savanna agro-ecozone (Sanginga et al., 2003) **(Figure 4)**, and (ii) micro-dose fertilizer applications in legume-sorghum or legume-millet rotations with retention of crop residues and water harvesting techniques in semi-arid agro-ecozones (Bationo et al., 1998) **(Figure 5)**. As for the grain legume-maize rotations, application of appropriate amounts of mainly P to the legume phase ensures good grain and biomass production, the latter in turn benefiting a subsequent maize crop and thus reducing the need for external N fertilizer (Sanginga et al., 2003). As for the micro-dose technology, spot application of appropriate amounts of fertilizer to widely spaced crops as sorghum or millet substantially enhances its use efficiency with further enhancements obtained when combined with physical soil management practices aiming at water harvesting.

Figure 4. Application of P fertilizer to a dual purpose soybean variety that produces substantial amounts of leafy biomass and leaves a net amount of fixed N in the soil, then rotating this soybean variety with a N-efficient and disease-resistant maize variety that receives a minimal amount of N fertilizer is a good example of an ISFM strategy. Adapting fertilizer rates to prevailing soil fertility conditions would qualify such intervention as 'Complete ISFM'.

Dissemination of ISFM

The gradual increase in complexity of knowledge as one moves towards complete ISFM **(Figure 3)** has implications on the strategies to adapt for widespread dissemination of ISFM. Furthermore, a set of enabling conditions can favor the uptake of ISFM. The operations of every farm are strongly influenced by the larger rural community, policies, and supporting institutions, and markets. Not only are farms closely linked to the off-farm economy through commodity and labor markets, but the rural and urban economies are also strongly interdependent. Farming households are also linked to rural communities and social and information networks, and these factors provide feedback that influences farmer decision-making. Because ISFM is a set of principles and practices to intensify land use in a sustainable way, uptake of ISFM is facilitated in areas with greater pressure on land resources. The first step towards ISFM

acknowledges the need for fertilizer and improved varieties. An essential condition for its early adoption is access to farm inputs, produce markets, and financial resources. To a large extent, adoption is market-driven as commodity sales provide incentives and cash to invest in soil fertility management technologies, providing opportunities for community-based savings and credit schemes. Policies towards sustainable land use intensification and the necessary institutions and mechanisms to implement and evaluate these are also that facilitates the uptake of ISFM. Policies favoring the importation of fertilizer, its blending and packaging, or smart subsidies are needed to stimulate the supply of fertilizer as well. Specific policies addressing the rehabilitation of degraded, non-responsive soils may also be required since investments to achieve this may be too large to be supported by farm families alone.

While dissemination and adoption of complete ISFM is the ultimate goal, substantial improvements in production can be made by promoting the greater use of farm inputs and germplasm within market-oriented farm enterprises. Such dissemination strategies should include ways to facilitate access to the required inputs, simple information fliers, spread through extension networks, and knowledge on how to avoid less-responsive soils.

A good example where the 'seeds and fertilizer' strategy has made substantial impact is the Malawi fertilizer subsidy program. Malawi became a net food exporter through the widespread deployment of seeds and fertilizer, although the aggregated AE was only 14 kg grain per kg nutrient applied (Chinsinga, 2008). Such AE is low and ISFM could increase this to at least double its value with all consequent economic benefits to farmers. As efforts to promote the 'seed and fertilizer' strategy are under way, activities such as farmer field schools or development of site-specific decision guides that enable tackling more complex issues can be initiated to guide farming communities towards complete ISFM, including aspects of appropriate organic matter management of local adaptation of technologies. The latter will obviously require more intense interactions between farmers and extension services and will take a longer time to achieve its goals. BC

Dr. Vanlauwe is a Principal Scientist leading activities on Integrated Soil Fertility Management at the Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture (CIAT) in Nairobi, Kenya; e-mail: b.vanlauwe@cgiar.org. Dr. Zingore is the IPNI Regional Director for Africa. E-mail: szingore@ipni.net

Photos by A. Bationo

Figure 5. Microdosing fertilizer in the planting pit of cereals (inset) with relatively large plant spacing, and after concentrated use of farmyard manure, is another good example of an ISFM intervention. The planting pit also serves as a means to harvest water.

This article is modified from an earlier published paper: Vanlauwe, B., A. Bationo, J. Chianu, K.E. Giller, R. Merckx, U. Mokwunye, O. Ohiokpehai, P. Pypers, R. Tabo, K. Shepherd, E. Smaling, P.L. Woomer, and N. Sanginga. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. Outlook on Agriculture, 39:17-24.

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IPNI Award Available to Scientists in 2011

Each year, IPNI offers the IPNI Science Award to recognize and promote distinguished contributions by scientists.

The Science Award goes to one individual each year, based on outstanding achievements in research, extension, or education which focus on efficient and effective management of plant nutrients and their positive interaction in fully integrated crop production, enhancing yield potential and/or crop quality. It requires that a nomination form (no self-nomination) and supporting letters be submitted by mail before September 30. The Award announcement is December 1. It includes a monetary prize of USD 5,000 (five thousand dollars).

More information about past winners of this award, plus details on qualifications and requirements, can be found at the IPNI website: >www.ipni.net/awards<. BC

Description and Nomination Format for the

IPNI
Science Award

A Program of the
International Plant Nutrition Institute (IPNI)

IPNI

Nomination deadline: September 30, 2011
Award announcement date: December 1, 2011

Optimize Nitrogen for Alabama Wheat Yields with and without Fall Tillage

By Kipling S. Balkcom and Charles H. Burmester

Increased no-till or reduced tillage within Alabama wheat fields has raised research questions on how the trend might impact optimal N fertilizer rates and timings. Monitoring tiller growth as a means to predict N requirements was another option assessed across major soil types within the region.

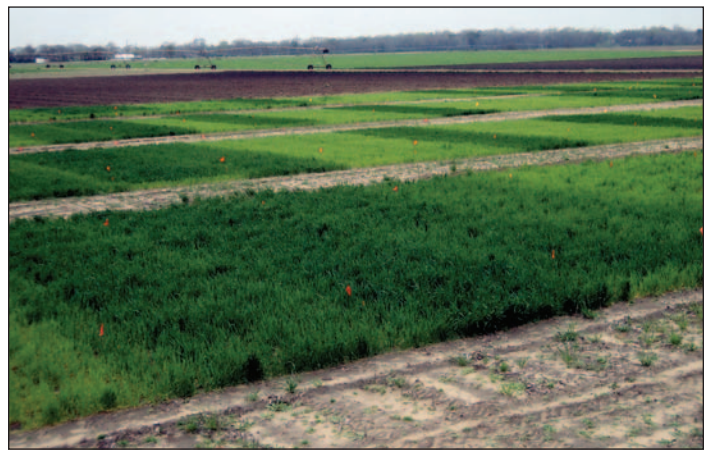
Alabama wheat farmers are changing management practices to maximize yields and reduce trips across their fields. Some recent changes include using higher N fertilizer and wheat seeding rates, and planting wheat in no-till or reduced tillage systems. Non-inversion tillage has been widely adopted in summer row crops, particularly cotton on Alabama's Coastal Plain soils (Simoes et al., 2009), while conservation tillage at planting has become a primary method on silt loam soils in the Limestone Valley (Schwab et al., 2002). However, there are concerns that tillage systems that maintain surface residue will slow vegetative growth and reduce tillering in wheat (Weisz and Bowmann, 1999). Questions have been raised about N fertilizer rates and application timings according to tillage practices used at planting. The practice of monitoring wheat tillering is also being used in some wheat-growing areas to adjust spring N fertilizer rates. As a result, tillage practices, rates and times of N fertilizer application, and tiller counts need further evaluation under Alabama growing conditions.

Experimental Design

Four locations were used across Alabama during the 2008, 2009, and 2010 wheat-growing seasons resulting in eight site-year comparisons. These locations were at the Tennessee Valley Research and Extension Center (TVS) in Northern Alabama, the E.V. Smith Research Center (EVS) in Central Alabama, the Wiregrass Research and Extension Center (WGS) in Southeast Alabama, and the Gulf Coast Research and Extension Center (GCS) in Southwest Alabama. The TVS location represents Limestone Valley soils, while the other three locations represent Coastal Plain soils. Diversity among soil types and regions, as well as seed supplies, required using different wheat cultivars across locations. Wheat cultivars used were USG 3209 (TVS-2008, TVS-2009, EVS-2009), Pioneer 26R31 (GCS-2009, WGS-2009), and AGS 2060 (all 2010 locations). Each cultivar was treated with a fungicide and had a target seeding rate of 22 seed/ft on a 7.5-in. row spacing.

Each wheat location followed cotton and consisted of a split plot design with tillage as the main block and all N fertilizer treatments as subplots with each treatment replicated four times. At TVS, tillage variables included fall chisel plowing versus no-tillage before planting. At all other locations, surface tillage consisting of disking twice, chisel plowing, and field cultivation was compared to a KMC Gen II subsoiler-leveler (Kelley Manufacturing Com., Tifton, GA). The subsoiler-leveler operation was performed immediately after planting wheat to avoid tractor wheel ruts within the small plots. Nitrogen fertilizer treatments for each tillage system are listed in **Table 1**. At each location, fall N was applied by hand at planting as granular urea at TVS, and as NH_4NO_3 at the other locations. Streaming fertilizer tips were used to apply 28-0-0-5S liquid urea-ammonium nitrate (UAN) fertilizer to corresponding treatments at Zadoks Growth Stage (GS) 25 and GS 30 (Zadoks et al., 1974) using a self-propelled plot sprayer or spray apparatus mounted on a four-wheeler. Wheat tillering counts were determined at GS 25 by counting all tillers with three or more leaves within a 1 ft^2 section of each plot. Wheat yields were harvested from the center of each plot using a small, self-propelled combine designed for small plot research.

Abbreviations and Notes: N = nitrogen; NH_4NO_3 = ammonium nitrate; S = sulfur.



View of treatment differences among N fertilizer rates and application times for wheat grown with different tillage systems in Alabama.

Table 1. Nitrogen fertilizer rates and timings tested in wheat across four locations in Alabama.

