The Role of Fertilizer in Growing the World's Food

By T.L. Roberts

According to the United Nations (UN), the global population of 6.7 billion is expected to reach 9.2 billion by 2050. The Millennium Project and its State of the Future (2008) report indicated that food production will have to increase by 50% by 2013 and double in 30 years to help solve the current food crisis. This increased food production will have to occur on less available arable land and this can only be accomplished by intensifying production. However, intensifying production must be done in an environmentally safe manner through ecological intensification. The goal of ecological intensification is to increase yield per unit of land, approaching the "attainable yield" of farming systems, with minimal or no negative environmental impact.

The world will not be able to meet its food production goals without biotechnology and improved genetics, and without fertilizer. Commercial fertilizer is responsible for 40 to 60% of the world's food production. Our responsibility is to develop and employ management practices that use fertilizer effectively and efficiently. This article explores the role of fertilizer in producing the world's food and associated best management practices (BMPs) that help ensure production and environmental goals are met.

Early in 2008, the world was focused on the food crisis. A doubling of rice, wheat, and maize prices in early 2008 sparked food riots in poor nations and caused some countries to impose limits on crop exports. The food crisis resulted in the Food and Agriculture Organization of the UN (FAO) convening a "High-Level Conference on World Food Security" in Rome where governments and other organizations from 185 countries met to discuss the challenges that climate change, bioenergy, and food prices caused to world food security. By midyear, global attention had shifted from food security to credit as food prices declined and the financial crisis emerged. However, the food crisis has not subsided, but the sense of urgency associated with it has given way to the global recession.

The number of undernourished people in the world reached an estimated 923 million in 2007, up from 848 million in 2003-05 and from the 1990-92 World Food Summit baseline of 842 million (FAO, 2008a). About 98% of the chronically hungry are in the developing world. The world was making progress towards the Millennium Development Goal to halve hunger by 2015. The proportion of undernourished people steadily declined from the baseline of 20% in 1990-92 to 16% in 2003-05, but by the end of 2007 the trend had reversed and we were no longer making progress.

FAO estimates that 37 countries are facing a food crisis. The "Millennium Project 2008 State of the Future" report attributes the food crisis to increased demand for food in developing nations, high oil prices, biofuels, high fertilizer prices, low global cereal stocks, and market speculation (Glenn et al. 2008). Food security is one of the great challenges facing humanity. With the current world population of 6.7 billion expecting to reach 9.2 billion by 2050, the 2008 State of the Future report suggests that food production has to increase by 50% by 2013 and double in 30 years. The report's authors identify better rain-fed agriculture and irrigation management, genetic engineering for high yielding crops, precision agriculture, drought-tolerant crops, and several other factors required for new agricultural approaches as critical long-term strategies to feed the world, but they say little of the role of fertilizer.

Many believe that plant biotechnology holds the key to producing more food. The genetics and biotech industries have assured us they can deliver increased yields, promising leaps in genetic yield potential of 3 to 4 % per year (Fixen, 2007; Jepson, 2008). Monsanto, the world's largest seed company, promised to develop new varieties of corn, soybeans, and cotton by 2030 that will yield twice as much grain and fiber per acre while using two-thirds the water (Monsanto, 2008). These kinds of technological advances will be required if we hope to feed the world's hungry. However, history suggests genetic advances alone may not be able to solve the world's food shortage. For example, Cassman and Liska (2007) point out the 40-year trend for maize (corn grain) yields in the USA has been linear, with an annual increase of 112 kg/ha or a 1.2% relative gain compared to the current 9.2 t/ha yields. This 1.2% annual yield increase has been supported by the introduction of hybrids, expansion in irrigation, conservation tillage, soil testing, and balanced fertilization, plus the introduction of transgenic insect resistant "Bt" maize. If the genetics industry can deliver on the promised yield increases and if that genetic potential can be converted into more yield, nutrient consumption will increase significantly. Going forward through 2020, Fixen (2007) estimated the extra production from a 3% annual increase in maize yields in the USA would require an additional 18% N, 21% P, and 13% K compared to average fertilizer use from 2004 to 2006.

