BIOFUELS AND NUTRIENT MANAGEMENT

Paul E. Fixen
International Plant Nutrition Institute, Brookings, SD
pfixen@ipni.net (605)692-6280

ABSTRACT

Few developments have had as dramatic or rapid an impact on crop production as did grain-based ethanol on corn in 2006 and 2007. In response to strong market signals, corn acreage in the U.S. in 2007 jumped from a three-year average of 80 million acres to nearly 93 million, an increase of more than 15%. Secondary effects on prices of other commodities soon followed. Nutrient demand increased as well as the cost of many inputs needed for crop production. The purpose of this paper is to evaluate the impact of biofuels in general on nutrient management now and in the near future and the impact of nutrient management on the future of biofuels. The discussion will be divided into three major sections: 1) consideration of the context of the expansion of biofuels including historical, concurrent agronomic changes, and the contemporary issues associated with nutrient use; 2) the consequences of increased crop and nutrient demand and; 3) the implications for agronomic research and education.

BIOFUELS IN CONTEXT

"*Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with beauty. Abuse it and the soil will collapse and die taking man with it.*" This quote is attributed to the Sanskrit literature from between 2000 and 1500 BC (Johnston and Dawson, 2005). It is an indicator of the ancient history of biofuels and a clear reminder that agriculture as a source of fuel is far from a new concept. However, the advent of new technology coupled with a desire to reduce dependence on imported oil and intensification of concern over climate change, has us in the midst of a modern day agricultural revolution. This ancient quote also reminds us of the importance of resource stewardship as agriculture strives to capitalize on the opportunities biofuels provide.

The explosive growth of biofuels comes at a time of myriad changes impacting crop production and nutrient management. Among these changes are:

- New biofuel crops (or new geographic areas for old crops). The nutrient needs of these crops and cycling aspects when intensively managed for high yields are often poorly defined.
- Varieties with end-use specific traits that could alter nutrient relationships. For example, will a low protein corn hybrid developed for biofuel differ in nutrient needs from feed corn?
- Climate change. Evidence is strong that climate in many agricultural regions is undergoing change and is likely to change further. The consequences for crop nutrient demand, soil nutrient supply, nutrient losses, and fertilizer effectiveness are not known but are the subject of research. An excellent global review on this subject has been recently completed by Brouder and Volenec (2007).

- Genetic improvement in protection from multiple pests, drought stress tolerance, and nutrient use efficiency. The seed industry has promised substantial changes that could alter how nutrients are managed both directly and indirectly. It appears unclear as to whether these changes alter yield produced per unit uptake or recovery of nutrients from the soil profile. Also unclear is whether the net effect of these changes will alter optimum nutrient rates.
- Advances in fertilizer sources, nutrient sensing, and application technology. These technologies show promise for improving yields while reducing nutrient losses from the field. Several papers will be presented on these topics during this conference.

Considering these changes in the genetics of the crops to be grown, the climate in which they will be grown, and the technology available for growing them, future fertilizer best management practices (BMPs) could be different than in the past. How does one know? One learns through production research designed appropriately to address system-level interactions at high yield levels (relative to site-specific yield potential) and high nutrient use efficiency. These changes may lead us to approaches that are more measurement-based rather than historical since past performance in a specific region many not reflect future performance. We have entered a new age where such "ecological intensification" research needs high priority. The sustainability of biofuels will likely depend on this research … more on that later.

Figure 1. A multitude of economic, environmental, and social issues involving crop nutrients.

Food supply and costs	Reducing & responding to global warming	Coastal hypoxia
Fertilizer costs & security	**Biofuels**	Fresh water eutrophication
African food crisis	Food quality	Air quality
Organic agriculture	Conserving natural lands	Biodiversity in natural eco-systems

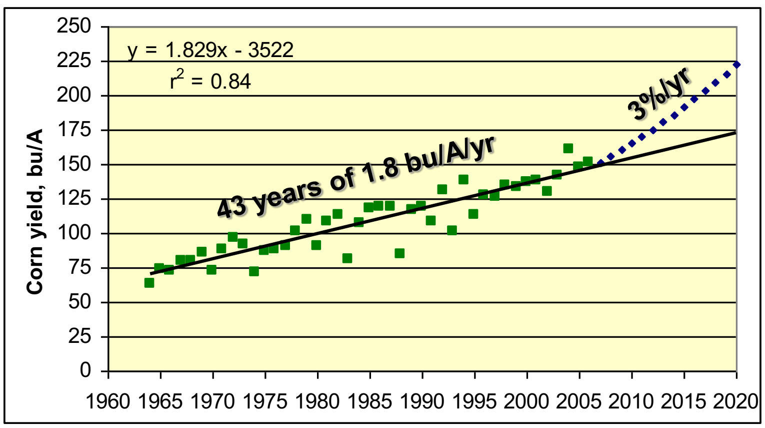
The context of biofuels is also defined by the economic, environmental, and social issues involving crop nutrients. Figure 1 is a matrix of 12 issues that have some connection to nutrient use and that are often part of the global debate over the appropriate future of biofuels. Through these issues, biofuels and nutrient management are intricately linked. Society's acceptance of an expansion of the role of agriculture to include bioenergy, will depend at least in part on the real or perceived impact of that expansion on these issues. Thus, the "quality" of nutrient management may very well impact the future of biofuels and biofuel crops.

