BETTER CROPS
WITH PLANT FOOD

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BETTER CROPS WITH PLANT FOOD

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Our cover: A fertilizer dealership is surrounded by wheat fields in the Palouse area of Washington state.
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Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* (and previous issues) can be found as PDF files at the IPNI website: **>www.ipni.net/bettercrops<**

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 2009. The IPNI Board meeting took place in Shanghai, China, in conjunction with the 77th Annual Conference of the International Fertilizer Industry Association (IFA).

Mike Wilson, President and Chief Executive Officer (CEO) of Agrium Inc., Calgary, Alberta, was elected Chairman of the IPNI Board for a two-year term.

Joachim Felker, Member of the Board of Executive Directors, K+S Aktiengesellschaft, Kassel, Germany, is the new Vice Chairman of the IPNI Board. Stephen R. Wilson, Chairman, President, and CEO of CF Industries Holdings, Inc., Deerfield, Illinois, was re-elected Chair of the Finance Committee.

Patricio Contesse, CEO and President of SQM, Santiago, Chile, concluded his term as Chairman of the IPNI Board of Directors and was recognized for outstanding leadership and service in that role since 2006. Dr. Terry L. Roberts continues as President of IPNI. BC

Mike Wilson, Chairman of IPNI Board

Patricio Contesse (left) was recognized for his dedicated service as Chairman of the Board since IPNI was founded in late 2006. Mr. Contesse is CEO and President of SQM in Santiago, Chile. IPNI President Dr. Terry Roberts, right, expressed the appreciation of the other Board members and the entire organization.

Stephen Wilson, IPNI Board Finance Committee Chair

Joachim Felker, Vice Chairman of the IPNI Board

IPNI Crop Nutrient Deficiency Photo Contest – 2009

The IPNI crop nutrient deficiency photo contest is part of a continuing effort to encourage the art of field observation and increase understanding of the physical appearance of crop nutrient deficiencies and the varying conditions in which they may appear in the field.

There are four categories in the competition: **Nitrogen (N)**, **Phosphorus (P)**, **Potassium (K)**, and **Other**. Entrants are limited to one entry per category (one individual could have an entry in each of four categories). Cash prizes are offered in each of the four categories as follows:

First place = US$150; Second place = US$75. A Grand Prize of US$200 will be awarded to the entry with the best combination of photographic quality and supporting evidence across all categories.

Photos and supporting information can be submitted until December 15, 2009, and winners will be announced in January of 2010. Winners will be notified and results will be announced at the IPNI website and in this publication. Entries are encouraged from all regions of the world. However, entries can only be submitted electronically as high resolution digital files to: >www.ipni.net/photocontest<. BC

Progress in Wheat, Sunflower, and Sugar Beet Cultivation in Russia

By Vladimir Nosov and Svetlana Ivanova

Progress with wheat, sunflower, and sugar beet production in Russia has been observed since the 1990s. Sugar beet cultivation has benefited the most due to the adoption of modern crop production technologies, including nutrient management. There are also real expectations for moderate yield improvement in wheat. Sunflower crop management is trailing and requires serious improvement before any large-scale gains in productivity can be expected.

During most of the 1990s, Russian agriculture experienced a dramatic loss of capital and all the key indicators of agricultural profitability and productivity deteriorated. However, after devaluation of the ruble in 1998, Russian agriculture, especially its crop production sector, has grown steadily. The restructuring has allowed important organizational changes to emerge and strengthen, particularly within the corporate-farm segment. In this new situation, entrepreneurs appear interested in investing in new machinery, fertilizers, quality seeds, and professional consultation in order to improve their profitability potential due to more intensive crop production.

The emergence of large commercial operations, called agro-holdings, has been one of the most drastic changes in Russian agriculture. Agro-holdings may be owned by either Russian or foreign managing companies. They form a production chain from growing the crops to processing/storage and sales. They now dominate cereals, sugar beet, and sunflower production.

Wheat is Russia's major cereal crop.

Currently, there are three types of agricultural producers in Russia: 1) agricultural enterprises are joint stock companies, and the most advanced are subsidiaries of agro-holdings; 2) commercial farmers; and 3) subsistence farmers, or households. ROSSTAT (2009) reports that 76% of the area under wheat in 2007 was cultivated by agricultural enterprises. For sunflower and sugar beet in 2008, agricultural enterprises accounted for 65% and 88%, respectively. The remainder of the area is cultivated by farmers and, to a lesser extent, by subsistence farms. Russia's major cereal crop is wheat, sunflower is a major oil crop, and sugar beet is the only sugar crop. Of the total 76.9 million (M) ha cropped in 2008, wheat occupied 35% of the area in the country, sunflower 8%, and sugar beet 1%. On average during the last 18 years, wheat area increased by 1% annually, sunflower by as much as 6% per year, but sugar beet acreage has decreased by 3% yearly (**Figure 1**).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; ROSSTAT = Russia's Federal State Statistics Service.

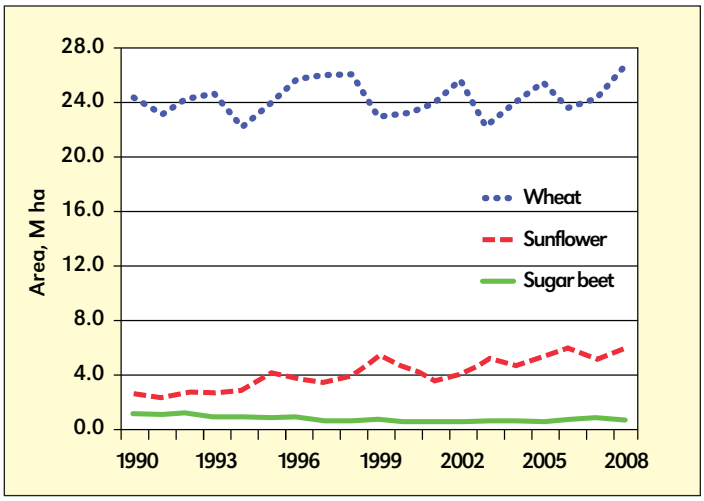

Figure 1. Area planted to wheat, sunflower, and sugar beet in Russia from 1990 to 2008 (ROSSTAT 2009).

Among these three crops, major progress has taken place in sugar beet cultivation over the last 5 to10 years. Sugar beet yield declined from 22.1 t/ha in 1990 to less than 15 t/ha at the end of 1990s, after the collapse of the USSR. Since then, yields have more than doubled to 35.4 t/ha in 2008 (**Figure 2**). A concentration of sugar beet cultivation in the most advanced and profitable agricultural enterprises with the best crop management explains these positive developments.

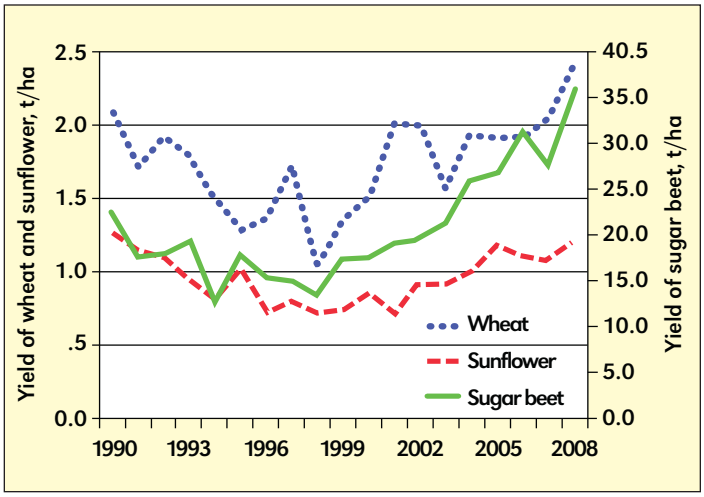

Figure 2. Yields of wheat, sunflower, and sugar beet in Russia from 1990 to 2008 (ROSSTAT 2009).

Data in **Table 1** show that mineral fertilizer application to sugar beet has increased considerably.

Sunflower production covers about 8% of Russia's cropped area.

In wheat, moderate progress has been achieved in management over recent years. The average yield was 2.1 t/ha in 1990, but poor management after the collapse of the USSR reduced it to a low of 1.0 t/ha in 1998. Poor crop management at that time led to low yields in all crops. However, wheat yields have since recovered and now average 2.4 t/ha (2008). Data on mineral fertilizer use in wheat indicates a slight improvement over the recent past (**Table 1**).

Similarly, sunflower yields declined to 0.7 t/ha by the end of the 1990s from a peak harvest of 1.3 t/ha in 1990. Data from 2008 indicate a recovery to 1.2 t/ha. In contrast to wheat and sugar beet, there has been a very small increase in fertilizer use for this crop as gains in production have simply been achieved through area expansion at the expense of other crops (**Table 1**).

It is important to note that in recent years the fertilized area increased noticeably for all crops. Unfortunately, country statistics on fertilizer use by crop are collected only from agricultural enterprises, and not all of them submit data to ROSSTAT. Whereas only 36% of the sunflower area in agricultural enterprises received fertilizers in 2008, 56% and 91% of the area planted to wheat and sugar beet, respectively, were fertilized. Taking into consideration the available fertilizer statistics for agricultural enterprises and the total crop acreage in the country in 2008, reported data may represent the fertilizer use for about 85% of sugar beet, 68% of wheat, and only 55% of sunflower production area.

IPNI has developed the AgriStats software (IPNI, unpublished data) that is intended to project fertilizer use by crop in a long-term perspective. The input data include estimates of the attainable crop yield and the average fertilizer application rates to achieve this attainable yield. The most realistic growth rate of crop planting area and the potential area that could be expected to receive fertilizer nutrients in the future are also estimated.

Based on recent research field experiments conducted in various soil-climatic zones of Russia (Sandukhadze et al., 2007; Kalichkin et al., 2008; Tsirulev, 2008; Vasyukov and Tsygankov, 2008; Lugantsev, et al., 2008; Zhivotovskaya, et al., 2007), we estimate average attainable yields of wheat as 4.5 t/ha, sunflower as 2.6 t/ha, and sugar beet as 46.0 t/ha (**Table 2**). IPNI defines attainable yield as productivity achieved by a modern variety in farmer fields with current best management and ample (non-limiting) nutrient supply. Attainable yield is not influenced by economics, but shifts according to the regional growing environment and technological advances.

Thus, there is a large yield potential in both sunflower and wheat, but the actual yield of sugar beet is closer to our attainable yield estimation. The estimated fertilizer application rates (kg N-P_2O_5-K_2O/ha) needed for the attainable yields are: 90-45-45 in wheat, 40-60-30 in sunflower, and 130-150-130 in sugar beet. Therefore, nutrient management of wheat, and especially sunflower, should be a serious concern in Russia. Fertilizer use in sugar beet needs to be improved too, particularly P and K application.

It is estimated that the attainable fertilized area for wheat may reach 80% for N and 70% for both P and K. The attainable fertilized area (%N/%P/%K) for sunflower and sugar beet is projected as: 90/90/70 and 100/100/100, respectively.

During 2003-2007, the profitability of sunflower cultivation was the highest of the three crops, fluctuating between 36% and 103% return on investment in production.

Wheat and sugar beet were less profitable, with ranges of 16 to 57% and 8 to 28%, respectively (ROSSTAT, 2009). Mironov (2008) reported that the cost of sugar production from sugar beet (i.e. sugar beet cultivation plus processing) in Russia was about 77 to 88% of wholesale sugar prices in 2003-2006 and reached 100 to 101% in 2007-2008. This is

Table 1. Fertilizer application to wheat, sunflower, and sugar beet and proportion of area under these crops that was fertilized in agricultural enterprises in Russia from 2003 to 2008 (ROSSTAT, 2009).