Future increases in food production will have to occur on less available arable land, which can only be accomplished by intensifying production. And, it must be done in an environmentally safe manner through ecological intensification. The goal of ecological intensification is to increase yield per unit of land, i.e. intensify production, while meeting acceptable standards of environmental quality (Cassman, 1999).

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

World Fertilizer Situation

Food supply and inflation and fertilizer prices made headline news at the beginning of 2008. Such media attention has made politicians and the general public more aware of the fertilizer industry than ever before. World fertilizer consumption increased steadily from the early 1960s through the mid 1980s and then declined through the mid 1990s before starting to rise again (**Figure 1**). Since 2001, N use has grown by 13%, P_2O_5 by 10%, and K_2O by 13%. Global cereal production and fertilizer consumption are closely correlated (**Figure 2**).

Fertilizer is a world market commodity subject to global supply and demand and market fluctuations. This past year saw unprecedented demand for fertilizer and record prices (**Figure 3**). World price for fertilizer remained relatively constant from 2000 through 2006, but in 2007 prices started to escalate. Prices peaked in September and October of 2008 before declining in December. Fertilizer prices increased so dramatically for a variety of reasons (TFI, 2008; IFA, 2008). Rising global demand and a shortage of supply was the major driving force in price increases. Other factors putting pressure on fertilizer prices included: increasing ethanol production, higher transportation costs, a falling US dollar, strong crop commodity prices, and some countries curbing fertilizer exports.

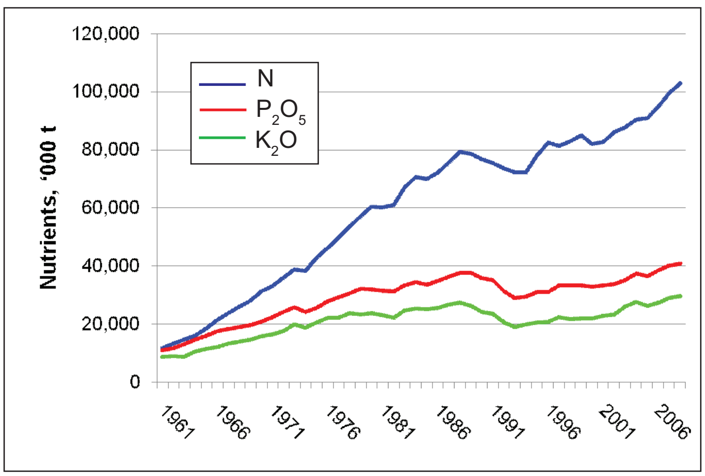

Figure 1. World consumption of N, P_2O_5, and K_2O (IFA Statistics 2007).

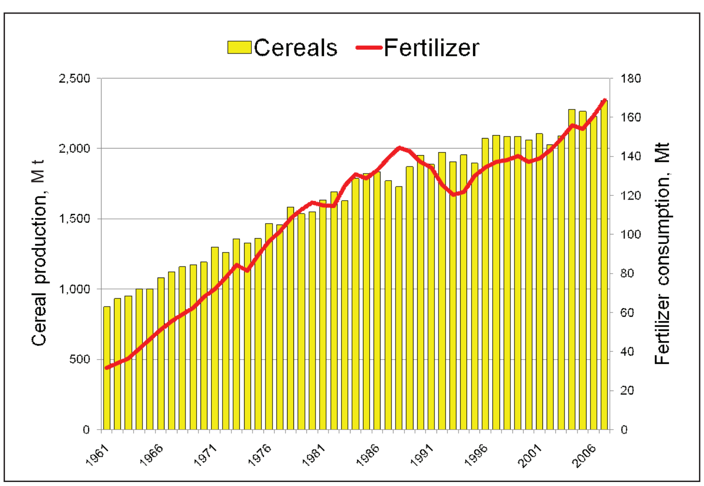

Figure 2. World cereal production and fertilizer production, 1961-2007 (IFA Statistics, 2007; FAOSTAT, 2008).