CONSEQUENCES OF INCREASED CROP AND NUTRIENT DEMAND

The corn grain requirement for ethanol production in the U.S. is estimated to grow from its current level of around 2.5 billion bushels to nearly 4 billion bushels by the 2011 crop year or about 30% of total U.S. corn grain production (Fairchild, 2007). At an international scale, Ken Cassman recently modified the Food Policy Research Institute predicted increase in global demand for corn, rice and wheat from 1995 to 2025 to include use of 5% of global grain supply for biofuels and bio-based industrial feedstocks in 2025. The result was a predicted increase in demand of 1.56% per year. This exponential increase in demand becomes more meaningful when it is compared to the actual global linear rates of yield increase for corn, rice, and wheat from 1966 to 2004 of 61, 54, and 41 kg/ha respectively or 1.24, 1.36, and 1.42% proportional rates of gain based on 2004 yields (Cassman, personal communication).

So, a significant consequence of biofuels expansion is a contribution to a situation where crop demand is predicted to increase faster than crop yields with a resulting reduction in global grain stocks unless historical yield trends are altered or more land is brought into production. Since the global supply of additional land "acceptable" for grain production is generally limited and since acreage shifts among major commodity crops, as occurred with U.S. corn in 2007, are over time buffered by crop price reaction, the need to increase crop yields faster than in the past is very real. A recent CAST commentary called for policies and national goals for increasing overall capacity of crop production systems (Fales et al., 2007).

Figure 2. Genetic improvement in corn yields promised by the seed industry.



This production-encouraging market comes at a time when the seed industry is promising leaps in yield potential of 3% per year (Fitzgerald, 2006). The significance of this projection can be better appreciated by considering the history of yield improvement. In spite of the tremendous technological advances in corn production systems in the U.S. over the last 43 years, corn yield has increased at a linear rate of 1.8 bu/A/yr, following the global trends mentioned earlier (Cassman, et al., 2006). Figure 2 shows what a 3% annual rate of increase looks like projected out to 2020 (Fixen, 2007). If the seed industry can deliver on the promised increased genetic potential, and if agronomic researchers, educators, crop advisers, and growers can convert that genetic potential into bushels in the bin, we will indeed be in the midst of a revolution, not experienced since the hybridization of corn.

Another consequence of increased crop demand has been an increase in feed grain prices to the livestock industry. In response to this concern in March of 2007, Collin Peterson, Chair of the House Agriculture Committee noted "What people fail to realize is that over the last number of years corn prices have been below the cost of production, and the livestock industry has benefited from this. What's going on now is that we are repricing agriculture because we have a new opportunity, a new market in agriculture."

The increased value of agriculture Mr. Peterson refers to is an important consequence of biofuels not only to the developed world, but also to the developing world where it translates into improved economic growth, especially in rural areas. It some cases, is has created profit opportunities where none existed. For example, IPNI's Northern Latin America program has been coordinating a site-specific nutrient management study on corn in Columbia. Dr. Jose Espinosa, the regional director, reported recently, "Interestingly enough, when we started this project we had a lot of criticism for working in a crop without a future, but suddenly, the situation has changed radically due to the ethanol issue and the lack of corn surplus from the US. Now the countries in the region need to grow their own corn, prices are a lot better and finally corn growers can be profitable."

However, the negative consequences of this increased value of agriculture and the associated increased cost of agricultural products, includes the potential for higher food prices to increase malnutrition, pressure to increase yields without ecologically sound crop and soil management practices, and pressure to expand crop production into marginal or natural lands (Cassman and Liska, 2007). The extent to which these potential negative impacts are realized will be greatly influenced by the rate at which crop yields are increased.

Table 1. Reference points for the potential impact of biofuels on fertilizer use in U.S. (updated from Fixen, 2007)

	1000 tons			% of annual U.S. fertilizer (04-06)		
Ethanol source	**N**	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Corn grain - 10 mil ac from soy[1]	934	158	134	7.6	3.5	2.6
Corn grain - 3 mil ac from cotton[1]	95	30	14	0.8	0.7	0.3
10 refineries - stover (10 mil tons)[2]	80	29	200	0.6	0.6	3.9
Bioenergy crops, 10 mil ac, 6 t/A[3]	550	134	690	4.5	2.9	13.5
Total	**1659**	**351**	**1038**	**13.5**	**7.7**	**20.3**

[1] Net increase in fertilizer use. [2] Nutrient removal; represents 16% of sustainably collectable stover based on 1995-2000 production with no change in tillage (Graham et al., 2007). [3] Crops like switchgrass or Miscanthus; 50% of removal for P and K; 110 lb N/A.