Crop	Year	N	P_2O_5	K_2O	Area fertilized, %
		kg/ha sowing area			
Wheat	2003	19.3	6.7	2.6	39
	2004	19.8	7.5	3.0	43
	2005	21.4	8.1	3.5	44
	2006	23.0	8.7	3.6	44
	2007	26.8	9.4	4.3	51
	2008	30.7	9.7	4.4	56
Sunflower	2003	4.6	5.4	3.1	22
	2004	5.0	6.1	3.1	25
	2005	5.7	7.0	2.7	29
	2006	6.1	7.3	2.7	30
	2007	7.5	8.0	3.2	35
	2008	9.6	8.6	3.8	36
Sugar beet	2003	76.4	50.5	50.4	77
	2004	82.9	66.7	72.9	78
	2005	96.2	74.8	80.7	82
	2006	106.8	68.9	69.3	87
	2007	109.2	79.6	82.0	90
	2008	104.2	81.3	88.4	91

Table 2. Projections of area, yield, and fertilizer use for wheat, sunflower, and sugar beet in Russia in 2027, as estimated by AgriStats (IPNI, unpublished reference).

Crop	Area, M ha	Attainable yield, t/ha	Attainable fertilizer rates, kg/ha (for total sowing area)			Attainable area fertilized, %		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	30.9	4.5	90	45	45	80	70	70
Sunflower	6.3	2.6	40	60	30	90	90	70
Sugar beet	1.0	46.0	130	150	130	100	100	100

an indication that the sugar beet industry has encountered serious difficulties.

According to our estimates, wheat cropping area could increase to about 30.9 M ha by 2027, assuming that Russia will be an important exporter of wheat grain in the future. Sunflower and sugar beet area are projected to increase slightly by 2027 to 6.3 M ha and 1.0 M ha, respectively, based mainly on domestic consumption of vegetable oil and sugar.

Currently, Russia has two internal drivers to boost agricultural production. They are substitution of imported agricultural products (sugar, livestock husbandry products, and milk), and emerging opportunities to increase export of cereals, particularly wheat. Domestic agricultural producers are also able to take advantage of currency devaluation in Russia due to the recent global financial crisis and any related increases in prices of imported agricultural commodities. The Russian federal government stimulates crop production through minimum purchase prices of grain (wheat, barley, rye, and maize), fixed domestic prices on mineral fertilizers, development of animal husbandry, subsidized credits, and decreased taxes. During the last 2 years, the Russian grain market has gained the spotlight as officials are increasingly aware of apparent competitive advantages.

Sugar beet production has not been as profitable as other crops in recent years.

In 2007/08, grain production reached 108 M t of grains – the highest over the past 18 years. Russia ranked third in world wheat exports in 2008. Export of grain and flour is estimated at 20 M t for the 2008/09 season, or US$5 billion. This is another record in terms of value, which is comparable with other widespread foreign-trade operations such as wood and lumber (US$7.3 billion in 2008), and weapons (US$8 billion).

However, grain exports could be larger. During the first 6 months of 2008, prohibitive export taxes of 30 to 40% were in effect. Great volumes of Russian grain can't reach global markets because of infrastructure problems such as transport vehicle shortages and insufficient elevators and grain port terminals. Russia's other problem is its traditional reliance on export of low value feed grains, which is a symptom of producers' reliance on inferior seed stocks and insufficient ability to access long-term grain storage facilities. In March 2009, the government addressed these problems through the formation of the United Grain Company (UGC), which reorganized all main state assets and also privately-owned facilities.

Grain harvest in Russia.

The recent financial crisis has found prices and volumes of raw material deliveries from Russia on the decline, but grain exports can increase in comparison since the country has first-rate arable areas under cereals that are primed for yield intensification through the adoption of knowledge-based technologies. BC

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New Website for IPNI Eastern Europe and Central Asia Group

The Eastern Europe and Central Asia (EECA) Group of IPNI has recently introduced a new website. The URL is: >http://eeca.ipni.net<.

"The site offers current agricultural news about the region, updates on program activities, publications, and links to other resources," explains Dr. Svetlana Ivanova, EECA Group Vice President. She is responsible for the overall EECA program plus Central Russia. Dr. Vladimir Nosov is responsible for the IPNI program in Southern and Eastern Russia.

The content of the website is presented primarily in English, although some of the content and links will also be available in Russian. BC

Robert Norton Joins Staff of IPNI as Program Director for Australia/New Zealand

Dr. Robert M. Norton, Director for Australia and New Zealand

Dr. Robert M. Norton is joining the IPNI staff as Director for Australia and New Zealand, effective October 1, 2009. He is based at Horsham, Victoria, Australia and will establish a program of agronomic research and education for IPNI in the region.

"This announcement marks a significant milestone in our progress at the Institute and we are very pleased that Rob Norton has accepted this opportunity to extend our efforts in this key region," said IPNI President Dr. Terry L. Roberts. "With his well established and respected record of achievement in agronomic research, teaching, and administration, Dr. Norton can make this transition in stride. We have great expectations and this new role will fit his talents."

For the past 28 years, Dr. Norton has worked in a wide range of responsibilities in the Melbourne School of Land and Environment at the University of Melbourne. His recent research has looked at incorporating elevated carbon dioxide (CO_2) responses into estimates of climate change impacts on the Australian grains industry using information from the Australian Grains Free Air Carbon Dioxide Enrichment (FACE) project he established and led. He also has considerable experience in soil and fertilizer use, oilseed agronomy, crop water use, alternative grain crops, and farming systems.

Dr. Norton has authored more than 60 refereed articles, as well as another 100 conference papers and project reports. He has recently supervised six Ph.D. students, most based at Horsham in western Victoria where he established an agronomy research group in collaboration with the Victoria Department of Primary Industries. He is also the Australia coordinator of a FACE project in Beijing, China, in collaboration with the Chinese Academy of Agricultural Sciences (CAAS).

A native of Australia, Dr. Norton earned his B.Agr.Sc. in 1975 and Dip. Ed. in 1976, both at Melbourne University. He was awarded the Ph.D. degree in 1993 at La Trobe University. His main areas of expertise include: soil and plant nutrition, especially nitrogen management for grain crops; field crop agronomy, particularly canola; farming systems development, with emphasis on new crops; and crop responses to high CO_2 environments.

Dr. Norton has considerable international experience, with professional visits to Canada, China, Denmark, Spain, Italy, and the USA. He has also hosted scientists from numerous countries. BC

BRAZIL

Valter Casarin Joins Staff of IPNI as Deputy Director, Brazil Program

Dr. Valter Casarin, Deputy Director for the Brazil Program

Dr. Valter Casarin joined the IPNI staff as Deputy Director, Brazil Program, effective August 15, 2009. He will be based in the IPNI office in Piracicaba, São Paulo, Brazil, and will work in coordination with Dr. Luís Ignácio Prochnow, Director of the Brazil Program.

"Dr. Casarin is an outstanding scientist and has a strong record of academic achievement plus other valuable experience," said IPNI President Dr. Terry Roberts. "Brazil is a key program for IPNI and we are very pleased to have the excellent talents of Dr. Casarin cooperating in the successful efforts ongoing in this critically important agricultural region."

Dr. Casarin was born in Brazil, where he received most of his education before earning his Ph.D. in soil science at the Superior Agronomical School of Montpellier (Ecole Nationale Supérieure Agronomique de Montpellier), France, in 1999. His thesis emphasized chemical actions performed by ectomycorrhizal fungi on the rhizosphere and consequences on the bioavailability of P. Before that, he studied at the University of Agrarian and Veterinary Science of Jaboticabal, UNESP, in São Paulo and became Agronomist Engineer in 1987. In 1994, he achieved an exceptional accomplishment by earning an undergraduate degree as Forest Engineer and his M.S. degree in Agronomy at Superior Agriculture School, University of São Paulo. His masters dissertation was on liming materials applied to a dark red latossol supporting an orange orchard.

Dr. Casarin has worked as an agricultural and forestry consultant, including the coordination of several research and fertilizer development projects. Earlier in his career, he had responsibilities in lecturing and research at universities in the state of São Paulo.

During his professional career, Dr. Casarin has been involved in several working groups and has collaborated in a large number of seminars and conferences related to various crops and nutrient concerns. He has published several papers in peer-reviewed journals and has chapters in three books. He also has an extensive record of participation and presentations at various congress, symposia, and scientific meetings. BC

World Fertilizer Nutrient Reserves—A View to the Future

By Paul E. Fixen

The stewardship responsibilities of agriculture include the wise use of the raw materials from which commercial fertilizers are produced. Development and implementation of fertilizer best management practices (BMPs) with focus on the 4Rs—right source, right rate, right time, right place—are timely not only for short-term economic and environmental reasons, but also for the wise stewardship of the non-renewable nutrient resources upon which food, feed, fiber, and fuel production depend.

The extreme spike in N, P, K, and S fertilizer prices midway through 2008 sent shock waves around the world. Some pondered whether fertilizer nutrient reserves were reaching critically low levels and contributing to market volatility. This paper will attempt to review the status of world nutrient reserves in terms of current production.

Phosphate

The main raw material used in the production of nearly all phosphate fertilizers is phosphate rock (PR). There are two general types of PRs, igneous and sedimentary. Insular or island deposits are a special type of sedimentary deposits. **Figure 1** shows a map of PR deposits currently being mined, those that have been mined in the recent past, and those that have been shown to be potentially economic (McClellan and Van Kauwenbergh, 2004). They are widespread throughout most of the world.

Igneous PRs typically contain apatite as the P form along with other igneous minerals. Igneous deposits often yield low grade ores, but can be beneficiated to higher grades in the range of 36 to 40% P_2O_5 (Stewart et al., 2005). Ores from igneous deposits are relatively unreactive. Consequently, they are not well suited for direct application to cropland and typically must be finely ground for use in fertilizer processing.

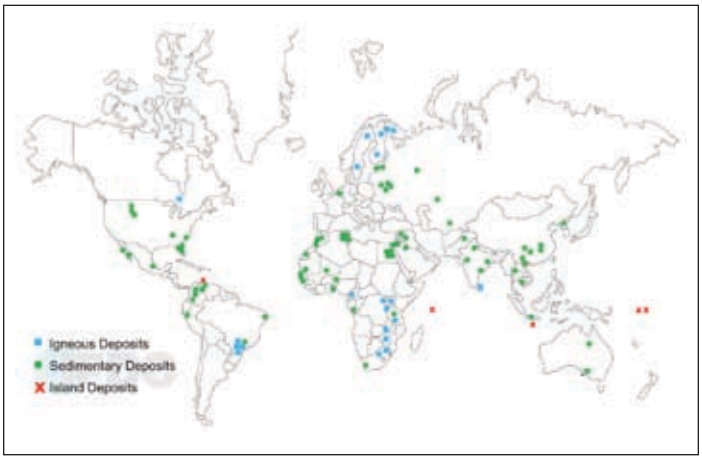

Figure 1. Economic and potentially economic phosphate deposits of the world (Source: S.J. Van Kauwenbergh, IFDC).

About 80% of the PR produced in the world is from sedimentary deposits. These deposits vary markedly in both physical and chemical properties, ranging from loose, unconsolidated materials to hardened rocks and from fluorapatite with almost no carbonate substitution to 6 to 7% carbonate for phosphate substitution (Stewart et al., 2005).

World PR production since 1981 has been generally rather flat overall, ranging from 120 to 165 million metric tons (M t) per year (**Figure 2**). However, the breakup of the Soviet Union caused a substantial disruption in phosphate production, resulting in major declines in the early 1990s. World production has just recently climbed back up to pre-breakup levels exceeding 160 M t. China has been the major source of production increases during the last 20 years.