Treatment	Fall applied	GS 25	GS 30
	lb N/A		
1	0		60
2	0		90
3	0		120
4	0	30	30
5	0	45	45
6	0	60	60
7	20	40	
8	20	70	
9	20	100	
10	20		40
11	20		70
12	20		100

Tiller Counts

All tiller counts were collected at each location prior to UAN application at GS 25. Therefore, fall N and fall tillage were the only experimental variables examined in this study that could influence tiller counts. For the Limestone Valley soil (TVS), fall tillage had no impact on GS 25 tiller counts

View of subsoiler-leveler operation in the fall.

Sprayer set-up to apply liquid UAN.

Table 2. Tiller counts affected by tillage system and fall N application for each location during the 2008-2010 growing seasons in Alabama.

	Tiller counts, no./ft^2					
	Fall tillage			Fall N		
Location	Conventional	Non-inversion	P ≤ 0.10	0	20 lb/A	P ≤ 0.10
TVS-08	110	125		118	117	
TVS-09	94	76		87	83	
TVS-10	57	60		54	64	x
EVS-09	80	102	x	85	96	x
EVS-10	48	56		48	55	x
GCS-09	84	84		80	88	x
WGS-09	63	75	x	60	78	x
WGS-10	39	49	x	42	46	x

(Table 2). At three of the five site-years within the Coastal Plain, non-inversion tillage used to limit surface soil disturbance to maintain surface crop residues while maximizing below-ground disruption, enhanced tiller counts compared to traditional conventional tillage. Although cotton, a low residue producing crop (Daniel et al., 1999), was the previous crop across all locations, these data indicate that maintaining surface residue did not hinder early season wheat development across the Limestone Valley soil, and can enhance its development across Coastal Plain soils. Fall-applied N promoted early season tiller development across all Coastal Plain site-years and one site-year (TVS-10) from the Limestone Valley.

A balance must be obtained between fall-applied N and wheat development. High fall-applied N rates could promote excessive vegetative development that can result in wheat being more susceptible to early freeze damage. Previous research in the upper Coastal Plain has related tiller development at GS 25 to subsequent N applications that maximize final yields. Weisz et al. (2001) reported a critical tiller density < 50/ft^2, which indicates that N should be applied at GS 25 to optimize no-till wheat yields. The relationship between tiller counts measured at GS 25 and wheat yields is shown in **Figure 1** across all eight site-years. Unfortunately, this relationship does not show a plateau, which would identify a critical tiller density at GS 25 to optimize wheat yields. Grouping site-years into Limestone Valley and Coastal Plain locations did not help identify a plateau response (data not shown). However, it should be noted that within site-years at TVS, EVS, and WGS, higher

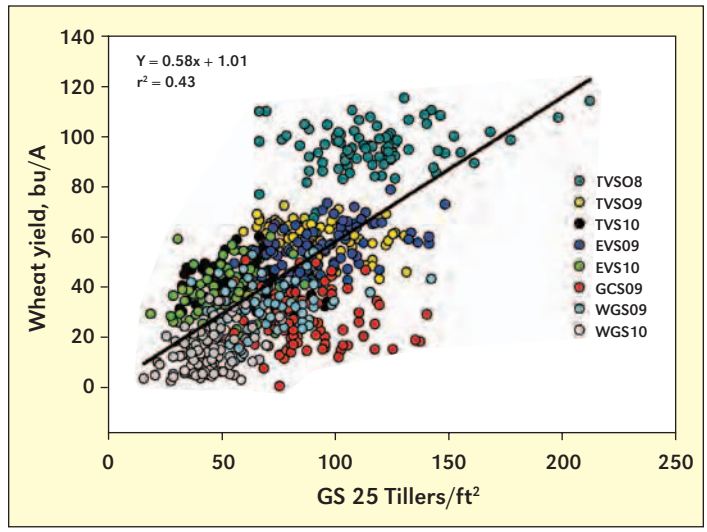


Figure 1. Relationship between GS 25 tiller counts/ft^2 and wheat yields across eight site-years in Alabama from 2008-2010. All counts were collected prior to spring applied UAN.

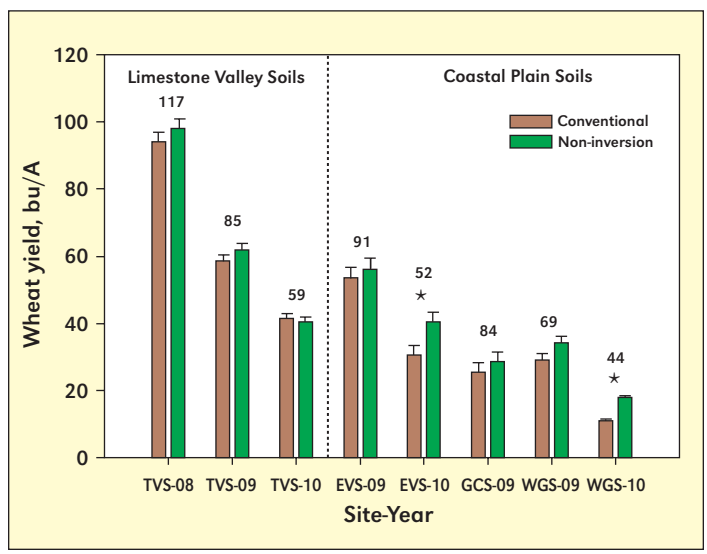


Figure 2. Wheat yields measured across conventional and non-inversion tillage systems for eight site-years from 2008-2010 in Alabama. Numbers above each site-year are the average tiller counts/ft^2 measured at GS 25 across all plots. * Indicates significant difference at 0.10 level of probability.

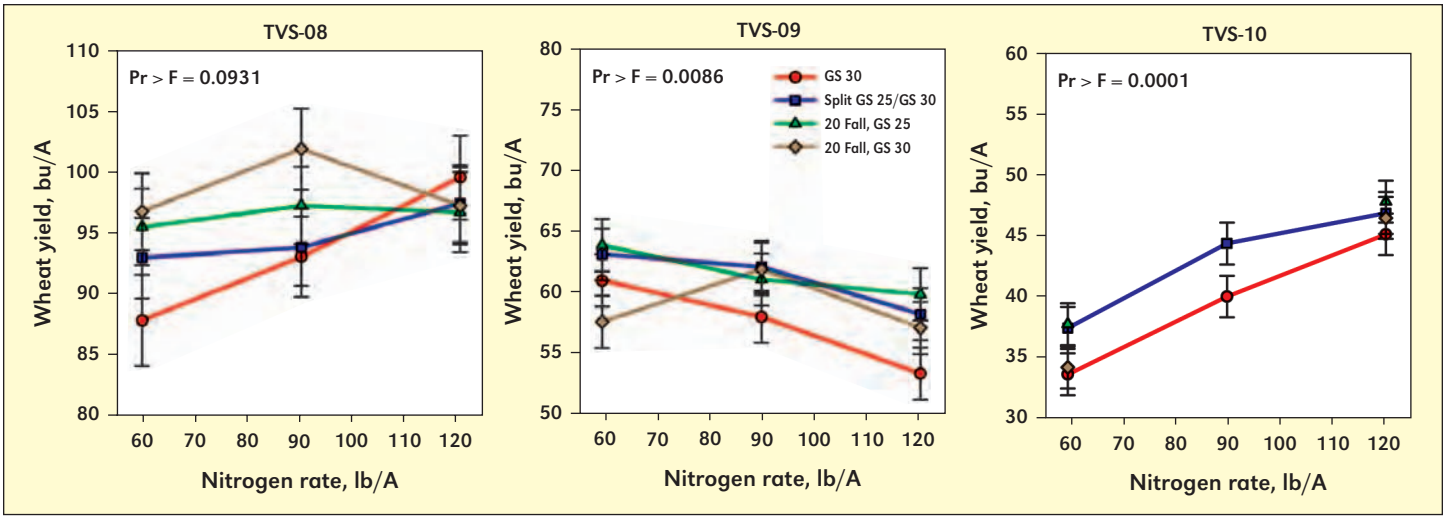


Figure 3. Wheat yields measured across different N rates and times of application for a Limestone Valley soil located in North Alabama across three site-years.

tiller densities at GS 25 resulted in higher final wheat yields.

Wheat yields

No differences were observed between wheat yields for conventional and non-inversion tillage systems at six of the eight site-year locations in Alabama **(Figure 2)**. For the remaining two site-years, non-inversion tillage wheat yields were increased 33% (EVS-10) and 64% (WGS-10) compared to conventional tillage. These results indicate that concerns about slow wheat development associated with surface residue and subsequently cooler soils (Weisz and Bowmann, 1999; Weisz et al., 2001) are not warranted in Alabama with cotton as the preceding crop.

Figure 2 also clearly illustrates wheat yield variability (< 20 to 96 bu/A) observed across all eight site-years. Some of this variability was caused by increased Hessian fly damage in 2009 and head scab disease in 2009 and 2010. The highest average number of tillers/ft^2 at GS 25 produced the highest