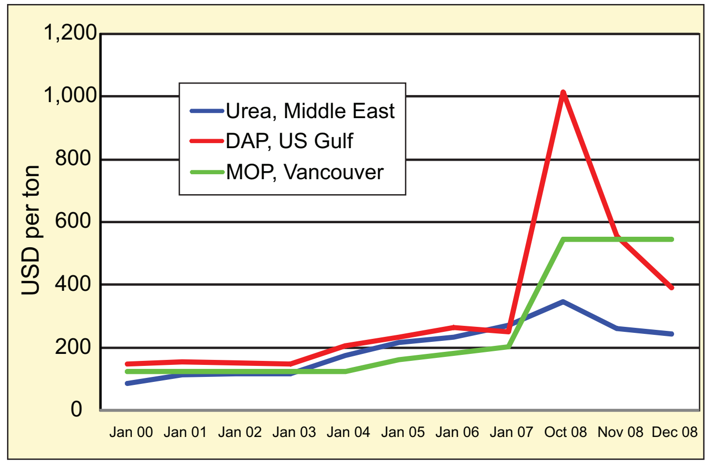

Figure 3. World fertilizer prices, monthly averages from January 2000 to December 2008 (Pike & Fischer, Green Markets).

Despite the recent volatility in the fertilizer market, demand is expected to remain strong. Solid economic growth in many developing countries has resulted in more money available to improve nutrition and human diets are shifting from low-protein, starch-based foods to more animal-based protein. The developing world still lags behind the developed world in meat consumption, but people are making the shift towards more meat. Since 1995, meat consumption in the developing world has increased by 16% and in China it has increased by almost 40%. Increasing demand for meat protein means greater demand for feed grains. Demand for feed grain is projected to double between 1995 and 2020 to 445 million metric tons (M t), while cereals for food consumption are projected to increase by 40% to 1,013 M t (Pinstrup-Andersen et al., 1999). World ethanol and biodiesel production is projected to continue to increase over the next decade (FAPRI, 2008). World cereals stocks have been declining and continue to be low despite a record cereal harvest in 2008 (FAO, 2008b). Crop yields for rice, maize, and soybeans in China, India, and Brazil continue to lag behind the USA, which presents a great opportunity to increase yields with better genetics, improved nutrient management, better water use efficiency, and other BMPs.

In May 2008, the International Fertilizer Industry Association (IFA) forecast total fertilizer demand to increase by an average of 3.1% per annum over the next 5 years (**Table 1**). However, the fertilizer industry was not isolated from the global financial crisis in the latter part of 2008, and as a consequence, consumption in the second half of 2008 was down.

Table 1. Medium-term global fertilizer consumption forecasts to 2012/13.

	Consumption, M t			
	N	P_2O_5	K_2O	Total
Ave. 2005/06 to 2007/08 (e)	95.8	38.6	27.6	162.1
2012/13 (f)	115.6	45.7	33.0	194.3

Heffer, 2008a
e = estimated; f = forecast

Later in the year, IFA adjusted their short-term forecast downward for the 2008/09 fertilizer season (**Table 2**). Nitrogen use is forecast to increase slightly by 0.5%, but P and K fertilizer use is expected to be down 4.6 and 8.3%, respectively, compared to 2007/08. However, global consumption is expected to recover in the 2009/10 season, with each nutrient expected to increase by at least 3% compared to this year.

Table 2. Short-term global fertilizer consumption forecasts to 2009/10.

	Consumption, M t			
	N	P_2O_5	K_2O	Total
2007/08 (e)	100.5	39.3	28.9	168.7
2008/09 (f)	101.1	37.5	26.5	165.0
2009/10 (f)	104.5	38.8	27.5	170.9

Heffer, 2008b

Contribution of Fertilizer to Cereal Production

Commercial fertilizer is necessary to maintain global crop productivity at current levels and will be even more crucial if yields are to be increased. In many countries fertilization is inadequate and unbalanced, which limits the expression of yield potential and negatively impacts crop quality. Even if the biotechnology industry can deliver on their promise to increase crop yields through genetics and improve nutrient uptake efficiency, fertilizer is still critical to avoid depletion of soil nutrients and ensure soil quality.