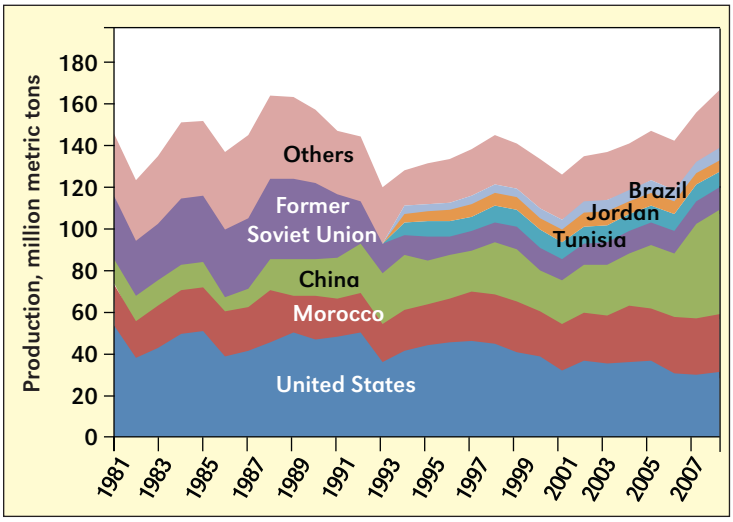

Figure 2. World phosphate rock production, 1981-2008.
[1]1992-1997 FSU includes Kazakhstan and Russia data; afterwards, Russia only.
[2]Compiled from USGS Mineral Commodities Reports, 1983-2009. Year 2008 estimated.

Estimation of PR reserves and resources is plagued with uncertainty due to limited information to assure accuracy of the estimates. Phosphate producers often consider reserve information to be confidential, leaving publicly available scientific papers and specific deposit reports as the primary information sources. Therefore, the reserve information presented here needs to be viewed as general approximations with broad confidence intervals.

Table 1 contains current estimates of world PR reserves and reserve base sorted by reserve base tonnage. Reserves and reserve base terms are defined by the U.S. Geological Survey (USGS) as follows. "Reserves – that part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserve base – includes those resources that are currently economic

Abbreviations and notes: BMPs = best management practices; N = nitrogen; P = phosphorus; K = potassium; S = sulfur.

(reserves), marginally economic, and some of those that are currently subeconomic."

However, personal communication with USGS indicated that current reserve estimates are based on market conditions from at least a few years ago and so do not reflect 2008 prices. Therefore, the portion of reserve base tonnage reported as reserves may be underestimated.

Morocco and Western Sahara are reported to have the largest PR reserve base and reserves in the world accounting for 45% of the world reserve base (**Table 1**). China follows with 21% of the reserve base, so these two countries have two-thirds of the world RP reserve base. **Table 1** also contains estimates of PR reserve life and reserve base life based on the average production of 2007 and 2008. At these production levels, world PR reserve and reserve base longevity would be estimated to be 93 and 291 years, respectively.

At this point, it is critical to remember the earlier comments about the reliability of these estimates. Two examples illustrate this point. First, in 2002, USGS was estimating PR world reserves and reserve base at 12,990 and 46,990 M t respectively (Stewart et al., 2005). The 2009 estimates discussed above represent 122% and 100% of these earlier estimates, even though an additional 7 years of production has occurred since they were made. As a second example, Sheldon (1987) reported world PR reserves at 15,259 M t (about the same as is being estimated today) and identified resources (reserve base plus inferred reserve base) as 112,431 M t. These identified resources based on today's production would amount to longevity of 696 years.

Clearly, great uncertainty exists in these estimates. And just as clearly, the world is not on the verge of running out of raw materials for phosphate fertilizer production. That said, these are non-renewable natural resources and deserve our very best stewardship.

Table 1. Phosphate mine production, reserves, and reserve base.

	Mine production[1] 2007	2008[2]	Reserves[3]	Reserve base[4]	Reserve life[5]	Reserve base life[5]
Country	--------- Million metric tons			----------	---Years	----
Morocco & W. Sahara	27.00	28.00	5,700	21,000	207	764
China	45.40	50.00	4,100	10,000	86	210
United States	29.70	30.90	1,200	3,400	40	112
S. Africa	2.56	2.40	1,500	2,500	605	1,008
Jordan	5.54	5.50	900	1,700	163	308
Australia	2.20	2.30	82	1,200	36	533
Russia	11.00	11.00	200	1,000	18	91
Israel	3.10	3.10	180	800	58	258
Syria	3.70	3.70	100	800	27	216
Egypt	2.20	3.00	100	760	38	292
Tunisia	7.80	7.80	100	600	13	77
Brazil	6.00	6.00	260	370	43	62
Canada	0.70	0.80	25	200	33	267
Senegal	0.60	0.60	50	160	83	267
Togo	0.80	0.80	30	60	38	75
Others	8.11	10.80	890	2,200	94	233
World total	156	167	15,000	47,000	93	291

[1]P_2O_5 content varies from 23 to 39% P_2O_5 with an average in 2007 of 32%. U.S. rock averages 29%. [2]Estimated. [3]Reserves can be economically mined at the time of determination. [4]Reserve base includes economic, marginally economic, and some currently subeconomic resources. [5]Life based on 2007-2008 production. Source: U.S. Geological Survey, 2009c.

Potash

Potash refers to a variety of K-bearing minerals with the most common ones being sylvite (KCl), sylvinite (KCl+NaCl), hartsalz (ore deposits with sulfate salts), and langbeinite ($K_2SO_4 \bullet 2MgSO_4$). Economic sources occur in sedimentary salt beds remaining from ancient inland seas (evaporate deposits) or in salt lakes and natural brines. The general locations of potash reserves and reserve base are shown in **Figure 3**. The world's largest reserves occur in Saskatchewan, Canada, where the ore is exceptionally high grade (25 to 30% K_2O) and occurs at depths of 1,000 meters up to greater than 3,500 meters. These deposits are mostly sylvinite, with some carnallite ($KCl \bullet MgCl_2 \bullet 6H_2O$), and clay.

Production, reserves, reserve life, and longevity based on USGS data are reported by country in **Table 2**. Canada has 53% of world potash reserves while Canada, Russia, Belarus, and Germany collectively have 92%. World potash reserves are huge, with a reported reserve life based on current production of 235 years and a reserve base exceeding 500 years.

New production of about 1 M t K_2O capacity is expected to be added per year from 2009 through 2011, mostly by Canada, Russia, and Israel, with some from Jordan and the USA. An additional 5 M t is expected in 2012 by Canada, Argentina, Belarus, and Jordan (Prud'homme, 2008). New production through 2012 would total to approximately 8 M t.

Sulfur

Sulfur is one of the more common constituents of the Earth's crust. USGS estimates resources of elemental S in evaporite and volcanic deposits and S associated with natural gas, petroleum, tar sands, and metal sulfides at about 5 billion tons. The S in gypsum and anhydrite is almost limitless, and some 600 billion tons of S is contained in coal, oil shale, and shale rich in organic matter, but low-cost methods have not been developed to recover S from these sources (USGS, 2009e). However, S is not generally produced intentionally as a primary product. Most of the S available on the world market today is extracted from natural gas and oil as crude oil contains from 0.1 to 2.8% S (IFDC, 2008). Some S is also recovered from coal, the roasting of sulfides in metallurgical processing, and by mining of pyrites.

About 80 to 85% of the world's S production is used to manufacture sulfuric acid. Half of the world's sulfuric acid production is used in fertilizer production, mainly to convert phosphates to water-soluble forms. About 1 ton of S is needed to produce a little more than 2 tons of diammonium phosphate (DAP) (IFDC, 2008).

The leading countries in S production are the USA, Canada, China, and Russia. These four countries produce almost half of the world's S. Because petroleum and sulfide ores can be processed long distances from where they are produced, USGS

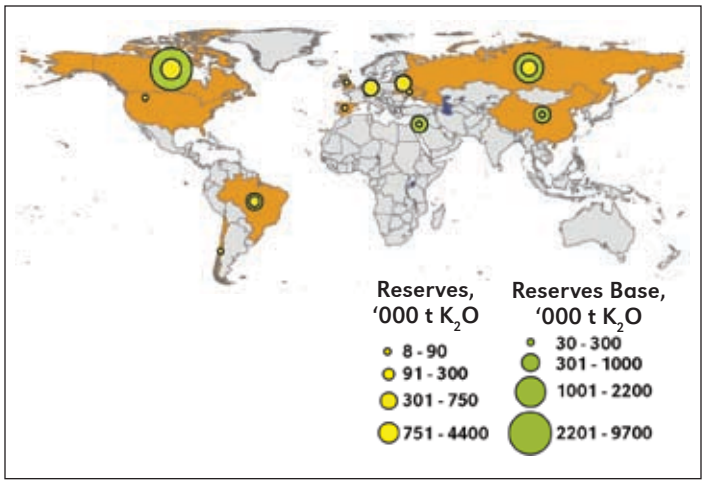

Figure 3. Potash reserves and reserve base (Source: U.S. Geological Survey, Mineral Commodity Summaries and Potash, January, 2008).

points out that actual S production may not be in the country for which reserves are attributed. This is one of the reasons that reserves and reserve base data are not reported by country for S. Gypsum ($CaSO_4 \bullet 2H_2O$) production is reported by country. A small amount of this product is used for agricultural purposes as a soil conditioner and a nutrient source. As an example, a little over 1 M t of the 12.7 M t of gypsum produced in the USA in 2008 was used in agriculture. In the long-term, the increase in world S supply is expected to overcome spot shortages as occurred in mid-2008 when S prices skyrocketed from less than $100/ton to over $800/ton. The price spike was driven by tight supplies resulting from lower than expected production in the USA and slow progress at new petroleum and natural gas developments coupled with increased consumption at phosphate fertilizer operations. A sharp decline in S demand in Asia in the third quarter of 2008 drove the price crash that occurred late in the year.

Table 2. Potash mine production, reserves, and reserve base.

	Mine production 2007	Mine production 2008[1]	Reserves[2]	Reserve base[3]	Reserve life[4]	Reserve base life[4]
Country	---Million metric tons K_2O equivalent---				----Years----	
Canada	11.10	11.00	4,400	11,000	398	995
Russia	6.60	6.90	1,800	2,200	267	326
Belarus	4.97	5.10	750	1,000	149	199
Germany	3.60	3.60	710	850	197	236
Brazil	0.41	0.43	300	600	719	1,437
Israel	2.20	2.40	40	580	17	252
Jordan	1.09	1.20	40	580	35	507
China	2.00	2.10	8	450	4	220
United States	1.10	1.20	90	300	78	261
Chile	0.50	0.58	10	50	19	93
Spain	0.58	0.59	20	35	34	60
Ukraine	0.01	0.01	25	30	2,083	2,500
United Kingdom	0.43	0.48	22	30	49	66
Other			50	140		
World total	34.6	36.0	8,300	18,000	235	510

[1]Estimated. [2]Reserves can be economically mined at the time of determination.
[3]Reserve base includes economic, marginally economic, and some currently subeconomic resources.
[4]Life based on 2007-2008 production. Source: U.S. Geological Survey, 2009d.

Nitrogen

Ammonia (NH_3) is the basic N source used in the manufacture of most N fertilizers. About 3% is used in direct application to crop land, mostly in North America. Non-fertilizer use accounts for about 16% of world NH_3 production (Abram and Forster, 2005). China, India, Russia, and the USA account for over 50% of total current NH_3 production, with China alone contributing nearly one-third of total production (**Table 3**).

Natural gas (CH_4) is the feedstock used in 75 to 80% of ammonia manufacturing (Abram and Forster, 2005) worldwide with about 1,230 cubic meters of gas required per ton of ammonia N (Huang, 2007). However, NH_3 manufacturing is a very small consumer of natural gas in most countries. Even if one assumes that all NH_3 is produced from natural gas, 5% of annual world gas consumption would be used for NH_3 production. In the USA, only about 1.5% of natural gas goes to NH_3 synthesis.

Thus, natural gas prices are generally independent of fertilizer markets, but greatly influence where fertilizers are manufactured. Rising natural gas prices in developed countries are causing a shift of N production to developing countries. Several companies have announced plans to build new ammonia plants in Algeria, China, Libya, and Peru (USGS, 2009b).