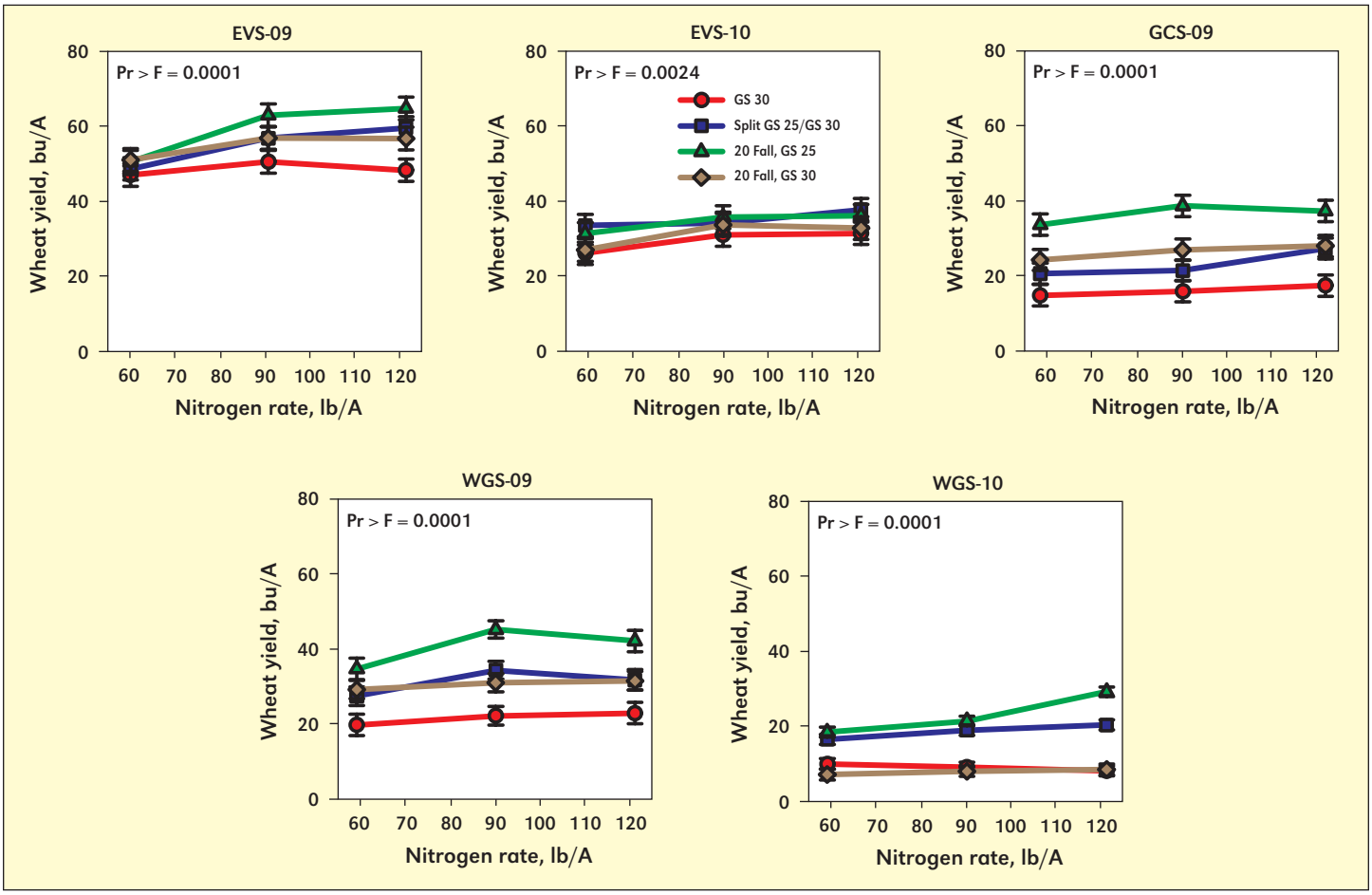


Figure 4. Wheat yields measured across different N rates and times of application for Coastal Plain soils located in Central and South Alabama across five site-years.

observed wheat yields, while the lowest number of tillers/ft^2 at GS 25 produced the lowest wheat yields. However, increased tiller counts/ft^2 did not correspond to increased wheat yields, which is also supported by data shown in **Figure 1**. For example, tiller counts measured at GCS-09 were 84/ft^2 at GS 25, but final yields were only about 25 bu/A. This observation highlights how yield potential can be decreased through the season by disease, insects, weather, or insufficient utilization of soil moisture and nutrients.

Although tiller counts at GS 25 can indicate the need for additional N, the amount required must also be determined for a specific region. In Alabama, differences between soil types created a natural distinction among site-years. For the Limestone Valley, results were inconsistent across site-years and incomplete for TVS-10 due to harvest issues **(Figure 3)**. Total N required to maximize wheat yields was different each year, and no clear response to fall-applied N was observed on this soil. This indicates some residual N may be available on these soils to the wheat crop following cotton, but it can be variable by year. This may be a function of winter rainfall levels or low temperatures that can inhibit N uptake from cold soils.

On the Coastal Plain, wheat yields were generally lower compared to the Limestone Valley. Fall-applied N followed by the remainder of N at GS 25 consistently maximized yields across all site-years **(Figure 4)**. Three out of five site-years showed that 20 lb N/A in the fall followed by 70 lb N/A at GS 25 produced maximum yields. However, WGS-10 required 100 lb N/A at GS 25 to complement the fall applied N and EVS-10 produced consistent yields regardless of N application or timing. The need for fall-applied N indicates no residual N was present for wheat following cotton on these sandy soils. This is not surprising considering the N leaching potential of sandy soils in a humid environment (Scharf and Alley, 1994).

Summary

Conclusions from this research are confined to wheat following cotton based on eight site-years, but some general conclusions were observed. Non-inversion tillage on the Coastal Plain soils and no-till on the Limestone Valley soils produced comparable or superior wheat yields across Alabama compared to conventional tillage. Fall-applied N was not necessary to optimize yields on Limestone Valley soils, but necessary for Coastal Plain soils. The N application window was wider for Limestone Valley soils, while Coastal Plain soils required all N applied by GS 25. Tiller counts were inconclusive as an effective tool to predict N requirements, but additional research may improve relationships between tiller/ft^2 and final wheat yields. BC

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Soil Fertility Evaluation and Control for Annual Crops in the Cerrado

By Djalma Martinhão Gomes de Sousa and Thomaz A. Rein

The authors review recommended practices for evaluating and managing liming and fertilizer use for high yielding annual crops growing under no-till (NT) cultivation within the Cerrado.

Brazil has increased its cultivated land area by 41% over the last 30 years, from 34 to 48 million ha. A great part of this land is located in the central savannah or Cerrado **(Map 1)**. Soils of the Cerrado are highly weathered, acid, and low in available plant nutrients. Until recently, past land cultivation in the Cerrado generally combined inadequate use of machinery plus monocrop cultivation of soybean. This has encouraged low soil quality, especially in terms of soil organic matter (SOM). No-tillage systems, as opposed to conventional tillage (CT), have now been implemented in about half of the Cerrado. This cultivation system has proven effective for improving soil quality, leading to more sustainable farming. This article focuses on NT soil fertility evaluation and control with macronutrients within the Cerrado. Extension of such management may be feasible to other tropical areas.

Soil Organic Matter

Among soil components and properties, SOM more closely relates to soil quality, maximizing soil resistance to erosion, water infiltration and retention, soil cation exchange capacity (CEC), soil nutrient stocks, and microbiological activity. Experiments comparing CT and NT show a trend for higher SOM at the soil surface with NT **(Figure 1)**. About 90% of CEC in these soils is accounted for by the SOM pool. Thus, a good option to increase nutrient recycling and nutrient use is to increase SOM. Example data from a long-term pasture-annual crop rotation leading to higher SOM (Area A), compared to plots exclusively under annual cropping (Area B), found that a 3.0 t/ha soybean yield was possible in Area A with only 3 mg/dm^3 of Mehlich I P and 3.7% of SOM, versus Area B, which required 6 mg/dm^3 of P with 2.8% of SOM. Consequently, in the Cerrado it appears critical to adopt and manage its soils under NT to promote a high input of crop residues that can maintain, or increase, SOM. Several research projects have been established lately to verify the best cropping system options for each region of the Cerrado. In general, systems involving pasture crops lead to higher SOM and soil quality, which with time contributes favorably to soil nutrient management.

Soil acidity

Surface and subsurface soil acidity should be very well evaluated and controlled before establishing a tropical NT system. This will help to improve root development, increasing nutrient and water uptake by crops.

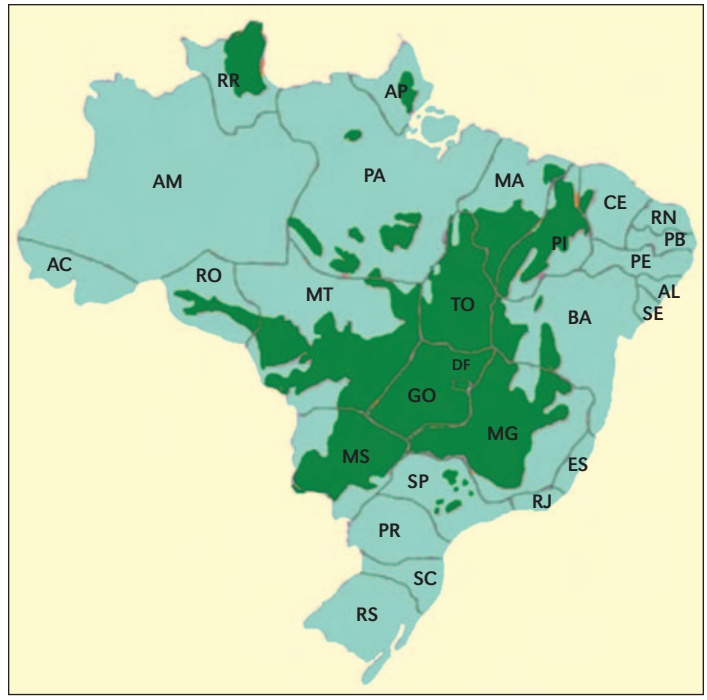
Surface soil superficial acidity (0 to 20 cm) is generally corrected to pH 6.0 in water, which in such soils relates to a base saturation[1] (BS) of 50%, by the formula:

$$Lime\ (\text{t/ha}) = \frac{(BS\ 2 - BS\ 1) * CEC}{ECCE}$$

where:
BS 2 = Ideal BS for specific crop systems.
BS 1 = Present BS obtained by soil analysis.
CEC = Cation Exchange Capacity at pH 7.
ECCE = Effective Calcium Carbonate Equivalent.

Note that the formula above takes into consideration properties of soil (BS 1 and CEC), crops (BS 2) and lime (ECCE), which leads to reasonably accurate rates of lime for each field situation. Calcium to Mg ratios should be in the range of 1:1 to 10:1, always with a minimum of 0.5 cmol$_c$/dm^3 of Mg. Before starting NT, lime should be uniformly incorporated in soil to a 20 cm depth. When feasible, lime should be incorporated at lower soil depths by correcting the amount showed in the formula above considering the analysis of 20 to 40 cm soil sample.

In general, soil acidification is slower under NT cultivation systems, as compared to CT **(Figure 2)**, where it occurs more intensively in the topsoil layer (5 cm) as a consequence



Map 1. Map of Brazil indicating (dark green) area of Cerrado region (Brazilian Savanah; 204 million ha = 20% of the country of Brazil). Source: IBGE, 2005.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc.