It is difficult to determine exactly how much crop yield is due to the use of commercial fertilizer because of inherent soil fertility, climatic conditions, crop rotations, management, and the crop itself. Some crops (e.g. legumes) are not responsive to N fertilization and crops differ in their nutrient requirements. Nevertheless, meaningful estimates of the contribution of commercial fertilizer to crop yield have been made using omission trials and long-term studies comparing yields of unfertilized controls to yields with fertilizer. Stewart et al. (2005) reviewed data representing 362 seasons of crop production and reported at least 30 to 50% of crop yield can be attributed to commercial fertilizer inputs. A few examples will be cited here.

Table 3 shows the impact of omitting N fertilizer on several cereal crops in the USA. Without N, average maize yields declined 41%, rice 37%, barley 19%, and wheat 16%. Eliminating N from soybeans and peanuts (both leguminous crops) had no effect on yield (data not shown). Had the authors measured the effect of eliminating P and K, the reductions were expected to be even greater.

Table 3. Estimated effect of omitting N fertilizer on cereal yields in the USA.

	Estimated crop yield, t/ha		% reduction
Crop	Baseline yield	Without N	from no N
Maize	7.65	4.52	41
Rice	6.16	4.48	27
Barley	2.53	2.04	19
Wheat	2.15	1.81	16

Stewart et al., 2005

The Magruder Plots, established in 1892 in Oklahoma, are the oldest continuous soil fertility research plots in the Great Plains region of the USA. Nutrient treatments have changed since the plots were established, with annual N (37 to 67 kg/ha) and P (15 kg/ha) applications starting in 1930. Averaged over 71 years, N and P fertilization in these plots was responsible for 40% of wheat yield (**Figure 4**).

The Sanborn Field at the University of Missouri was started in 1888 to study crop rotation and manure additions. Commercial fertilizer was introduced in 1914. Although application rates have varied over the years, comparing the plots receiving N, P, and K fertilizer to the unfertilized control showed that fertilizer contributed to an average of 62% of the yield of the 100-year period (**Figure 5**).

The Broadbalk Experiment at Rothamsted, England, has the oldest continuous field experiments in the world. Winter wheat has been grown continuously since 1843. Application of N fertilizer with P and K over many decades has been responsible for 62 to 66% of wheat yield compared to P and K applied alone (**Figure 6**). From 1970 to 1995, growing high-yielding winter wheat continuously receiving 96 kg N/ha, omitting P decreased yield an average of 44% and omitting K reduced yields by 36%.

These three long-term studies from temperate climates clearly show how essential fertilizer is in cereal productivity, accounting for at least half of the crop yield. Fertilizer is even more critical to crops in the tropics where slash and

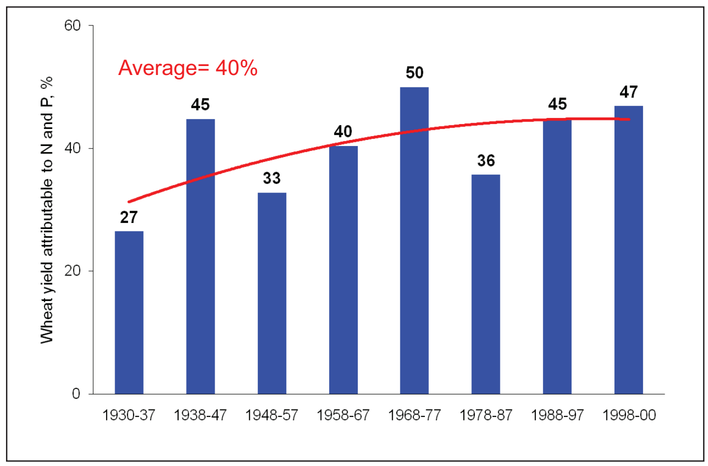

Figure 4. Wheat yield attributable to N and P fertilizer in the Oklahoma State University Magruder plots, 1930-2000 (Stewart et al., 2005).