The topic of reserves for N fertilizers, considering the dominant manufacturing processes in use today, essentially becomes a discussion of natural gas reserves. Gas consumption and reserves sorted by reserve quantity are reported in **Table 3**. Russia, Iran, and Qatar have 57% of proven world gas reserves. Globally, we are consuming about 3.2 trillion cubic meters of gas per year and report 175 trillion cubic meters of proven reserves, giving longevity of 55 years. However, world natural gas reserves have generally trended upward, indicating that thus far producers have been able to continue replenishing reserves with new resources over time (Energy Information Administration, 2008). The largest recent additions to natural gas reserve estimates were reported for Venezuela and Saudi Arabia.

Summary

World reserves and resources for N, P, K, and S appear adequate for the foreseeable future. However, nutrient costs will likely rise over time as the most easily extracted materials are consumed. Therefore, an added incentive for continued refinement and implementation of fertilizer BMPs is that the resulting gain in efficiency will slow the increase in fertilizer costs. Wise stewardship of non-renewable nutrient resources is a critical responsibility for the agriculture industry. BC

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This article is adapted from a presentation by the author to the Soil Fertility 2009 Symposium, Rosario, Argentina, May 12-13, 2009.

Table 3. Ammonia production and natural gas consumption and reserves.

Ammonia production, million metric tons N			Natural gas, cubic meters (January 1, 2008)			
				Consumption	Reserves[2]	
Country	2007	2008[1]	Country	Billion	Trillion	Total, %
China	42.48	44.60	Russia	610	47.57	27.2
India	11.00	11.00	Iran	112	26.84	15.3
Russia	10.50	11.00	Qatar	21	25.63	14.6
United States	8.84	8.24	Saudi Arabia	76	7.16	4.1
Trinidad and Tobago	5.10	5.10	United Arab Emirates	43	6.06	3.5
Indonesia	4.40	4.40	United States	653	5.97	3.4
Ukraine	4.20	4.20	Nigeria	13	5.21	3.0
Canada	4.10	4.10	Venezuela	27	4.70	2.7
Germany	2.75	2.80	Algeria	26	4.50	2.6
Saudi Arabia	2.60	2.60	Iraq	2	3.17	1.8
Pakistan	2.25	2.25	Turkmenistan	19	2.83	1.6
Iran	2.00	2.00	Kazakhstan	31	2.83	1.6
Egypt	1.75	1.90	Indonesia	23	2.66	1.5
Poland	1.90	1.90	Malaysia	33	2.35	1.3
Netherlands	1.80	1.80	China	71	2.27	1.3
Qatar	1.80	1.80	Norway	7	2.24	1.3
Japan	1.09	1.36	Uzbekistan	51	1.84	1.1
Bangladesh	1.30	1.30	Egypt	32	1.67	0.9
Romania	1.30	1.30	Canada	93	1.64	0.9
			Kuwait	13	1.59	0.9
			Libya	6	1.40	0.8
			Netherlands	46	1.40	0.8
			Ukraine	85	1.10	0.6
			India	42	1.10	0.6
			Azerbaijan	10	0.85	0.5
			Australia	29	0.85	0.5
			Oman	11	0.85	0.5
			Pakistan	31	0.79	0.5
			Bolivia	3	0.75	0.4
			Trinidad & Tobago	21	0.53	0.3
			Yemen	0	0.48	0.3
			Argentina	44	0.45	0.3
			United Kingdom	91	0.41	0.2
			Mexico	68	0.39	0.2
			Brunei	4	0.39	0.2
			Brazil	20	0.35	0.2
			Peru	2	0.34	0.2
Other countries	20.30	22.00	Other countries	727	3.83	2.2
World total	131.5	135.7	World total	3,196	175	100

[1]Estimated. [2]Reserves can be recovered under present technology and prices.
Sources: Ammonia = U.S. Geological Survey, 2009b; Gas = *Oil and Gas Journal*, 2007; NationMaster.com.
Note: Production of a ton of ammonia N requires 1,230 cubic meters of natural gas.

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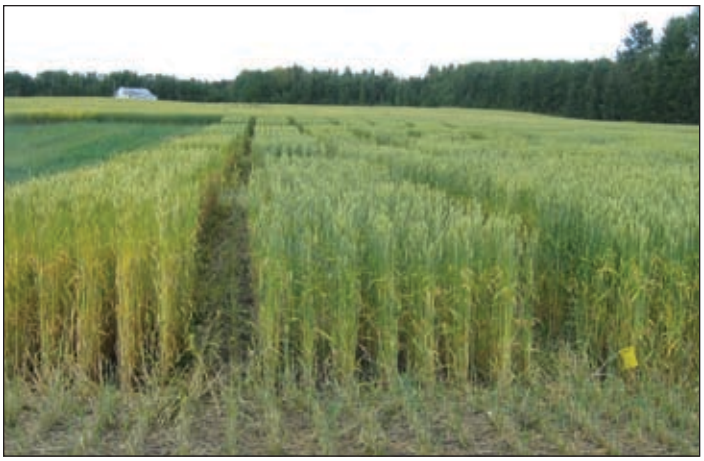
A Public-Private Cooperative Model for Updating Nitrogen Fertilizer Recommendations – the Manitoba Experience

By Rigas Karamanos, John Heard, and Tom Jensen

Field research results in Manitoba and adjacent areas in Saskatchewan conducted from 1989 through 2004 were used to update N fertilizer recommendations for wheat, barley, and canola in Manitoba. This was accomplished through a joint effort of a private industry soil fertility research unit (now part of Viterra, Inc.) and Manitoba Agriculture, Food and Rural Initiatives (MAFRI). They cooperated in reviewing, evaluating, and extracting pertinent research results to use in the updating. This is an example of cooperation between private industry research and government extension to improve fertilizer recommendations for use by farmers.

In Manitoba, as in most states and provinces in the Northern Great Plains (NGP), general fertilizer recommendations for N, P, and K are developed to assist growers in deciding what rate of fertilizer to use. In the province, these recommendations are reviewed and updated every 10 to 15 years depending on research data availability and the amount of changes in cropping systems to warrant an update. The latest update for N recommendations for spring wheat, barley, and canola, was released in March 2009 after adoption by the Manitoba Soil Fertility Advisory Committee, consisting of industry, government, and university researchers. This release was developed based on field research results from N response field experiments conducted from 1989 through 2004. These experiments were conducted by a private industry soil fertility research unit (now part of Viterra, Inc.) headquartered in Regina, Saskatchewan.

In 2004, MAFRI contacted Viterra, Inc. to determine whether or not their research database could be used to update the N fertilizer recommendations for spring wheat, barley, and canola. The last previous update in Manitoba was released in 1990. It was thought that an update was needed because of changes in the way soil fertility research trials were conducted, in relation to tillage systems, crop rotation, N fertilizer placement, and the availability of higher yielding varieties of wheat, barley, and canola.



Field research trials are used to generate data for development of nutrient recommendations.

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

Hybrid canola grown in Manitoba.

For canola, there has been the introduction and widespread adoption of higher yielding hybrid seed compared to open-pollinated canola seed used for the 1990 recommendations. Research trials used for the previous 1990 recommendations were based on soils that were either summer-fallowed the previous year or followed cereals with full conventional tillage with applied N broadcast and incorporated prior to planting. The more recent research was on land continuously cropped. It was planted using no-tillage or direct-seeding into standing stubble from the previous crop, and N fertilizer was generally applied in subsurface bands prior to or during the planting operation. The fields received a pre-plant weed and volunteer crop control application using a non-selective herbicide. Additionally, foliar applications of fungicides were made if leaf fungal populations reached threshold levels as assessed visually at each individual research site and year. Earlier studies did not receive foliar

Table 1. Average yield potentials for wheat and barley (bu/A) by moisture environment, crop, and year of update of N recommendations.

Moisture categories	Wheat		Barley	
	Pre-1990	2009	Pre-1990	2009
Moist	48	65	76	124
Dry	42	48	67	106
Arid	33	34	52	59

fungicide applications. The updated guidelines continue to be based on soil nitrate-N in the 0 to 24 in. depth.

The experiments were grouped and separate yield response equations developed for three agro-climatic categories, described as moist, dry, and arid for wheat and barley, and only moist for canola at present (there were not sufficient site-years for the arid and dry environments). However, canola is also grown throughout the province in all agro-climatic environments. The respective yield response equations are available for the various crop-environment combinations. These

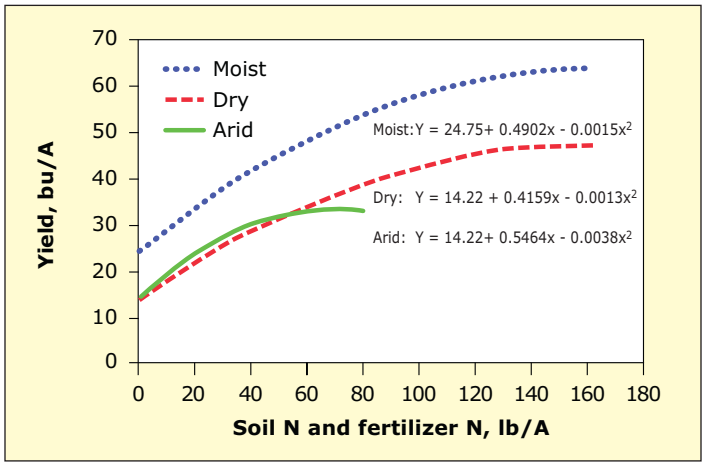
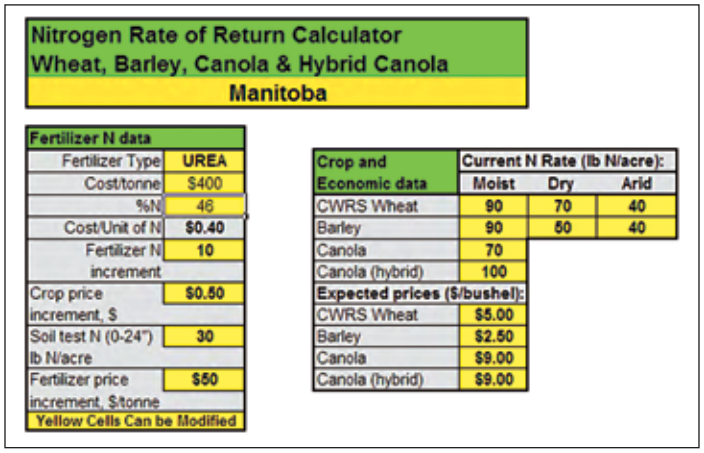


Figure 1. CWRS wheat response to N; 147 sites in three agro-climatic environments. Respective yield formulas are shown with corresponding curves.

improved yield response equations are useful to help growers better determine fertilizer N rates because yield potentials for most of the crop-climate combinations have increased from the 1990 recommendations as shown in **Table 1**. These increases are a result of improvements in genetic yield potentials, moisture conserving no-till cropping, more diversified crop rotations, N fertilizer placement in bands, and use of fungicides when beneficial for leaf fungal disease control.

General recommendations for fertilizer rates are available to farmers in the Manitoba Soil Fertility Guide (MAFRI, 2007), offered in both a printed hard-copy, or as an on-line version on the Manitoba Agriculture and Rural Initiatives website. The latest version of this guide contains the N recommendations based on the 1990 recommendations, and was updated and released in the year 2007.



Nitrogen Rate of Return Calculator
Wheat, Barley, Canola & Hybrid Canola
Manitoba

Fertilizer N data	
Fertilizer Type	UREA
Cost/tonne	$400
%N	46
Cost/Unit of N	$0.40
Fertilizer N increment	10
Crop price increment, $	$0.50
Soil test N (0-24") lb N/acre	30
Fertilizer price increment, $/tonne	$50
Yellow Cells Can be Modified	

Crop and Economic data	Current N Rate (lb N/acre): Moist	Dry	Arid
CWRS Wheat	90	70	40
Barley	90	60	40
Canola	70		
Canola (hybrid)	100		
Expected prices ($/bushel):			
CWRS Wheat	$5.00		
Barley	$2.50		
Canola	$9.00		
Canola (hybrid)	$9.00		

Figure 2. Partial view of the input screen for the MAFRI N Calculator.