[1]*Base saturation = BS = (K + Ca + Mg/CEC)*100, where CEC is the cation exchange capacity at pH 7.0.*

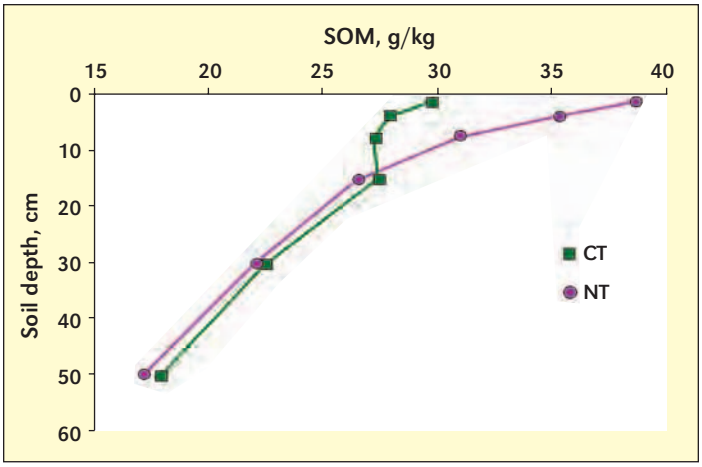


Figure 1. SOM contents of an Oxisol profile comparing CT and NT after 10 years of cultivation of corn and soybean.
Source: Nunes et al., 2008.

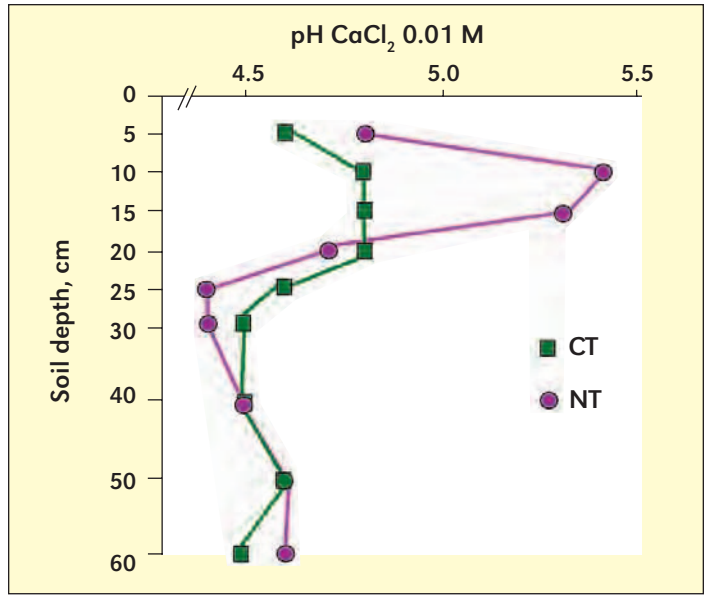


Figure 2. Soil pH in an Oxisol profile after 6 years of lime application as a function of cultivation system.
Source: Sousa and Lobato, 2004.

of nitrification after N mineralization of crop residues and use of N fertilizers. Some have observed reductions of up to 35% in the amount of lime necessary to maintain ideal BS in the top 20 cm under NT when both cultivations systems were compared. In a system already under NT, soil acidity evaluation is done by soil analysis, with application of lime to reach a BS of 50% recommended when present BS is under 40%. The distribution of lime in this case should be on the soil surface with no incorporation.

Subsurface soil acidity (20 to 60 cm) is also very common in the Cerrado region of Brazil. These soils are generally extremely low in Ca and may also be associated with high exchangeable aluminum (Al) or high Al saturation[2], which impose problems to plant root development. Consequently, soil sampling at these soil layers (20 to 40 cm and 40 to 60 cm or at least 30 to 50 cm) is extremely important. Either phosphogypsum ($CaSO_4 \cdot 2H_2O$; PG) or mined gypsum (gypsite) are generally utilized to ameliorate subsoil acidity. These products add Ca and S and can, in proper rates, minimize Al toxicity below the top 20 cm of soil. Application of PG is recommended when subsoil samples show Al saturation higher than 20% and/or exchangeable Ca is lower than 0.5 $cmol_c/dm^3$. In such cases, the amount of PG required to ameliorate sub soil acidity follows the formula:

PG (kg/ha) = *50 x SCC*

where:

SCC(%) = Soil Clay Content at soil depth of 30 to 50 cm or 40 to 60 cm

Due to higher solubility compared to lime and leaching of Ca and sulfate in the soil profile, PG is broadcasted over the soil surface with no incorporation necessary. Good responses to PG application have been noted for annual crops, especially for corn, wheat, soybean, beans, and cotton. **Table 1** presents some examples for PG responses in soils of the Cerrado. It is expected that similar responses may happen in similar soils of the world. The response to PG is due not only to the addition of S, but also to better root development **(Figure 3)**, which leads to higher nutrient and water uptake **(Table 2)**.

Table 1. Effect of phosphogypsum (PG) application on yields of cotton and soybean cultivated under NT.

PG Rate	Cotton	Soybean
	t/ha	
0	1.8b	3.3b
3	2.6a	4.0a

Averages followed by the same letter in the column do not statistically differ by the t test at 5% probability. Source: Sousa et al., 2008.

Soil Nutrient Management for High Yields

Studies have shown that fertilizer requirements in NT should be similar (initially) compared to CT. Definitions of fertilizer requirement in the Cerrado are based on soil analysis, nutrient source, and expected yield. Maintenance fertilizers are generally applied in the seed row, but in some situations (i.e. soils with medium to high levels of available nutrients) they can be broadcast on the soil surface. Broadcast applications are sometimes important to farm operations as they can allow the planting of large areas within the best planting period. However, the lack of soil disturbance under NT does leads to soil stratification in terms of SOM and nutrient bioavailability.

[2]*Al Saturation = (KCl-extractable Al/Effective Cation Exchange Capacity)*100.*

Table 2. Cottonseed nutrient contents as a function of PG rate in an Oxisol under NT.

PG Rate	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	kg/ha						g/ha				
0	32 b	7 b	12b	1.0 b	3.0 b	1.8 b	15 b	7 b	48 b	11 b	37 b
3	50 a	11 a	18 a	1.5 a	4.8 a	3.0 a	23 a	10 a	69 a	18 a	55 a

Averages followed by the same letter in the column do not statistically differ by the t test at 5% probability. Source: Sousa et al., 2008.

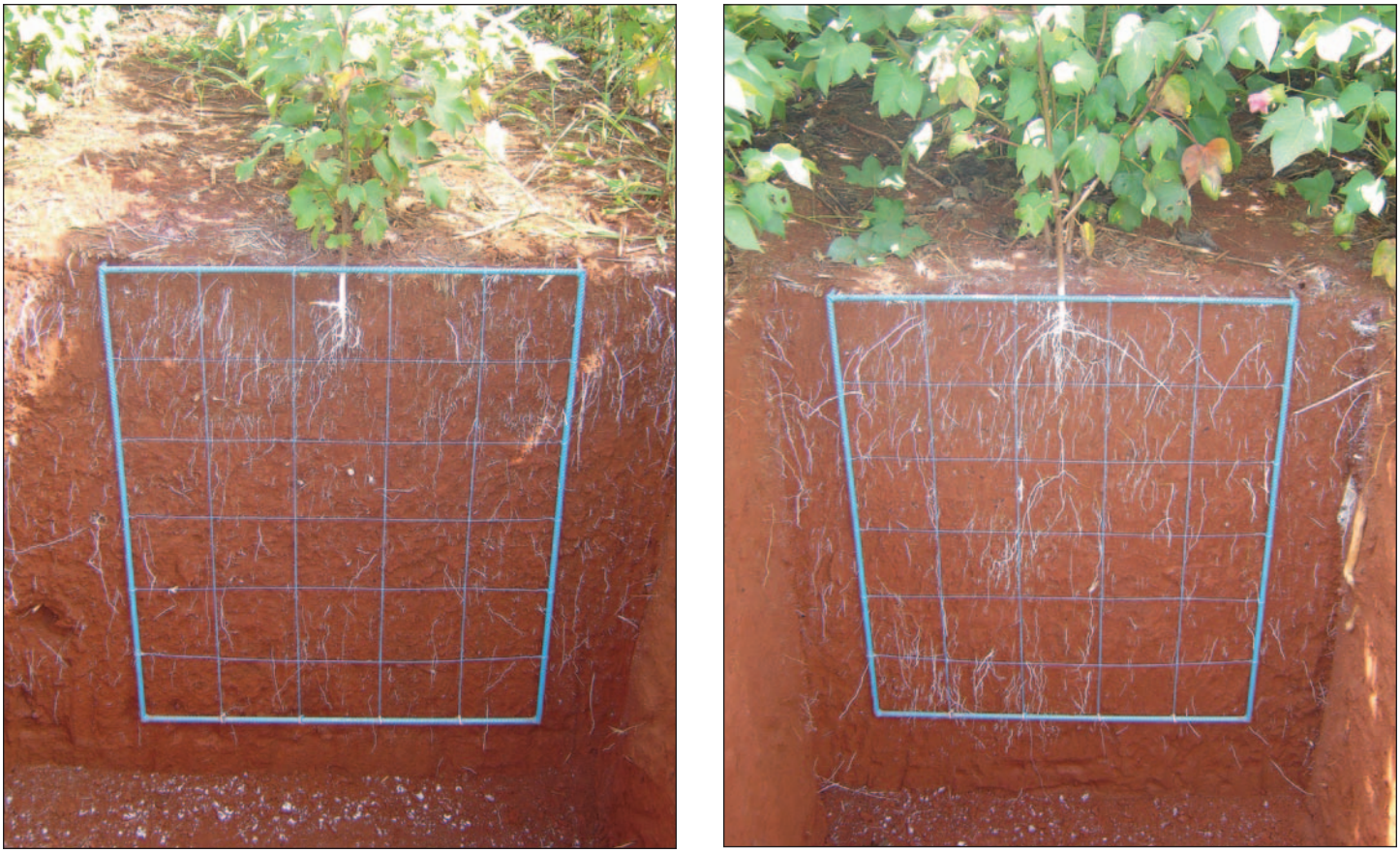


Figure 3. Cotton root development (at complete flowering) in the soil profile with (right) and without (left) PG application (grid of 15 cm x 15 cm). Source: Sousa et al., 2008.

Nitrogen

It is generally known that farmers should be careful in initial stages of NT cultivation regarding N because of lower rates of SOM mineralization and a higher possibility for N leaching due to reduced run-off and increased water infiltration through the soil profile. However, agronomic experiments in the Cerrado have shown similar yields without N application when comparing both cultivation systems. This should be related to higher rates of mineralization of crop residues in this environment, even under NT. Consequently, in the Cerrado, it is possibly not necessary to apply higher rates of N in crops planted within newly established NT fields compared to rates utilized in CT.