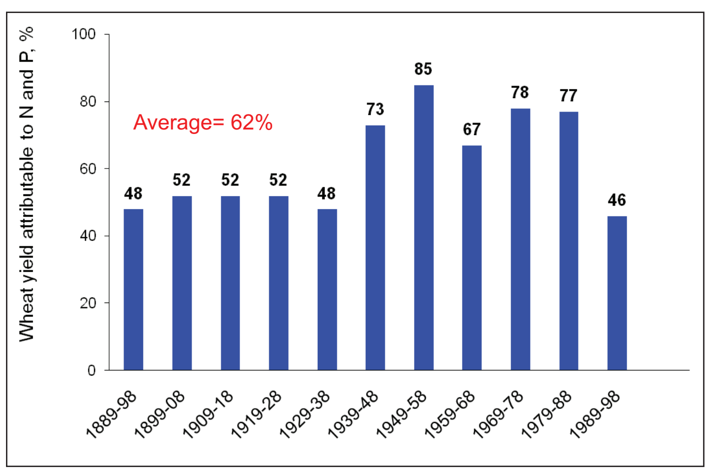

Figure 5. Wheat yield attributable to fertilizer, in the University of Missouri Sanborn Field plots, 1889-1998 (Stewart et al., 2005).

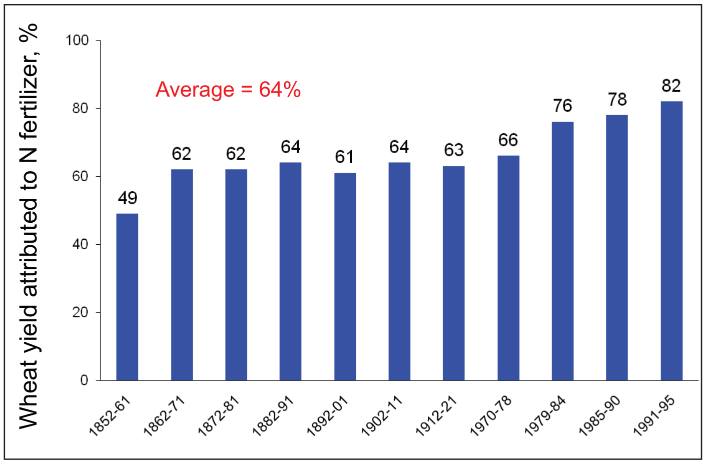

Figure 6. Wheat yield attributable to N fertilizer with adequate P and K compared to P and K alone in the Broadbalk experiments in Rothamsted, England, 1952-1995 (Stewart et al., 2005).

burn agriculture devastate inherent soil fertility. Stewart et al. (2005) refer to examples of continuous grain production in the Amazon Basin in Brazil and in Peru, where fertilizer applied the second year after slash-and-burn clearing was responsible for 80 to 90% of crop yield.

Fertilizer Best Management Practices

With the recent media attention directed to the fertilizer industry as a result of the food crisis and public recognition that fertilizer is part of the solution to world food security, it is incumbent on the industry to do everything practical to ensure fertilizer is used responsibly and efficiently. Fertilizer BMPs are intended to do that — to match nutrient supply with crop requirements and minimize nutrient losses from fields. The approach is simple: apply the correct nutrient in the amount needed, timed and placed to meet crop demand. Applying the 4Rs — right source (or product), right rate, right time, and right place is the foundation of fertilizer BMPs (Roberts 2007).

IPNI has developed a global framework describing how the 4Rs are applicable in managing fertilizer around the world (Bruulsema et al. 2008). Fertilizer management is broadly described by the four "rights", however, determining which practice is right for a given farm is dependent on the local soil and climatic conditions, crop, management conditions, and other site-specific factors. The purpose of IPNI's framework is to guide the application of scientific principles to development and adaptation of global BMPs to local conditions, while meeting the economic, social, and environmental goals of sustainability.

Summary

Global demand for fertilizer remains strong. A growing population with the desire and means to improve their diet will ensure fertilizer consumption will continue and will increase. Meeting the world's escalating food needs cannot be achieved without fertilizers. Without fertilizer, the world would produce only about half as much stable foods and more forested lands would have to be put into production. Inorganic fertilizer plays a critical role in the world's food security. It cannot be replaced by organic sources…although where available, organic nutrient sources should be utilized…but fertilizer must be used efficiently and effectively. The 4Rs — right source, right rate, right time, and right place — are the underpinning principles of fertilizer management and can be adapted to all cropping systems to ensure productivity is optimized. BC

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