The 2009 release of information as described in this article uses the refined and updated recommendations based on the Viterra research. Dr. Karamanos has prepared an Excel spreadsheet N Calculator using the yield equations derived from the field research experiments. An example of the yield equations for Canadian Western Red Spring (CWRS) wheat is shown in **Figure 1**. The calculator presents an easy-to-use format for estimating N fertilizer rates. Not only does it estimate the rate, but it includes an economic component based on the principle of net return described by Dr. M. Rankin of the University of Wisconsin (Rankin, 2005). The calculator is available on the MAFRI website: >http://www.gov.mb.ca/agriculture/financial/farm/nitrogencalc.html<. A partial screen shot of the input form of the calculator is shown below in **Figure 2**. The user can enter values for the fertilizer type and cost, percent N in the fertilizer, fertilizer N increments, expected crop prices, crop price increment, and soil test N, as lb N/A. The calculator will then determine the economic N rate for spring wheat, barley, open-pollinated canola, and hybrid canola based on the applicable moist, dry, and arid agro-climatic environments. An example of the output screen for spring wheat in the dry agro-environment is shown in **Figure 3**.

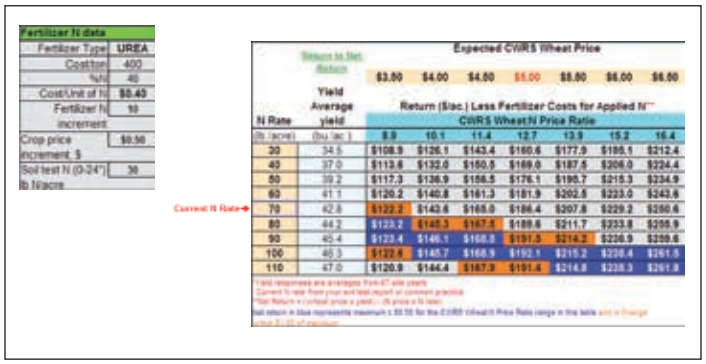


Figure 3. Screen shot of return ($/A) for wheat in a dry agro-climatic environment, as calculated using Manitoba N Calculator.

Conclusion

The Manitoba N Calculator is a valuable tool to assist Manitoba growers in deciding what rate of N fertilizer to apply to a crop of wheat, barley, or canola. It updates Manitoba N fertilizer guidelines to reflect current cropping practices. It is an excellent example of how private field research data can be used to improve agronomic extension activities. The cooperative efforts of Viterra, Inc. and MAFRI have produced a tool that will help increase net returns for Manitoba farmers. BC

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A New Approach to Assessing Phosphorus Use Efficiency in Agriculture

By A.E. (Johnny) Johnston and J. Keith Syers

It is frequently stated that P is used inefficiently in agriculture, with percent recovery of P applied in fertilizers usually between 10 and 20%. We argue that such low efficiencies are primarily an artifact of the method used to calculate efficiency. When efficiency is measured by the "Balance Method" – P removed in crop expressed as a percentage of P applied – and when soil P levels are being maintained near the critical level, the efficiency of fertilizer P use frequently exceeds 90%.

In a recent comprehensive review of world literature on P use efficiency for a wide range of cropping systems, soil types, and climates, Syers et al. (2008) showed that the recovery (efficiency) of applied fertilizer P plus residual soil P frequently ranged from about 50 to 90% when measured by a suitable method and over an appropriate time scale. This article shows how the concepts in the review can be developed further.

Percent recovery of an applied plant nutrient, X, is frequently calculated by the difference method:

$$\text{Percent recovery} = \frac{\text{uptake by crop given X minus uptake by crop without X}}{\text{Amount of X}} \times 100$$

While this method is generally appropriate for N fertilizers, it has more limited value for P and K. Why? Nitrogen applied as an inorganic fertilizer containing urea, ammonium, or nitrate and not used by the crop rarely remains as a residue of inorganic N in the soil. Nitrate left in the soil after crop harvest can be lost by leaching or denitrification and ammonium by volatilization. Thus, percent recovery of applied fertilizer N is best determined by the difference method which allows for any N taken up by a crop in the absence of applied N. However, only a very small amount, if any, of the residue from applied P and K fertilizer is lost from the soil. In most soils, any residue accumulates as a reserve of these two nutrients.

Rothamsted Research has plots with various P treatments going back to 1856.

The direct method – using the isotope ^{32}P – can be used to measure percent recovery of P applied in a fertilizer. However, percent recovery (efficiency) rarely exceeds 25%. But stop and consider. If only 25% of the P in a crop has come from the freshly applied fertilizer, the remaining 75% must have come from soil reserves of P. If soil P fertility is to be maintained, any P from the soil reserves must be replaced. So it is reasonable to consider that the total P in a crop, part from the fertilizer, part from soil reserves (which are maintained by fertilizer P addition), represents the long-term recovery of fertilizer P. Johnston and Poulton (1977) proposed this approach to measuring P use efficiency and it was developed further by Syers et al. (2008) who called it the "Balance Method" in which percent recovery of added P is calculated as:

$$\text{Percent recovery} = \frac{\text{P removal by crop}}{\text{P applied}} \times 100$$

This method has the advantage that the recovery of P from soil reserves is allowed for and there is no need for a control or check plot.

The second aspect of P use efficiency is related to recent developments in understanding the behavior of P in soil. In relation to the availability of soil P for uptake by plant roots, Johnston (2001) suggested that soil P could be considered to exist in four pools. This concept was further developed by Syers et al. (2008). Besides considering that the four pools of soil P were characterized by the availability of the P for uptake by plant roots, the latter authors related the four pools to the extractability of P by chemical reagents. In this way, a laboratory measure of "available" P can be related to soil P "availability" as seen by the growing crop in the field.

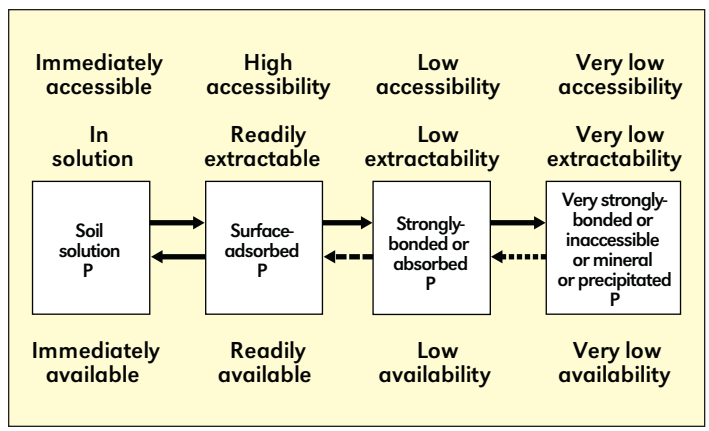

Figure 1. Efficiency of soil and fertilizer P.

The overall concept can be shown diagrammatically as in **Figure 1**.

The amount of P in each of the four pools is related to differences in bonding energy for P between sites both on the surfaces and within soil constituents able to retain P and variations in the proportion of such sites within the soil matrix. For P in the less readily available pool, it is further envisaged that there can be other reactions of P with soil constituents (Syers et al., 2008).

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

Phosphorus is taken up by plant roots as orthophosphate ions, principally $H_2PO_4^-$ and to a lesser extent HPO_4^{2-}. Earlier ideas about the fate of applied fertilizer P considered that if not used by a crop, the P became "fixed" in soil in forms that no longer supplied these ions to the soil solution and, therefore, this P was no longer available for uptake by roots. However, by the 1950s there were indications from field experiments which showed that where sufficiently large P reserves had accumulated in soil from past applications of fertilizer and organic manure, these reserves could provide sufficient P to increase crop yields.

The most important feature shown in **Figure 1** is the reversible transfer of P between the soil solution, the readily plant-available P pool, and the less-readily plant-available pool. Examples of supporting data from field experiments are given by Syers et al. (2008). Routine soil analysis for plant-available P measures the P in the soil solution and the readily plant-available pool. Because this is an operationally-defined fraction of soil P, the method of analysis used is not important. What is essential is that the data obtained accurately characterize a soil in terms of the response of a crop either to soil P or to an application of P fertilizer.

The reversible transfer of P between the first three pools implies an equilibrium between the P in these pools. Data for the increase in both Olsen P and total P in the top 23 cm of soil are available for a number of long-term experiments on the silty clay loam soil at Rothamsted, the sandy loam at Woburn, and a sandy clay loam soil at Saxmundham. For all three soil types there is a common linear relationship between the increase in

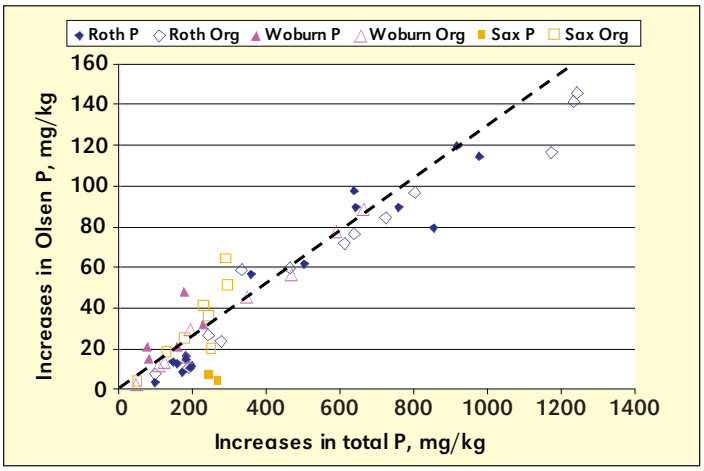

Figure 2. Relationship between total P and Olsen P.
(Dashed line represents 13% of added P remaining as Olsen P.)

Olsen P and the increase in total P (**Figure 2**).

Similarly, in an experiment in North Carolina, McCollum (1991) showed that after adding P for 9 years at rates up to 1,128 kg P/ha, only about 20% was extracted by the Mehlich-1 method.

A number of important practical questions arise from this concept of the behavior of soil and fertilizer P.

The first question is: "How much P should there be in the readily available pool to ensure optimum yield?"

When crop yield is related to readily available soil P measured by a reliable method for routine soil analysis, yield increases rapidly at first and then more slowly until it reaches a plateau – the asymptotic yield (**Figure 3**). The available soil P level at which the asymptotic yield is reached can be considered the critical level for that crop. Below the critical level, lack of available P results in a loss of yield. Applying P to soil with more than the critical level of available P would be done only to maintain soil P at a non-limiting level where no direct yield response is expected.

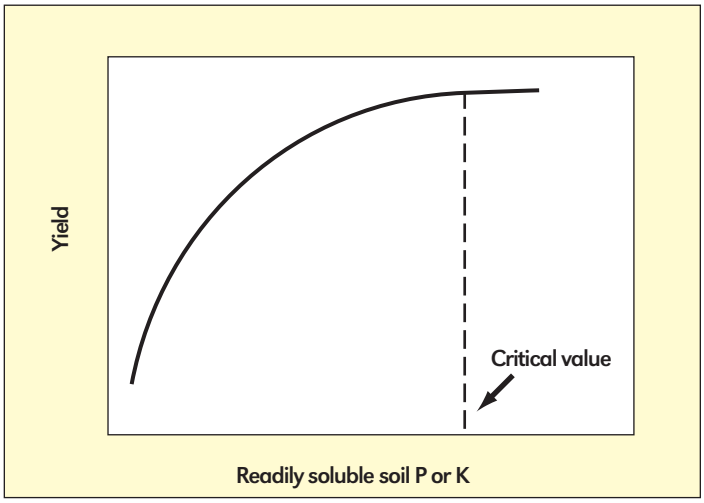

Figure 3. How much P should there be in the readily available pool?