Nitrogen sources, when conveniently managed in well-drained soils, present similar agronomic efficiencies. It is important to note that urea should be incorporated to avoid higher N volatilization. It is recommended that N application rates be split, with 1/5 to 1/3 of the total N rate applied at seeding and the rest top-dressed during crop development (i.e. time and rate as a function of soil, crop, total rate, and irrigation, if applicable). For corn, in Oxisols with high clay content and medium to high base saturation status throughout the soil profile, up to 100 kg/ha of N can be applied at seeding, without topdress application. There are several criteria for defining N rates in the Cerrado (Sousa and Lobato, 2004). On average, to produce 1 t/ha of corn, wheat, rice, barley, and sorghum, it is necessary to apply 20 kg, 30 kg, 20 kg, 25 kg, and 30 kg of N, respectively. For soybean, no N is recommended due to biological N fixation.

Phosphorus

Soil P bioavailability is often extremely low in soils of the Cerrado. Fertilization with P is achieved in two different steps: (i) corrective and (ii) maintenance fertilization. A formula taking into account the soil P buffer capacity (SPBC) was developed to calculate the amount of P used to increase soil P status to the critical level (Sousa et al., 2006):

$$P_2O_5 \text{ (kg/ha)} = (DSPC - SPC) * SPBC$$

where:
DSPC = Desired Soil P Content (mg/dm^3)
SPC = Soil P Content (mg/dm^3)
SPBC = Soil P Buffer Capacity **(Table 4)**

Phosphorus fertilizer for corrective application should be broadcast and incorporated, before conversion to a NT system. If the soil P level is adequate (around the critical level), as shown in **Table 4**, maintenance P_2O_5 rates of 60 to 100 kg/ha should be enough for grain yields of 3 to 5 t/ha of soybean or 6 to 10 t/ha of corn. When the soil P level (Mehlich I) is above 6 mg/dm^3, 12 mg/dm^3, 20 mg/dm^3, and 25 mg/dm^3 for very clayey, clayey, medium-textured, and sandy soils, respectively, the maintenance fertilization can be reduced by half (Sousa and Lobato, 2004). For water-soluble P sources in NT, it is recommended to apply the fertilizer preferably in the row when soil P is below the critical level. In soils above the critical level, P fertilizers can be applied either way (i.e. in the row or broadcasted at soil surface). When P fertilizer is broadcast, special attention to soil and water conservation

practices is required to avoid losing P-enriched topsoil or fertilizer P by erosion and runoff.

Potassium

Cerrado soils are low in exchangeable K and easily weatherable K-minerals. Potassium application in these soils can also be at corrective or maintenance levels. The corrective application is suggested when soil K (0 to 20 cm) is lower than 80 mg/dm³ or 40 mg/dm³ (Mehlich I), respectively, with CEC (pH 7.0) higher or lower than 4 $cmol_c/dm^3$. The amount of K applied follows the calculation below:

K_2O (kg/ha) = (DSKC – SKC) * 2.4

where:
DSKC = Desired Soil K Content (mg/dm³)
SKC = Soil K Content (mg/dm³)

Maintenance K fertilization is based on expected yield with the application of 60 kg/ha of K_2O for yields of 3.0 t/ha of soybean and 6.0 t/ha of corn. Once these soils generally have low CEC, it is recommended that application of rates of K_2O higher than 60 kg/ha should preferably be broadcast. For sandy or medium-textured soils with CEC lower than 4 $cmol_c/dm^3$, it is suggested to split the K rates, with 50% applied at sowing and 50% as topdressing. For corn, K topdressing generally takes place with the first N topdressing. For soybean, the recommendation is to apply K about 30 days after plant emergence.

With time under NT, the increase in SOM on the soil surface will lead to a reduction in K leaching. A study by Santos et al., 2008, has demonstrated that 89% of the K applied to a soybean-corn rotation in a clayey oxisol could be recovered after 8 years. Potassium recovered in this study considered K exported by plants plus exchangeable K in the top 30 cm of soil.

Conclusions

There are several management practices available to increase the effectiveness of lime and fertilizers in Cerrado soils or similar tropical soils. Practices such as cultivation under NT, crop rotation, inclusion of pasture and cover crops in the rotation to increase inputs of plant residues, maintenance of soil pH and associated BS at adequate levels, use of PG for subsoil acidity amelioration and adequate use of fertilizers, are essential to help farmers in the correct and effective use of fertilizers. Without adopting these practices, the general fertilizer efficiency, (defined here as proportion of the applied nutrient taken up by plants) is on average 55%. By utilizing such alternatives the efficiency can be as high as 85%. This translates into higher yields and, consequently, higher return on the investment for fertilizer. BC

Table 4. Soil P critical level in dryland annual crops cultivation systems and values of soil P buffer capacity utilized to calculate rates of corrective P_2O_5 application in Cerrado soils, as a function of soil clay content and method of P analysis.

Soil Clay	Soil P critical level in dryland cultivation systems[1]		Soil P buffer capacity (SPBC)[2]	
	Mehlich I	Resin	Mehlich I	Resin
%	------ mg/dm³ ------		(kg P_2O_5/ha)/(mg/dm³ of P)	
10-15	20	15	5	6
16-25	17	15	7	8
26-35	15	15	10	10
36-45	12	15	16	12
46-55	9	15	26	15
56-65	6	15	42	17
66-70	4	15	70	19

[1] For crops under irrigation, multiply by 1.4.
[2] Rate of P_2O_5 to increase soil P level by 1 mg/dm³. Based on soil samples from 0 to 20 cm.
Source: Sousa et al., 2006.

This article was originally published in the IPNI Brazil newsletter Informações Agronômicas. *The article was adapted and translated for* Better Crops *by Dr. Luís I. Prochnow, IPNI Brazil Program Director.*

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A Long-term Analysis of Factors to Improve Nutrient Management for Winter Wheat Production in China

By Xiaoyan Liu, Ping He, and Jiyun Jin

Data from 895 field experiments conducted between 2000 and 2008 were analyzed to calculate yield gaps, indigenous nutrient supplies, and nutrient use efficiencies – with the goal of improving nutrient management for wheat. Results showed an average yield gap of 0.76 t/ha between attainable yields and yields with farmers' practice. Successive inputs of large amounts of nutrients have significantly increased soil nutrient supply, and therefore contribute to lower use efficiencies since recommendations for N, P, and K have not been adjusted downward.

In the last three decades, an increase in nutrient inputs has played a major role in increasing food supplies in China. However, crop yields have not increased at the same rate as fertilizer application. Over application of N fertilizer is a common problem in wheat-maize and wheat-rice rotation systems. In the case of N, it has led to nutrient imbalances, inefficient use, and large losses to the environment – impacting air and water quality, biodiversity, and human health. Nutrient management within this system must be improved, and essential precursors to improving nutrient management in wheat include an assessment of wheat yield gaps, indigenous nutrient supplies, and nutrient use efficiency (NUE).

Inefficient crop management may cause actual yield to deviate from potential yields – this difference is termed the "yield gap" (Tittonell et al., 2008; Neumann et al., 2010). Field experimentation provides a direct measure of yield potential that integrates crop management practices designed to minimize many yield-limiting factors, such as nutrient deficiencies or toxicities, damage from insects, pests and disease, and competition from weeds. Indigenous nutrient supply can be defined as the cumulative quantity of nutrients from all non-fertilizer sources that are found in the soil solution surrounding the root system (Dobermann et al., 2003). NUE is an important index not only for fertilizer recommendations on a field-scale, but also for forecasting fertilizer demand on regional- and national-scales. Partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE), and partial nutrient budgets (PNB) of applied nutrients are frequently used in agronomic research to assess NUE (Dobermann, 2007; Snyder and Bruulsema, 2007).

China, with the world's largest wheat sowing area of 24 million ha, produced 115 million t of wheat grain in 2009. Winter wheat is mainly planted in North central (NC) China and the middle and lower reaches of the Yangtze River (MLYR) **(Figure 1)**. This area accounts for more than 90% of China's total wheat production. NC China is dominated by a temperate climate and a winter wheat/maize annual rotation. The MLYR has a temperate to subtropical humid climate and predominant rice/wheat rotation system.

Data were obtained from field experiments conducted by the IPNI China Program and other published studies between 2000 and 2008 **(Figure 1)**. Treatments consisted of optimum nutrient treatments (OPT) based on soil testing and target yields (He et al., 2009), a series of nutrient omission treatments consisting of an OPT-N, OPT-P, OPT-K, a check without any fertilizer applied (CK), and farmers practice (FP). The average rates of applied nutrient in these OPT treatments are shown in **Table 1**. Plot size ranged from 20 to 50 m² depending on location. These experiments covered a wide range of soils, crop varieties, agronomic practices, cropping systems, and climatic conditions.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Y_a = attainable yield; Y_{ck} = yield without nutrient applied; Y_f = yield with farmer's practice.

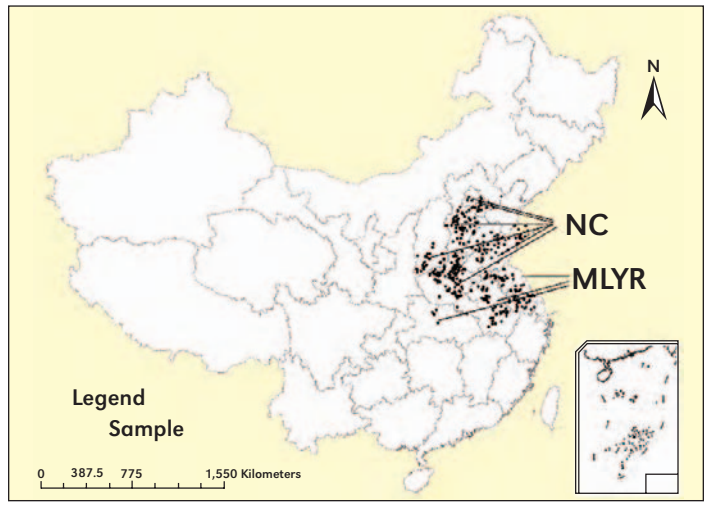

Figure 1. Geographical distribution of studied locations in different wheat production regions in China.