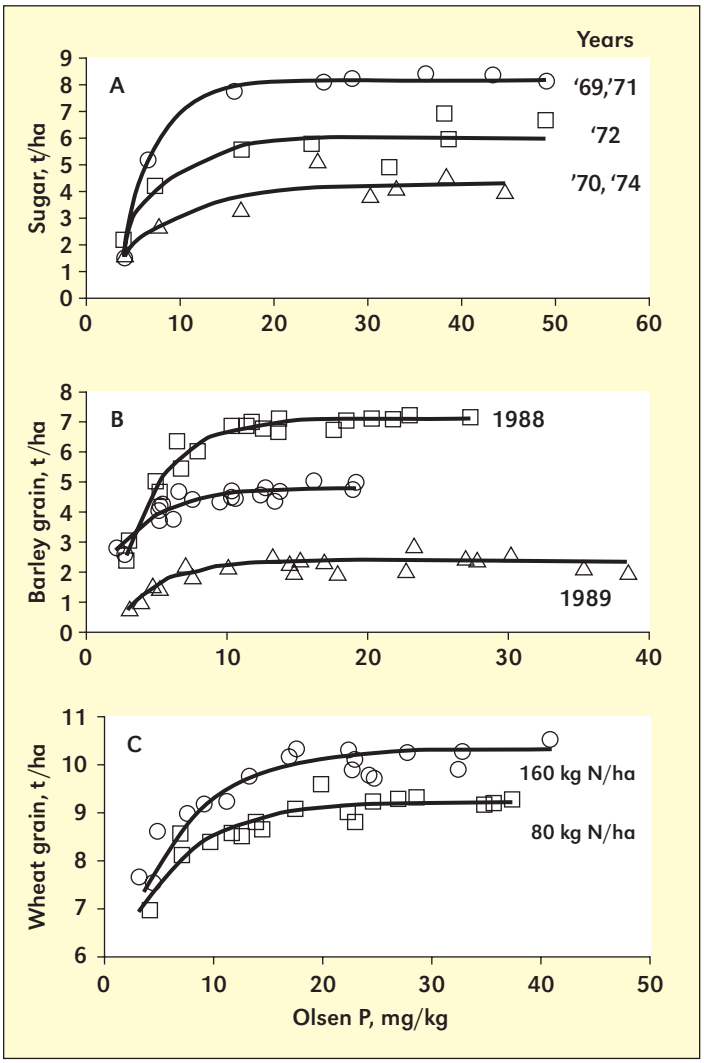

Figure 4. Example of critical values for arable crops.

Examples of yield/Olsen P response curves from Rothamsted experiments are shown in **Figure 4**. For the three crops, sugar beet (sugar yield), spring barley, and winter wheat, although the maximum yield differed between years due to weather factors or to the amount of N applied, the critical level differed little. To achieve the larger asymptotic yield did not require more Olsen P in the 23 cm of topsoil.

The second question is: "How much P must be added to increase plant-available P to the critical level?"

The answer to this question is site-specific. For this reason much further work is required. Soil type, soil bulk density, depth of P incorporation and sampling will influence the result. Two examples show what can be done. An experiment started in 1856 on the silty clay loam at Rothamsted Research has been modified to measure the amount of P required to increase Olsen P (Poulton and Johnston, personal communication). Five P treatments between 1856 and 1901 had given a narrow range of Olsen P levels. The range of Olsen P was increased between 1986 and 1991 by applying 264 to 786 kg P/ha. Averaged over appropriate treatments, the total P applied, the P balance, and the initial and final Olsen P levels are given in **Table 1**. On soils initially with 7 mg/kg Olsen P, a positive P balance of 182 kg P/ha increased Olsen P to 18 mg/kg. Spring barley was grown each year (1986 to 1991). From the P response curve, the mean 98% asymptotic grain yield was 52.1 t/ha and the associated Olsen P was 14 mg/kg. Thus, 182 kg P/ha incorporated into the top 23 cm of soil was sufficient to increase Olsen P in 6 years to above the critical level. In the experiment discussed by McCollum (1991), the soil was a fine sandy loam and Mehlich-1 P was measured in the top 15 cm of soil during the initial 9-year period when P was added. At the start of the experiment, the soil was already at about the critical level for maize (18 to 22 g/m^3) and above that for soybean. However, over the 9-year period, 0 to 1,120 kg P/ha was applied; the increase in Mehlich-1 P was linear and 10 kg P/ha increased Mehlich-1 P by 1 g/m^3.

Table 1. Total P added and P balance 1986-1991; Olsen P, mg/kg, in 1986 and 1991.

P added, kg/ha	P balance[1], kg/ha	Olsen P, mg/kg	
		1986	1991
786	700	7	48
522	437	8	38
264	182	7	18

[1] P applied in excess of removal by crops.

The third question is: "How much P is needed to maintain the critical level of Olsen P?"

The Rothamsted experiment was continued, but no P was added between 1993 and 1999. By 1999, Olsen P ranged from 2 to 31 mg/kg so that the yield response to Olsen P could be measured. From 2002 to 2006 when winter wheat was grown, 20 kg P/ha was applied each year to replace the maximum offtake in grain plus straw on plots that had received P from 1986 to 1991. These additions maintained the 1999 Olsen P levels.

The data from this experiment show that maximum grain yield was with a soil at the critical level of plant available P (Olsen P) and when this level was maintained by replacing the P removed in the harvested crop, then P use efficiency of the annual application exceeded 90% (**Table 2**).

Table 2. Relationship between Olsen P, maximum yield of winter wheat grain, total P removed in grain plus straw, P applied annually, and percent recovery of applied P, estimated by the balance method.

Olsen P, mg/kg, in 2004	9	14	23	31
Winter wheat grain, t/ha	7.1	7.8	7.9	7.9
P removed in grain plus straw, kg/ha	14	17	19	19
P applied annually, kg/ha	20	20	20	20
Percent recovery of applied P estimated by the balance method	70	85	95	95

Table 2 shows that the maximum yield was 7.9 t/ha at 23 mg/kg Olsen P and yield was not further increased at 31 mg/kg. On soil with less than 14 mg/kg Olsen P, yield was decreased, which would result in a financial loss to the farmer. Maintaining the Olsen P at the critical level by replacing the P removed in the harvested crop resulted in more than 95% efficiency of the annual application. Similarly, in the experiment described by McCollum (1991), replacing the P removed in the harvested crop maintained the critical level of Mehlich-1 P.

Summary

A recent review of the behavior of soil and fertilizer P envisages soil P as existing in four pools according to the availability of the P for uptake by roots and extractability of the P by reagents used for routine soil analysis, and that these two measures are closely correlated.

This concept has practical implications for the efficient use of P fertilizer. Namely, for most soils the amount of P in the readily plant-available pool of soil P should be raised to a critical level such that yield is not limited by lack of P and the benefits of all other inputs, especially N, required to achieve optimum yield are used as effectively as possible. For most soils that can be maintained at about the critical level of P, replacing the P removed each year in the harvested crop will typically result in P efficiency exceeding 90% when measured by the balance method. A project to develop an experimental protocol is being formulated, and sponsors sought, to extend the critical P concept to a wider range of cropping systems, soil types, and climates. BC

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Impact of Removing Straw from Wheat and Barley Fields: A Literature Review

By David D. Tarkalson, Brad Brown, Hans Kok, and Dave L. Bjorneberg

The sustainability of straw removal from wheat and barley fields from the standpoint of its effects on soil properties and nutrient cycling is a concern. A recent literature review reveals that there is no negative effect of small grain straw removal on soil organic carbon (SOC) content with irrigated conditions. With rainfed conditions, the results could be more variable and depend on site productivity. Large amounts of nutrients are removed when straw is removed, accelerating the rate of nutrient depletion and cost of replacing these nutrients.

Removal of straw from small grain fields has raised concerns about its effects on soil properties and nutrient cycling. Removal of straw for animal bedding and feed, the potential for cellulose-based ethanol production, and impacts on fertilizer and fuel costs are issues of concern.

Straw produced from small grains such as wheat and barley is a source of cellulose for biofuels. The average annual above-ground biomass from all wheat and barley production from 2001 to 2006 in the USA was 70.9 million (M) tons/year (dry weight basis). The total wheat and barley above-ground biomass represented only 25% of the stover produced from corn production in the USA in 2000.

Addition of crop residues to soils is important because they are a major source of organic carbon (C) and nutrients. Organic C positively impacts soil fertility, soil structure, water infiltration, water holding capacity, and bulk density, and it sustains microbial activity. Above-ground crop residues also have many benefits in the field. They act as a physical barrier between the soil and the erosive forces of wind and rain, reduce evaporation, increase water infiltration, and serve as a nutrient source.

This review focuses on two issues: the effects of straw removal on SOC and nutrient depletion. Literature was reviewed to evaluate changes in SOC where small grain straw was either removed or maintained.

Photo by Hans Kok

Effects of removing straw depend on irrigation and other management.

Irrigated Conditions

Bordovsky et al. (1999) measured the SOC concentration in the top 0 to 3 in. of soil for continuous irrigated wheat production under both reduced tillage and conventional tillage, and for a wheat-sorghum doublecrop rotation over an 11-year period in Texas. They found that the SOC concentration increased whether residue was removed or incorporated. However, the SOC increased more rapidly when straw was not removed from the field. Average grain yield and above-ground biomass production during this period was 6% higher when the crop residue was not removed for both tillage systems.

A 3-year furrow-irrigated study conducted by Bahrani et al. (2002) in Iran found a trend for higher SOC in the 0 to 12-in. soil depth when residue was incorporated, measured 3 years after the study was initiated. However, the SOC concentration did not decline during this time, even when residue was removed. The average wheat grain and straw yields were

Table 1. Annual amount of C and straw inputs of wheat needed to maintain soil organic C levels from reported research (adapted from Table 3 of Johnson et al., 2006).

Location	Study duration, years	Tillage	Crop	Irrigation	MSC	MSR
					---- lb/A/yr ----	
Montana	6	V-blade 9-12 cm	Wheat	NI	268	670
Washington	30	Moldboard plow	Wheat-Fallow	NI	3,571	8,928
Nebraska	22	Moldboard plow	Wheat-Fallow	NI	803	2,008
Colorado	84	Moldboard plow	Wheat-Fallow	NI	982	2,455
Washington	23	Moldboard plow	Wheat-Fallow	NI	1,071	2,678
Mexico	5	Moldboard plow	Wheat-Corn	I	1,294	3,235
Sweden	31	Hand tillage	Wheat-Barley	NI	1,339	3,348
Washington	30	Moldboard plow	Wheat	NI	1,785	4,463
Kansas	42	Moldboard plow	Wheat	NI	1,785	4,463
Oregon	45	Moldboard plow	Wheat-Fallow	NI	1,875	4,688

I = irrigated, NI = not irrigated.
MSC = Minimum above-ground annual C inputs needed to maintain SOC levels (minus C from grain). Values are based on above-ground straw residues and do not include below-ground root residues. Data obtained from research.
MSR = Minimum annual above-ground biomass requirement to maintain SOC (minus grain biomass). MSR = MSC/0.4.

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

significantly greater in plots where the residue was removed or burned than where the residue was incorporated.

Undersander and Reiger (1985) did not measure any difference in SOC between the residue removal treatments during a 14-year study in Texas with furrow irrigation. They found that the average SOC for all treatments increased from 0.76 to 1.24% between 1967 and 1980 at the 0 to 6-in. depth, and remained at 0.67% at the 6 to 12-in. depth. There were no long-term differences in wheat grain yields (average 50 bu/A) and above-ground biomass (average 1.85 tons/A) between residue management treatments.

Curtin and Fraser (2003) showed no difference in total SOC between residue management treatments at the end of a 6-year study with sprinkler irrigation in New Zealand. There were no effects of residue management on straw or grain yield during the study except for one year when incorporating straw reduced grain yield.

Follett et al. (2005) found an increase in SOC in the 0 to 12-in. depth over 5 years with border irrigation for all the straw management treatments receiving N fertilizer. The SOC increased more rapidly when residue was left on the surface with no-tillage than when residue was incorporated with conventional tillage or when the residue was burned. The average wheat yield where residue was burned and tilled was significantly higher (97 bu/A) than when the residue was incorporated into the soil (85 bu/A). The return of residues to the soil consistently increased SOC faster than when crop residue was removed or burned.