Table 1. Fertilizer application rates (kg/ha) in OPT and FP treatments.

	OPT				FP			
Regions	N	P	K	n[1]	N	P	K	n
NC	199	56	111	595	230	42	52	123
MLYR	220	47	96	300	234	48	40	32

[1]n = number of observations.

Yield Gaps

In this study, we define yield potential as Y_a given best nutrient management practices under experimental conditions. Y_a, Y_f, and Y_{ck} define yields obtained from OPT, FP, and CK treatments, respectively. The farmer-based yield gap (YG_f) is the yield difference between Y_a and Y_f. The check-based yield gap (YG_{ck}) is the yield difference between Y_a and Y_{ck}.

YG_f in NC China and the MLYR were 0.79 and 0.69 t/ha, and were 11% and 10% of Y_a, respectively **(Figure 2)** – values similar to those calculated by Neumann et al. (2010).

Y_{ck} is usually used as the indicator of soil fertility. Y_{ck} obtained in NC China and the MLYR averaged 4.52 and 2.79 t/ha, respectively, indicating that basic soil fertility was higher in NC China compared to the MLYR. YG_{ck} was 2.65

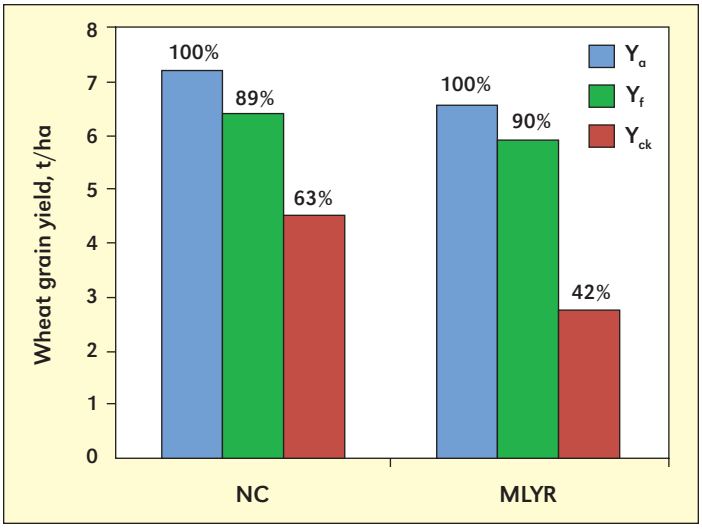

Figure 2. Differences Y_a, Y_f, and Y_{ck} in experimental plots for winter wheat in NC China and MLYR, respectively.

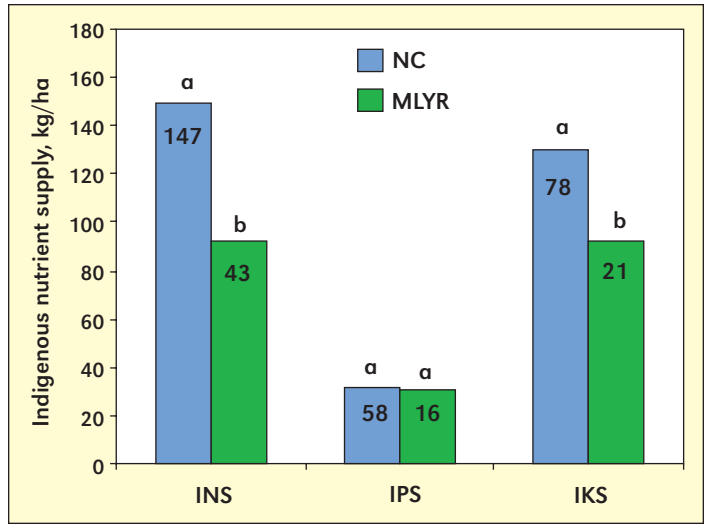

Figure 3. Variation in the indigenous nutrient supply in wheat fields in NC China and the MLYR. Numbers within each bar in the graph indicate the numbers of experiments with omission plots in each region. Different letters above the columns indicate a significant difference at $p < 0.05$.

and 3.77 t/ha in NC China and the MLYR, respectively. Data indicated that 37% and 58% of winter wheat yield was due to chemical fertilizer application in NC China and the MLYR, respectively. Thus fertilizer omission had its largest impact on yield in MLYR.

Indigenous Nutrient Supply

Indigenous nutrient supply refers to the contribution from all soil and environmental sources. The indigenous supplies of N (INS), P (INP), and K (INK) were estimated from total plant nutrient accumulation at maturity in 0-N plots, 0-P plots, and 0-K plots, respectively. Large differences were observed in INS and IKS supplies between the NC China and MYLR regions (58 and 38 kg/ha, respectively) **(Figure 3)**. However, this regional difference was non-significant for IPS.

The average INS in NC China was similar to the values determined in some recent studies (Cui et al., 2008; He et al., 2009). Interestingly, however, these values were almost 2.4 times that reported by Liu et al. (2006) for a study period between 1985 and 1995. Similarly, the IPS and IKS values in the present study were also higher than those obtained by Liu et al. (2006). In addition, INS, IPS, and IKS values for winter wheat in China were far more than those determined for Punjab state in northwest India (Khurana et al., 2008) and for northeast Thailand (Nakland et al., 2006). These relatively high levels of indigenous nutrient supplies are likely a result of large nutrient input, which has contributed to nutrient accumulation over the past decade, and should be an important consideration in formulating efficient nutrient management recommendations for winter wheat in China.

Nutrient Use Efficiencies of N, P, and K

Nutrient use efficiency parameters included PFP, AE, RE, and PNB from OPT plots. PFP, calculated as units of crop yield per unit of nutrient applied, is an appropriate index for comparing the economic benefit of fertilization among different regions. The average PFP_N of winter wheat in China was 36.2 kg/kg **(Table 2)**. Compared with PFP_N of wheat in NC China, the PFP_N in the MLYR was relatively low (33.3 kg/kg). In these two regions, average PFP_P was 143 kg/kg while average PFP_K was 72.7 kg/kg. No statistically significant differences for PFP_P and PFP_K were found within the two regions studied.

Average results for AE_N, AE_P, and AE_K were 10.0, 21.8, and 7.7 kg/kg, respectively, for winter wheat in China. Dobermann (2007) reported that AE_N in cereals varied between 10 to 30 kg/kg and could reach >30 kg/kg, in well-managed systems, with low levels of N, or with low soil N supply. The average AE_N in China only reached the baseline reported by Dobermann (2007) and the value was only 55% of the world average (18 kg/kg) reported by Ladha et al., (2005). The AE_N in the MLYR was higher than in NC China. However, there was no significant difference for AE_P and AE_K between the MLYR and NC China.

RE is defined as the increase in crop uptake of a nutrient in above-ground parts of the plant in response to application of that nutrient. Mean RE of applied N, P, and K fertilizer observed in OPT experiments were 39.5%, 20.7%, and 26.5% for winter wheat in China, respectively **(Table 2)**. RE_N and RE_P in NC China were lower than that in the MLYR. But RE_K showed no significant difference across the two regions. Compared to RE measured between 1985 and 1995, these current RE values are 5.5, 1.3, and 20.5% lower for N, P, and K, respectively (Liu et al., 2006). A review of worldwide data on use efficiency for cereal crops from researcher-managed experimental plots reported that single-year fertilizer RE_N averaged 57% for wheat (Ladha et al., 2005). Most of the data reported by Ladha et al. (2005) were based on multi-year or long-term trials with stationary treatment plots, but that also indicated that the RE_N of wheat in China was far less than the world's average, especially when compared against the United States, and some European countries (Pathak et al., 2003; Ladha et al., 2005; Dobermann, 2007).

PNB is used to evaluate the sustainability of a cropping system and is calculated in units of nutrient uptake by harvested portion per unit of kg nutrient applied. PNB is >1 in nutrient deficient systems (fertility improvement), <1 in nutrient surplus systems (under-replacement) and slightly less than 1:1 in sustainable systems (Snyder and Bruulsema, 2007). The PNB of N, P, and K averaged 0.95, 0.96, and 1.82 kg/kg, respectively **(Table 2)**. PNB_N in NC China was significantly

Table 2. Nutrient use efficiency of applied N, P, and K fertilizer in OPT treatments for winter wheat production regions of China.

Regions	PFP kg/kg	PFP n[1]	AE kg/kg	AE n	RE %	RE n	PNB kg/kg	PNB n
				N use efficiency				
NC	37.5 a[2]	518	9.5 b	210	35.2 b	122	1.10 a	188
MLYR	33.3 b	234	11.3 a	90	48.1 a	60	0.81 b	155
Average	36.2	752	10.0	300	39.5	182	0.97	343
				P use efficiency				
NC	141.8 a	506	23.0 a	137	17.8 b	46	1.07 a	89
MLYR	145.7 a	220	18.4 a	51	25.9 a	26	0.91 a	40
Average	143.0	726	21.8	188	20.7	72	1.02	129
				K use efficiency				
NC	71.0 a	481	7.6 a	374	23.7 a	70	1.67 b	85
MLYR	76.2 a	234	8.3 a	69	34.2 a	26	1.73 b	46
Average	72.7	715	7.7	443	26.5	96	1.69	131

[1]n = number of observations.
[2]Means within a column followed by different letters are significantly different ($p<0.05$).

higher than that in the MLYR, while there was no significant difference in PNB_P between the two regions. This surplus of N and P nutrients can again be related to the observed increase in indigenous nutrient supply, and in turn, decreased RE and AE of N and P. PNB_K showed no significant difference between the two regions. PNB_K is >1 in the two regions, indicating that K application rates were not replacing K removal.

Conclusion

Compared to the OPT, the FP treatments over applied N and under applied K. High N input has contributed to increased INS, and in turn decreased many indices of NUE. It should be noted that some OPT treatments in this study only focused on better nutrient management and ignored other high-yield cultivation techniques (i.e. high yielding varieties with stress tolerance, optimum sowing date, optimum water content, etc.) so yield gaps may be under estimated. The YG_f of 10 to 11% could be narrowed through improved fertilizer management (i.e. adopting 4R nutrient stewardship that focuses on providing the right nutrient source at the right rate, time, and place based on soil testing and target yields), which would provide agronomic, economic, and environment benefits.