Photo by Brad Brown

Straw management is becoming more important.

The maintenance and increases in SOC observed when residue was removed or burned is noteworthy and likely results from contributions from plant roots and microbial biomass. Studies have reported a range in contributions by below-ground biomass to SOC. Some estimate that between 25 to 50% of the total plant C is present in below-ground biomass.

Precise measurement of below-ground biomass is difficult to measure because of problems associated with sampling and difficulty in estimating C inputs from roots and exudates. Additionally, when crop residue is removed, an unknown and variable portion of the residue remains in the field due to an inability to remove all the biomass.

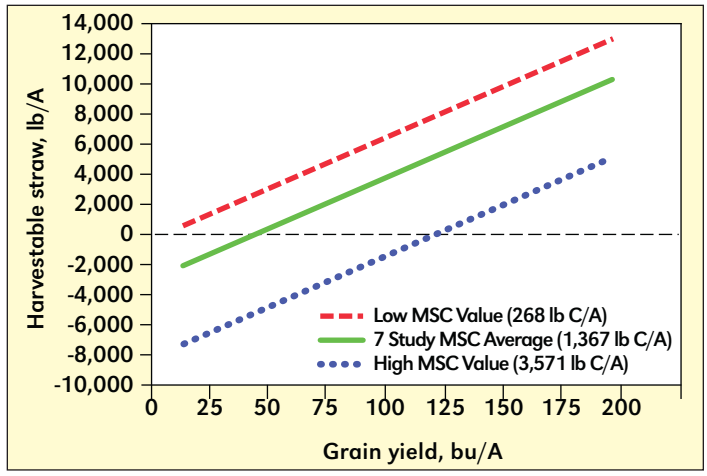

Figure 1. Quantity of annual harvestable wheat straw that maintains SOC (MSC) at a range of grain yields. The solid line represents the average of seven research studies. The dotted and dashed lines represent the upper and lower limits of published information not included in the average line. Specific literature citations used for this study are available from the authors.

Minimum Annual Above-ground Crop Residue Inputs Needed to Maintain SOC

The quantity of C from above-ground wheat residue that needs to be left in the field to maintain SOC levels (MSC) has been previously estimated in rainfed conditions, but this information can be useful for producers making straw-removal decisions from irrigated fields.

Johnson et al. (2006) published the MSC values for wheat production in cropping systems from global literature (**Table 1**). Most of these studies were conducted under rainfed systems in environments where the water supply is variable. With irrigation, plant productivity is generally stabilized at high yield levels, so direct transfer of MSC values between production systems may be only approximate.

We used the MSC values from Johnson et al. (2006) to determine the amount of wheat residue that could be harvested at a range of grain yields while maintaining SOC (**Figure 1**). The middle line represents the average of seven studies that indicated the need for an annual input of 1,367 lb C/A to maintain steady state SOC. Using this line, to maintain SOC, no straw should be removed unless grain yield exceeds 46 bu/A. At a grain yield of 100 bu/A, over 3,500 lb straw/A could be removed without depleting SOC. The dotted and dashed lines indicate the extreme values obtained from the literature. More details on the calculations and methodology are available from the authors.

Table 2. Average nutrient content of wheat and barley straw. Values based on multiple sources.

Crop	N	P_2O_5	K_2O
	lb/ton		
Wheat	16.2	2.4	20.6
Barley	12.8	1.6	33

Table 3. Economic value of nutrients in wheat and barley straw based on low and high fertilizer prices occurring from 2001 to 2008.

Crop	N	P_2O_5	K_2O	Total
	---------- US$/lb ---------			
Low Prices	0.22	0.25	0.14	
	---------- US$/ton ----------			
Wheat	3.56	0.60	2.88	7.05
Barley	2.82	0.40	4.62	7.84
	---------- US$/lb ---------			
High Prices	0.63	0.90	0.47	
	---------- US$/ton ----------			
Wheat	10.21	2.16	9.68	22.05
Barley	8.06	1.44	15.51	25.01

Nutrient Removal

Wheat and barley straw contains valuable plant nutrients, so removing this material from the field will speed nutrient depletion and have economic impacts. The average content of N, P, and K in wheat and barley straw based on several published reports is presented in **Table 2**.

Using average nutrient concentrations and a range of fertilizer prices, the nutrient value of straw ranged from US$7.05 to US$22.05/ton for wheat and from US$7.84 to US$25.01/ton for barley straw (**Table 3**).

Straw removal enhances the rate of nutrient depletion compared to systems where only grain is removed. Straw contains less P and N than grain, but a higher proportion of K. The average straw: grain mass nutrient ratio in wheat is 0.47 for N, 0.26 for P, and 4.12 for K. The straw: grain nutrient ratio in barley is 0.49 for N, 0.35 for P, and 5.04 for K. When both grain and straw are removed from fields, soil nutrient depletion (especially K) is more rapid, compared with harvesting only grain.

Nutrient Value in Straw

Estimating the true value of straw must include the need for additional nutrients in subsequent years. For example, fields high in soil K may not immediately require fertilizer inputs to replace the nutrients removed in straw. But in the long-term, nutrients removed in straw will ultimately require replacement to maintain sustainable yields.

It is more difficult to place a value on N removed in straw. When plant residues remain in the field, many recommendations suggest adding extra fertilizer N to overcome temporary N immobilization. The addition of fertilizer can enhance the rate of SOC accumulation. However, if straw is removed, less N may be needed for the following crop until a new organic matter equilibrium is established.

In farming, there are often rental agreements between tenants and landowners. Tenant farmers may be more concerned with short-term economic costs while the landowner may be more concerned with the long-term economic and sustainability impacts. Both parties need to consider the essential role of plant nutrients when making these decisions.

Complex crop rotations on irrigated land that include wheat and barley may be different from those summarized in this paper. For example, in the Pacific Northwest, small grain rotations commonly include alfalfa, corn, potato, or sugar beet. There is very little data that directly relates to these diverse irrigated rotations and the maintenance of SOC.

Photo by Hans Kok

Large amounts of surplus straw are produced with irrigation.

Summary

Consulted data indicate no negative impact on SOC levels by removing small grain straw under irrigated conditions. However, under rainfed conditions, some above-ground residue is generally needed to maintain SOC levels. Under irrigated, high-productivity conditions, it is likely that higher yield levels provide sufficient below-ground biomass to soils to maintain or gradually increase SOC over time. Significant quantities of nutrients are removed from the field when straw is removed. Producers need to include costs of future nutrient replacement to determine the true value of the straw. BC

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Effects of Different Patterns of Land Use on Status of Heavy Metals in Agricultural Soils

By Shao-wen Huang, Ji-yun Jin, and Ping He

Long-term use of high rates of chemical fertilizers and organic manures in open vegetable fields and field-scale greenhouse vegetable production contributed to the accumulation of Cu and Zn, while changes for other heavy metals were not detected. The contents of total Cu, Zn, and other heavy metals in soils increased with vegetable production history.

Farmers in China use much higher nutrient application rates in their vegetable production systems compared to grain production systems. Long-term and excessive fertilization, especially in the case of P fertilization and organic manure use, can increase the risk for serious heavy metal pollution. Vegetable production within the environment of suburban China can also be easily affected by the waste air, water, and residue from industry, plus exhaust emitted by automobiles. Water and soils in the suburbs have suffered from heavy metal pollution to some extent, which might lead to excessive accumulation of one or several heavy metals, such as Cd, Hg, Cr, As, and Pb in vegetables (Huang et al., 2007).

Less information is available on the effect of long-term use of high rates of chemical fertilizers and organic manures on accumulation of heavy metals in more rural regions, especially in vegetable production areas. The objective of this study was to analyze heavy metal contents and their contamination status in agricultural soils under three typical land use practices to provide scientific basis for improving environmental quality in these agricultural soils and fertilization techniques for high yield and high quality crop production.

Table 1. Environmental Quality Standard for Soils (GB15618-1995; mg/kg, weight of air-dried soil).

Item	Background values of uncultivated soil	The 2nd criterion of Environmental Quality Standard for Soils		
		pH < 6.5	pH 6.5-7.5	pH > 7.5
Cu	35	50	100	100
Zn	100	200	250	300
Cd	0.2	0.3	0.3	0.6
Pb	35	250	300	350
Cr	90	150	200	250
As	15	40	30	25
Hg	0.15	0.3	0.5	1

Source: Xia, 1996.

Rural locations that were a significant distance from suburban areas were selected from 10 counties (or districts or cities) in four provinces or municipalities within the Huabei plain in northern China. The selected land use patterns included open vegetable fields (fields under open air), greenhouse vegetable fields (under large-scale plastic greenhouses), and grain crop fields. Specifically, the experimental regions were Shunyi district of Beijing municipality; Xiqing, Beichen and Wuqing districts of Tianjin municipality; Dingzhou city, Yongnian and

The three land use patterns selected for this study included plastic-covered greenhouse vegetables (lower left and right), open vegetable fields (upper left), and grain crop fields (upper right).

Abbreviations and notes: Cu = copper; Zn = zinc; Cd = cadmium; Pb = lead; Cr = chromium; As = arsenic; Hg = mercury; P = phosphorus.

Table 2. Contents of heavy metals in rural soils under different patterns of land use.

Heavy metal	Item	Open vegetable fields	Greenhouse vegetable fields	Grain crop fields
Cu	Range, mg/kg	9.4-73	12.9-81	6.7-41
	Mean, mg/kg	27.7 a	29.9 a	22.3 b
	C.V., %	46	49	38
	Samples > background levels, %[1]	24	25	11
Zn	Range, mg/kg	28-189	38-223	21-112
	Mean, mg/kg	72 a	82 a	57 b
	C.V., %	54	50	40
	Samples > background levels, %	21	20	7
Cd	Range, mg/kg	0.3-1.1	0.3-1.0	0.2-0.9
	Mean, mg/kg	0.6 a	0.6 a	0.6 a
	C.V., %	29	27	27
	Samples > background levels, %	100	100	100
Pb	Range, mg/kg	13-55	15-57	11-49
	Mean, mg/kg	30 a	29.4 a	28 a
	C.V., %	34	35	32
	Samples > background levels, %	26	20	22
Cr	Range, mg/kg	40-128	44-154	35-121
	Mean, mg/kg	83 a	88 a	79 a
	C.V., %	22	24	28
	Samples > background levels, %	26	52	31
As	Range, mg/kg	3-13	3-10	2-11
	Mean, mg/kg	7 a	7 a	6 a
	C.V., %	30	24	31
	Samples > background levels, %	0	0	0
Hg	Range, mg/kg	0.1-0.3	0.1-0.2	0.1-0.2
	Mean, mg/kg	0.1 a	0.1 a	0.1 a
	C.V., %	40	34	39
	Samples > background levels, %	40	28	29

Means with the same letter are not significantly different at $p < 0.05$.

Yutian counties of Hebei province; Shouguang and Qingzhou cities, and Huantai county of Shandong province.

Three to six sampling areas for each land use practice were selected from each of the 10 investigated regions. Each sampling area was about 20 ha. Composite soil samples from a total of 38 open vegetable fields, 40 greenhouse vegetable fields, and 45 grain crop fields were collected using a stainless steel drill from the soil surface layer (0 to 20 cm) between June 18 and 26, 2007. All soil samples were air-dried and ground through a sieve (2 mm for soil pH and 0.149 mm for heavy metals) prior to analysis. The soils were classified as Eutric Cambisols and Haplic Luvisols (FAO, 1988). Soil pH was 7.6±0.8, 7.2±1.0, and 7.8±0.7 for the open vegetable fields, greenhouse vegetable fields, and grain crop fields, respectively. Production history ranged from 5 to 20 years for the open vegetable fields and greenhouse vegetable fields which were previously cropped to wheat and corn, and the grain crop fields had production histories of over 20 years. The main vegetable crops were cabbage, Chinese cabbage, Welsh onion, and eggplant for the open vegetable fields, while tomato, cucumber, Chinese celery, and watermelon were grown on the greenhouse vegetable fields. The most common grain crops were winter wheat and summer corn.

Information of crop production history, including varieties, rotations, and chemical fertilizer and organic manure use from 2005 to 2007 was collected for all of the soil sampling sites mentioned above. Nutrient application rates for one crop season were averaged from 2005 to 2007. Annual nutrient application rates were considered to be the total amount of the nutrient applied for the first and second crop each year (first and second vegetables in open and greenhouse vegetable fields, and the wheat-corn rotation).

The soil samples were digested using aqua regia (HCl/HNO_3, 3:1 solution)-$HClO_4$ (Lu, 2000), and the concentrations of total Cu, Zn, Cd, Pb, and Cr were measured by atomic absorption spectroscopy. The soil samples were digested by a 1:1 HCl/HNO_3 solution for total As (Lu, 2000) and a 2:1 HCl/HNO_3 solution for total Hg (Fan, 2003), and the concentrations of the two elements were determined by atomic fluorescence spectroscopy. Soil pH was measured in a 2.5:1 water:soil suspension using a glass pH electrode. **Table 1** provides the background values for heavy metals in uncultivated soil and the Environmental Quality Standard for Soils (GB15618-1995) taken as assessment criteria for soil heavy metal status (Xia, 1996).

Significantly higher contents of total soil Cu and Zn were found in open vegetable fields and greenhouse vegetable fields compared to grain crop fields (**Table 2**). However, contents of total soil Cd, Pb, Cr, As, and Hg for open vegetable fields and greenhouse vegetable fields did not differ statistically from levels measured within grain crop fields. Obvious differences were observed for the percentage of soil samples having heavy metals contents beyond the assessment criteria. All samples had Cd contents beyond background values for uncultivated soil, while 60 to

Table 3. Fertilizer application rates (kg/ha/year) averaged from 2005 to 2007 for rural soils under different patterns of land use.

Nutrient	Item	Open vegetable fields	Greenhouse vegetable fields	Grain crop fields
N	Fertilizer	650±350	800±520	440±190
	Manure	230±330	670±580	20±70
	Total	880±370	1,470±830	460±170
P_2O_5	Fertilizer	330±290	730±660	170±90
	Manure	210±290	620±540	20±70
	Total	540±340	1,350±880	190±90
K_2O	Fertilizer	260±200	650±720	90±80
	Manure	160±210	390±330	10±50
	Total	420±250	1,040±880	100±90

Table 4. Contents of heavy metals in rural soils under different vegetable production history.

Heavy metal	Land use pattern	5 to 10 years		11 to 20 years	
		Number of sampling sites	Mean, mg/kg	Number of sampling sites	Mean, mg/kg
Cu	Open[1]	17	22.7±9.1	21	31.7±14.3
	Greenhouse[2]	22	27.6±10.4	18	32.7±18.6
Zn	Open[1]	17	56.5±19.5	21	84.7±45.8
	Greenhouse[2]	22	76.9±38.3	18	89.1±44.6
Cd	Open[1]	17	0.61±0.19	21	0.64±0.18
	Greenhouse[2]	22	0.63±0.19	18	0.65±0.16
Pb	Open[1]	17	29.0±9.1	21	31.6±11.5
	Greenhouse[2]	22	29.2±10.4	18	29.5±10.5
Cr	Open[1]	17	80.6±14.6	21	84.3±21.1
	Greenhouse[2]	22	82.9±19.0	18	94.0±22.8
As	Open[1]	17	6.4±1.4	21	7.2±2.4
	Greenhouse[2]	22	6.6±1.6	18	6.6±1.6
Hg	Open[1]	17	0.12±0.05	21	0.14±0.05
	Greenhouse[2]	22	0.12±0.04	18	0.15±0.05

[1]Open vegetable field; [2]Greenhouse vegetable field.

80% of samples were above the Environmental Quality Standard for Cd. The percentages of soil samples with Cu, Zn, Pb, Cr, As, and Hg contents beyond reported background values were lower, with values ranging between 0 to 53%, and the contents of all six heavy metals were below the Environmental Quality Standard.

Previous reports list the main sources of heavy metal pollution in agricultural soils as effluent of waste air, water, and residue from industry, auto exhaust, sewage irrigation, and the use of agrochemical materials (Zhu and Zhou, 1999; Zheng et al., 2006). In this study, the selected farmlands (which were considerably more rural), were observed to not be affected by the list of pollution sources above, and no sewage irrigation was found within these experimental regions. Since heavy metals can naturally occur within some P fertilizers, and relatively high contents of Cu, Zn, and other heavy metals occur in organic manures (Nicholson et al., 2003), continuous and combined use of these nutrient sources at high application rates can lead to the accumulation of heavy metals in agricultural soils. Application rates of N, P_2O_5, and K_2O from fertilizer and manures varied considerably with each cropping system, but were noted to be much higher in the selected open vegetable and greenhouse vegetable fields compared with grain crop fields (**Table 3**). Average respective total application rates for the bare vegetable, greenhouse vegetable, and grain crop fields were 882, 1,474, and 455 kg/ha/year for N with 26%, 46%, and 4% of each total originating from manure; 538, 1,349, and 188 kg/ha/year for P_2O_5 with 38%, 46%, and 8% coming from manure; and 416, 1,036 and 103 kg/ha/year for K_2O with 38%, 37%, and 12% coming from manure, respectively. The significantly higher accumulation of soil Cu and Zn for open vegetable and greenhouse vegetable fields in this study are likely a result of both higher application rates from fertilizers and manures, as well as higher proportions of manure application in these systems. However, vegetable production history is also a significant factor. Contents of total soil Cu, Zn, Cd, Pb, Cr, As, and Hg (especially Cu and Zn), increased with vegetable production history (**Table 4**). Under production histories between 5 to 10 years and 11 to 20 years, the respective total soil Cu contents were 22.7 and 31.7 mg/kg for open vegetable fields, and 27.6 and 32.7 mg/kg for greenhouse vegetable fields. Similarly, total soil Zn contents for the two production history ranges were 56.5 and 84.7 mg/kg for open vegetable fields, and 76.9 and 89.1 mg/kg for greenhouse vegetable fields.

These data indicate that soil Cd in all three land use patterns is a potential threat to the food production chain. Although the contents for the remaining six heavy metals were below recognized soil assessment criteria, trends suggest that current vegetable management practices are significantly affecting soil Zn and Cu under both vegetable production systems. BC

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Dr. W.R. Raun Selected as Nutrients for Life Foundation Professor at OSU

The Oklahoma State University (OSU) A&M Board of Regents recently approved the appointment of Dr. William R. Raun to the post of Nutrients for Life Foundation Professor of Soil and Crop Nutrition. The professorship was established in 2008 through a matching funds arrangement backed by oil and energy executive T. Boone Pickens, an OSU alumnus. The announcement came from Dr. Robert E. Whitson, Vice President, Dean, and Director of the OSU Division of Agricultural Sciences and Natural Resources.

The International Plant Nutrition Institute (IPNI) joined with the Nutrients for Life Foundation (NLF) and The Fertilizer Institute (TFI) in providing monetary gifts totaling US$250,000 to the university. Those funds were matched by Pickens' Commitment. In turn, the Oklahoma State Regents for Higher Education will match the US$500,000 for a total impact of US$1 million in endowed funds.

"Dr. Raun's professorship will allow exploration of linkages between fertilizer use and food nutritional quality. The three sponsoring organizations hope to advance understanding of how nutrients can be managed to optimize the nutritional content of food while also supporting high yields needed for a sufficient and affordable food supply," explained IPNI President Dr. Terry L. Roberts.

In his 7 years at CIMMYT and 18 years at OSU, Dr. Raun has an impressive list of accomplishments in teaching, research, and extension. He has over 144 refereed publications, six patents, over 300 additional scholarly works, 54 graduate students completed, recognition as Fellow by two professional societies, and numerous other achievements.

Dr. Bill Raun was named Nutrients for Life Foundation Professor of Soil and Crop Nutrition in July 2009.

"This professorship will allow us to more fully extend the environmentally sensitive and cost-effective GreenSeeker sensing technology that was developed at OSU," Dr. Raun stated. "We currently have ongoing field projects in Zimbabwe, Kenya, Ethiopia, Afghanistan, and Mexico where third-world farmers have realized increased production and profitability by using our nitrogen recommendations for cereal production." BC

For more about Dr. Raun's recent programs and collaborative projects, visit this website: http://nue.okstate.edu/

Conversion Factors for U.S. System and Metric Units

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
0.159	kg/ha	bu/A, corn (grain)	62.7
0.149	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.

Plant Nutrition Stewardship: Science and Ethics

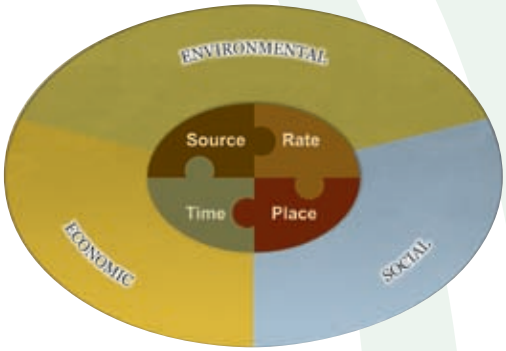
Stewardship involves both science and ethics. A recent Bouyoucos Conference sponsored a small group of scientists and philosophers to meet in Nebraska to discuss the topic "Soil Stewardship in an Era of Climate Change." They focused their discussion on three areas: ethics, sustainability, and communication. The goal was to integrate these areas to come up with practical advice for applying science to soils.

Scientists are often uncomfortable talking about ethics. Ethics depend more directly on beliefs and values than on the observable facts, testable hypotheses, and logical conclusions that form the mainstay of science. Nevertheless, this group agreed that the choice for science as a career is often ethically motivated, and that ethics play a role in both the conduct and application of science.

An ethic is a belief about the value something holds and proper conduct towards it. Ethical arguments are normative—dealing with what ought to be—but include rational and logical premises as well. Facts and causal relationships do not determine what ought to be, but we need to know them in order to specify ethical behavior, guidelines, and goals.

Sustainability is an example of an ethical goal. It can be motivated by concern for future generations, or by beliefs about the value of the natural environment. Soil faces sustainability challenges, including erosion and other forms of degradation, not just from existing practices, but also from future changes in climate.

The four "rights" of plant nutrition stewardship also have an ethical component. There is a moral value judgment to choosing the right nutrient source, metering out the right rate at the right time and in the right place. The value judgment is based on how this combination of actions meets sustainability goals. These goals are determined, not by science, but by scientifically-informed people who apply their beliefs and values to choose targets for outcomes. For example, in a setting where a pre-plant application of nitrogen optimizes yield but results in excess groundwater nitrate, a stewardship approach would seek a management strategy (perhaps split-application, perhaps a controlled-release source, perhaps a technology yet to be developed) that both optimizes yield and limits nitrate loss to groundwater. If these benefits are understood by the stakeholders, support for changes in technology should be easier to obtain.



Setting sustainability goals involves science communication. Many scientists feel their work is not adequately understood or appreciated, and is not appropriately used in development of policy, regulation, and practical recommendations. Science can help define the right management to achieve particular sustainability goals, but scientists must recognize the ethics, beliefs, and values of their audience to meaningfully engage public dialogue on such goals. Cal DeWitt, Professor, University of Wisconsin, described the situation in this way: "Plant and soil scientists, agronomists, and agricultural extension agents—together with farmers, gardeners, and every person on earth—are in a continual, sustained, and interactive relationship with plants and soils." Science not only pulls out the facts and describes cause and effect, but also builds appreciation for the complexity and beauty of ecosystems, both natural and managed.

Can we improve our sustainability ethic? Codes of ethics for professional crop advisers, agronomists, and soil scientists often emphasize ethical behavior in terms of the interest of the client. But they also include the interest of the public, which extends to sustainability and therefore, sustainability ethics. Can we more clearly define a professional ethic for the conservation, renewal, and improvement of the resources involved in plant nutrition, including soil, water, air, nutrient supplies, and plant genetics?

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