Our research only clarified the extent that YG_f can be closed, but there is still a long way to narrow the yield gaps, improve nutrient efficiency, and diminish nutrient loss to the environment. Simple balanced fertilizer management (including macro-, secondary, and micronutrients) has not been given enough attention by many farmers in China. Many farmers equate more N application to more yield, and many farmers in China obtain more knowledge and experience from their neighbor rather than from research-based educational programs. A recent survey showed that, in developed regions of China, only 11 to 17% of farmers applied fertilizer rates that are based on soil testing, and the results are even lower in less developed regions (Magen et al., 2007). Scientific success in research plots does not guarantee the adoption of a new technology and does not guarantee yield increases in farmer's fields. Improving education and the technological training of farmers will make an important contribution to meeting China's demands for wheat. BC

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Acknowledgments

We thank the National Basic Research Program of China (973 Program) (2007CB109306) and International Plant Nutrition Institute for financial support. Special thanks to local cooperators from North-central, Middle and lower reaches of the Yangtze River for data collecting from field experiments.

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IPNI Crop Nutrient Deficiency Photo Contest 2011

Once again we welcome all those with a keen eye and ready access to agricultural production, at either the field or research plot scale, to seek out and gather their best examples of crop nutrient deficiency for entry into the 2011 edition of our photo contest.

The competition continues to foster awareness about, and focus attention on, identifying the common traits of nutrient deficiency for a wide range of crops. We are proud of how this contest has grown into an international challenge to field researchers, farmers, students, and other interested in crop production.

The competition continues with its four categories: Nitrogen (N), Phosphorus (P), Potassium (K), and Other (Secondary and Micronutrients). Entrants are limited to one entry per category (i.e. one individual could have an entry in each of the four categories). The winner in each category will receive a cash prize of USD 150 while second place receives USD 75. Selection of winners will be determined by a committee of IPNI scientific staff.

Photos and supporting information can be submitted until December 13, 2011. Winners be notified and the results will be announced at our website and in this publication in January of 2012. Entries should only be submitted as original, digital files. Please see the contest site www.ipni.net/photocontest for all details. BC

2010 Prize winning entry from Yogesh Mahida, Arya Agro Biotech & Research Center, Gujarat, India, who captured this image of boron (B) deficiency in a papaya (Honey Dew Variety) plantation near Santokpura.

Photo by Matt Wiebers

Nitrogen deficiency in corn, Terra Haute, Indiana.

Photo by Bhushan Prakash Phadnis

Potassium deficienct grape, Maharashtra, India.

Recent Release: Crop Nutrient Deficiency Image Collection

IPNI has assembled a new image collection comprised of more than 400 examples of nutrient deficiency symptoms in common crops. Images have been collected from various field settings around the world …some originating from our annual contest described above.

The images are organized in groups including primary nutrients, secondary nutrients, and micronutrients. Text and diagrammatic descriptions of nutrient deficiency are also available as supporting information.

The IPNI Crop Nutrient Deficiency Image Collection is available either in CD format for USD 30.00 (thirty dollars) or on a USB Flash Drive for USD 40.00 (forty dollars). Both prices include shipping for a single item. They can be ordered directly from the IPNI store, available at the website: www.ipni.net.

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Demonstrating a Link between Nutrient Use and Water Management to Improve Crop Yields and Nutrient Use Efficiency in Arid Northwest China

By Shutian Li, Yu Duan, Tianwen Guo, and Yan Zhang

Northwest China is characterized by dry growing conditions that limit crop yields and nutrient use efficiency. Research trials evaluating the effect of different water and nutrient management scenarios on crop yield and nutrient use efficiency showed positive interactions between water supply and nutrients.

China's Northwest belongs to an arid and semiarid region with an annual rainfall of 200 to 400 mm or less, where potential evaporation often exceeds precipitation. Lack of moisture in the soil makes it a challenge to support adequate seedling growth in most spring seasons, and generally restricts agricultural production.

To improve crop yields, farmers try to irrigate with limited water resources and the use of water-saving irrigation including drip irrigation and low-pressure tube irrigation is growing rapidly **(Table 1)**. Some effective methods of using limited rainfall have been developed in recent years. For example, research in Gansu province has demonstrated that covering the land with plastic mulch or crop straw can reduce water losses by evaporation, as well as improve soil temperature (Wu et al., 2011). Research has also found that completely mulched double ridges and planting in furrows can support crop emergence with less than 10 mm of rainfall (Liu et al., 2008). These rainfall collecting techniques allow the full use of limited rain water by reducing evaporation in favor of transpiration, and significantly increased crop yield compared with the conventional non-mulched planting system.

Despite these advancements, a key challenge that remains is to manage nutrients under different water regimes to improve crop yields as well as nutrient and water use efficiencies. This article describes key examples of research related to this issue.

Water and Nutrient Interaction in Cotton

Cotton is a major cash crop in Northwest China. An experiment evaluating the interaction between water and nutrients in cotton in the Xinjiang province indicated a significant interaction between water and nutrient application. Low or medium water supply combined with medium nutrient supply produced higher lint yield as well as higher water and nutrient use efficiencies than other nutrient and water combinations **(Table 2)**. The best nutrient response, leading to some of the highest lint yields, was recorded with the lowest water application rate. The results showed that a balanced use of nutrients and irrigation water in combination can significantly increase crop yields more than nutrients and water alone.

Sprinkler Versus Flood Irrigation

Experiments on nutrient application under flood and sprinkler irrigation systems in 2009 and 2010 in Wuchuan and Chayouzhong Qi counties of Inner Mongolia province

Abbreviations and Notes: N = nitrogen, P = phosphorus, K = potassium.

Sprinkler irrigation improved potato tuber yield and nutrient use efficiency.

Table 1. Area and ratio of irrigated area in China Northwest region.

Province	Planting area, M ha	Irrigated area, M ha	Irrigated area, % total area	Water-saving irrigation[a], M ha	Water saving irrigation as a % of total irrigated area
IMAR[b]	6.86	2.87	41.8	2.01	70.0
Shaanxi	4.17	1.30	31.2	0.84	64.6
Gansu	3.87	1.26	32.6	0.80	63.5
Qinghai	0.51	0.25	49.0	0.07	28.0
Ningxia	1.21	0.45	37.2	0.23	51.1
Xinjiang	4.49	3.57	79.5	2.55	71.4

[a]Water-saving irrigation is given using techniques that save water and improve water use efficiency when compared with conventional irrigation (i.e. flood irrigation without canal seepage control). China Yearbook, 2009
[b]IMAR refers to Inner Mongolia Autonomous Region

Table 2.. Effect of water and nutrient on cotton lint yield (kg/ha) in Xinjiang province, 2003.

Water	113-69-27 N-P_2O_5-K_2O, kg/ha	226-138-54 N-P_2O_5-K_2O, kg/ha	340-207-81 N-P_2O_5-K_2O, kg/ha
2400 m^3/ha	1,239	1,496	1,575
3000 m^3/ha	1,315	1,608	1,330
3600 m^3/ha	1,250	1,437	1,253
Significant at Pr>F	Water	Nutrient	Water × Nutrient
LSD (0.05) = 156 kg/ha	*	***	*

*, *** indicates significance at $p<0.05$ and $p<0.001$, respectively.

Plastic-film mulched potato (left) and wheat (right) made full use of rain water and improved crop yield and nutrient use efficiency.

Table 3. Water/nutrient management on potato tuber yield and nutrient use efficiency in Inner Mongolia province (2009-2010).

Year/Location	Irrigation method[a]	Average yield, t/ha	AE_N, kg/kg N	AE_P, kg/kg P_2O_5	AE_K, kg/kg K_2O	RE_N, %	RE_P, %	RE_K, %	WUE, kg/ha/mm
2009/Chayouzhong	Flood	35.9 b	42.3 a	65.2 b	62.2 a	31.4 b	16.6 a	43.1 b	239.3 b
	Sprinkler	58.2 a	43.3 a	100.0 a	63.7 a	40.3 a	16.9 a	55.0 a	352.7 a
2010/Wuchuan	Flood	37.5 b	38.6 a	59.4 b	44.3 b	33.5 b	19.8 a	59.2 a	250.0 b
	Sprinkler	60.2 a	41.1 a	133.3 a	86.4 a	38.2 a	20.6 a	55.9 a	364.8 a

[a]N-P_2O_5-K_2O for flood and sprinkler irrigation system was 210-150-150 and 300-150-225 kg/ha in 2009, and 240-90-165 and 300-120-150 in 2010, respectively. All fertilizer application rates were calculated based on soil testing and target yield.
*Numbers followed by the same letter within the same column and for each year/location were not significantly different at $p<0.05$.

clearly demonstrated the importance of nutrient and water combination in improving potato yields and nutrient use efficiency **(Table 3)**. Potato tuber yields under sprinkler irrigation averaged 58.2 t/ha and 60.2 t/ha tuber in Chayouzhong and Wuchuan, respectively, which was significantly ($p<0.05$) more than that under flood irrigation in both locations. This effect cannot be attributed to irrigation system alone instead it was the result of a combined effect of nutrients and irrigation.

Although the amount of water used in both irrigation systems was the same, water use efficiency (WUE) was significantly ($p<0.05$) higher in the sprinkler system than in flood irrigation. Agronomic efficiency of N (AE_N) was not affected by the irrigation system employed **(Table 3)**. However, despite using a higher N rate in the sprinkler system, N recovery efficiency (RE_N) was significantly ($p<0.05$) higher in the sprinkler system than in flood irrigation. In contrast, agronomic efficiency of P (AE_P) with the sprinkler system was significantly ($p<0.05$) higher than in flood irrigation, while P recovery efficiency (RE_P) was not affected. The effect of nutrient and water combination on agronomic efficiency of K (AE_K) and K recovery efficiency (RE_K) was not consistent across the experimental sites.

Potato is more sensitive to water stress compared to many other crops and has a relatively shallow root-zone depth, which requires more frequent irrigation (Shock et al., 2007). In our study, 11 sprinkler irrigations were applied during the potato growing season, using 15 mm with each application (a total of 165 mm of water). On the contrary, flood irrigation split twice during the potato growing season normally resulted in low uniformity of water distribution in soils and deep percolation (Shock et al., 2007). This might explain why potato tuber yield and nutrient use efficiency under sprinkler irrigation were better than under flood irrigation.

Drip irrigation not only helped save water, but also improved potato tuber yield and N use efficiency.

Table 4. Combination effect of drip irrigation and N management on potato tuber yield and N use efficiency in Inner Mongolia province (2009-2010).

Year	N Management[a]	Irrigation	Average tuber yield, t/ha	Mean RE_N, %	Mean WUE, kg/ha/mm
2009	100% N basal	Drip	37.0 a	34.6 b	428.2 a
	50% N basal	Drip	33.3 b	50.8 a	385.4 b
	30% N basal + 70% N topdressing at flowering	Flood	33.3 b	23.7 c	222.0 c
	100% N Basal	Flood	31.6 b	17.2 d	210.7 c
2010	100% N basal	Drip	37.5 a	33.5 b	434.0 a
	50% N basal	Drip	32.9 b	42.1 a	380.8 b
	30% N basal + 70% N topdressing at flowering	Flood	35.0 b	29.7 bc	233.3 c
	100% N Basal	Flood	34.4 b	26.4 c	229.3 c

[a]N-P_2O_5-K_2O=210-90-165 kg/ha in 2009, N-P_2O_5-K_2O=240-90-165 kg/ha in 2010.
*Numbers followed by the same letter within the same column and for each year are not significantly different at $p<0.05$.

Drip Versus Flood Irrigation

Although sprinkler irrigation improved crop yield and nutrient use efficiency **(Table 3)**, this irrigation system does not fully save water in dry regions. A limited water resource requires water-saving irrigation techniques to reduce evaporation, and make most of the water available for crop transpiration to increase crop water use efficiency. Recently, in the irrigated areas more and more farmers have shifted to using drip irrigation. However, nutrient management, especially N application, has been both a challenge and an opportunity under these conditions.

IPNI conducted experiments on N management under flood and drip irrigation methods in irrigated potatoes grown on Chestnut soils in Wuchuan county of Inner Mongolia province. When the entire N recommendation was applied basally before planting under drip irrigation, it produced higher tuber yield and N recovery efficiency than 100% basal or split application under flood irrigation **(Table 4)**. Using 50% of the recommended N applied as basal under drip irrigation produced tuber yield similar to that obtained with 100% recommended N under flood irrigation. The former also led to significantly higher N recovery efficiency when compared with the flood irrigation method. The results indicated that drip irrigation can save more water (630 m^3/ha) and N fertilizer (105 to 120 kg/ha) than flood irrigation, while maintaining crop yields.

Under flood irrigation, split N application and 100% basal N application produced similar potato tuber yields, but higher N efficiency was obtained with split N application than with basal N application **(Table 4)**.

Plastic-Film Mulching Versus No Mulching

Trials conducted in 2009 in the Dingxi county of Gansu province showed that potato mulched with plastic-film and bunch-seeding produced 83% more tuber yield than without plastic-film mulching under similar fertilizer use scenarios. Another experiment in wheat also indicated that the recommended NPK application (150-120-84 kg/ha) produced 42% more grain yield under plastic-film mulching with bunch-seeding than without plastic-film mulching. For both crops the plastic mulch improved AE of N and K as well as water use efficiency **(Table 5)**.

The positive effect of plastic mulching can likely be explained by the effective maintenance of soil moisture content during earlier stages of plant growth, leaving a healthier moisture reserve deep in the soil (40 to 120 cm) for use during later crop growth stages (Li et al., 1999; Hou et al., 2010). In addition, plastic film mulching has been shown to improve soil surface temperature and increase crop growth at an early stage of plant development (Li et al., 2003). Our experiments clearly indicated that mulching, while expensive and labor-intensive, can improve nutrient use efficiency in arid regions where crops rely on the limited rainfall.

Conclusion

While China moves forward in its plan to sustain food security with population growth, an increasing emphasis will be placed on the arid northwest region of the country for additional food supplies. With the exception of water, growing conditions in the region are excellent for high yields of good quality food and cash crops. IPNI research in northwest China has clearly demonstrated that great potential exists to use both limited water supplies and fertilizer nutrients to optimize crop production and nutrient use efficiency, under both irrigated and rainfed conditions. BC

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Table 5. Effect of plastic-film mulching on potato tuber yield and nutrient use efficiency in Dingxi county of Gansu province (2009).

Crops	Water regime	N-P_2O_5-K_2O applied, kg/ha	Tuber yield, kg/ha	AE_N, kg/kg N	AE_P, kg/kg P_2O_5	AE_K, kg/kg K_2O	WUE, kg/ha/mm
Rainfed potato	Plastic-film mulching	225-105-90	16,616 a	10.6 a	14.1 a	31.9 a	61.1 a
	No mulching	225-105-90	9,066 b	8.6 a	14.1 a	12.5 b	33.3 b
Rainfed wheat	Plastic-film mulching	150-120-84	2,411a	5.1 a	4.9 a	1.9 a	8.9 a
	No mulching	150-120-84	1,693b	0.8 b	0.4 b	-0.8 a	6.2 b

*Rainfall from January to September was 272 mm.
**Numbers followed by the same letter within the same column and for each crop were not significantly different at $p<0.05$.

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Nitrogen, Phosphorus, Potassium, and Sulfur Posters Now Available

Four new colorful 18 x 24-inch posters printed on glossy paper illustrating the foods we need to eat to provide our bodies with N, P, K, and S are now available from IPNI. These posters in conjunction with our poster *Plants Also Need Proper Nutrition* demonstrate how closely aligned the foods we eat are to the nutrients plants require to thrive.

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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.

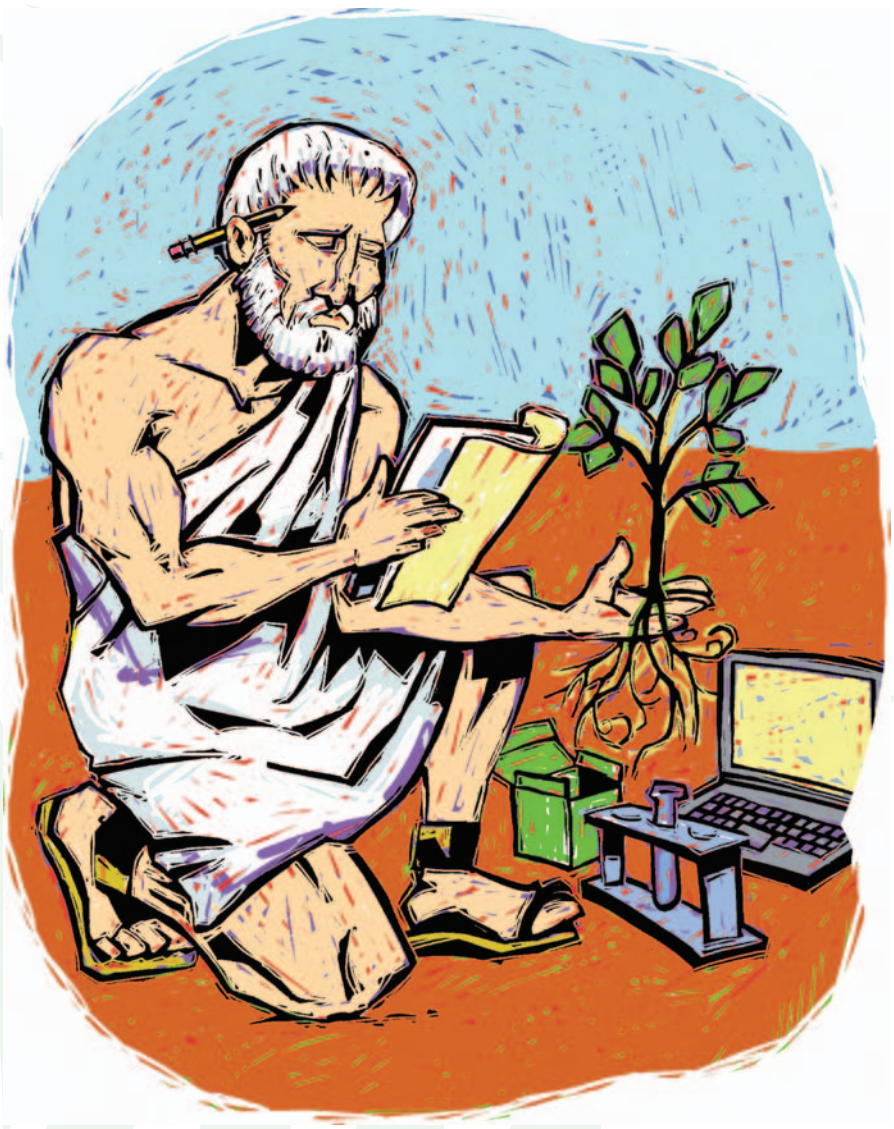
Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

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.

Current Principles and Future Knowledge

Aristotle, in his work *Ethics* where he is beginning to define the nature of politics, explains that he should, "...not forget the difference between reasoning *from* principles, and reasoning *to* principles..." This reminder of Aristotle's is relevant to us as scientists and practicing professionals. In science, we certainly have principles that we are taught and that we rely upon. Principles such as diffusive movement of nutrients, maximum nutrient influx rates of roots, and cation exchange are but just a few of the many we use in our discipline. When we diagnose crop nutrition problems or interpret research results, we often move *from* these principles to come up with explanations of what we observe.



The way in which principles sometimes come into play can be surprising, resulting in conclusions that may not at first be obvious. A recent surprise to me was that placing nitrogen deeper is not always the best practice for minimizing losses of nitrous oxide. It turns out that moisture at various depths is important, and if there is too much moisture deeper in the profile, denitrification can actually be greater compared to a shallower placement. The principle of nitrogen transformation hasn't changed, but it operates in a way that challenged my initial assumptions. I once heard a scientist say that if we aren't surprised now and then, we aren't doing science. We as humans are good at making assumptions – often the wrong assumptions. Science reminds us of that.

Some things that we encounter, however, don't seem to be explained by a simple reworking of the principles we already have. An example for me is the role of mycorrhizae in determining crop response to added phosphorus. These ancient fungi have influenced almost every phosphorus fertility study that has ever been conducted. They have contributed to the variability in those studies and they influence the extent to which a crop responds to phosphorus rate, placement, and timing. Still, our understanding of them is not extensive. Undoubtedly, as we learn more, we will be moving to new principles.

And so it is with science. We are caught somewhere between past knowledge that has provided principles we move *from*, and future knowledge that will provide new principles that we are moving *to*. In either case, we need to be surprised now and then. If we are not, we likely are not engaging in science.

BETTER CROPS
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