The direct consequence of increased corn demand on nutrient use in the U.S. in 2007 and the future potential impact of cellulosic biofuel production are estimated in Table 1. The shift to corn acreage meant substantial increases in use of all three major crop nutrients assuming farmers continued to fertilize the new corn acres as they did in the past based on USDA-ERS estimates of historical nutrient use on crops. Estimates of the impact of cellulosic production on nutrient use are much more uncertain since no commercial scale refineries are in operation, the mix of feedstocks that will eventually be used is unknown, and the nutrient content of the material actually leaving the field could vary markedly. However, some basic reference points are provided as an illustration of the potential impact.

Increased crop and associated nutrient demand has generally been viewed positively by crop producers and by suppliers of crop inputs and services. However, public reaction has not been so positive. A collection of news headlines from 2007 follow.

- "Corn Ethanol: More Water Pollution"
- "Ethanol surges in spite of questions about demand, environment, food"
- "More Ethanol Means More Corn – and More Water Pollution"
- "Erosion: Drive to increase corn acres could damage soil"
- "Maize of Deception: How Corn-Based Ethanol Can Lead to Starvation and Environmental Disaster"
- "Biofueling water problems"
- "Kill king corn"

There is no question that crop production is under great scrutiny today with the expectation that production cannot be increased to meet biofuel demand without negatively impacting the environment or disrupting domestic and international food supplies. We're under the magnifying glass where factors such as nitrate concentration in water, the extent of the hypoxic zone, greenhouse gas emissions, air quality and food prices will be the focus. And, whether real or perceived, negative movement in indicators of these factors will likely be attributed to agriculture's venture into biofuels.

The addition of biofuel crops to agriculture's portfolio mandates substantial gains in productivity per unit area of many crops. Those gains in productivity must be accompanied with a reduction in the size of agriculture's environmental footprint if biofuels are to be accepted by society. Failing to take this challenge seriously will likely lead one day to headlines about the "misadventure" of biofuels and the loss of a tremendous opportunity for agriculture. Nutrient management is in many cases the linchpin connecting productivity gains with acceptable environmental impact. Nutrient BMPs are in turn the working elements that comprise the nutrient management linchpin.

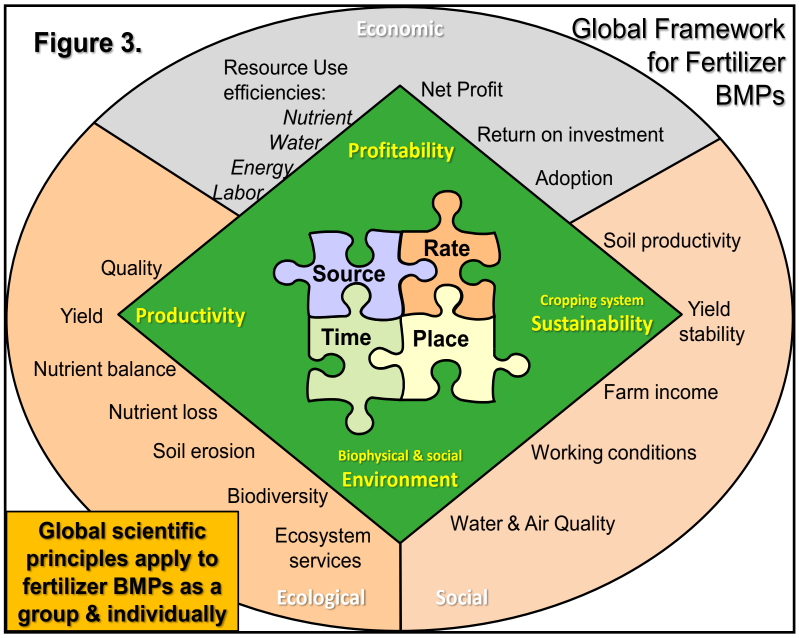


Figure 3.

A major consequence of biofuel-induced increased demand for crops is an elevated importance of nutrient BMPs. Implicit in this statement is the need for BMPs to indeed be "best" practices considering site properties, available technologies, and management objectives; and that those practices are in fact in use. An international working group within IPNI, in cooperation with an IFA Task Force, has been working on a global framework for farm-level fertilizer BMPs to facilitate their refinement and adoption (IPNI, 2007). The framework is shown schematically in Figure 3 and has as a backdrop the economic, ecological, and social goals of sustainable development. The framework guides the application of scientific principles to determine which BMPs can be adapted to local conditions at the practical level.

At the practical level, cropping systems are managed for multiple objectives involving productivity, profitability, system sustainability, and the biophysical and social environment. Best management practices are those that most closely attain those objectives. Management of fertilizer use falls within a larger agronomic context of cropping system management. A framework is helpful for describing how BMPs for fertilizer use fit in with those for the agronomic system. Fertilizer use BMPs can be aptly described as the selection of the right source for application at the right rate, time and place.

At the perimeter of the cropping system diamond in Figure 3 are examples of performance indicators that reflect the influence of fertilizer BMPS on all four crop management objectives. The framework is helpful in ensuring that the suite of indicators chosen provides a balanced reflection of the four objectives, in harmony with sustainable development goals. Agriculture's expansion into biofuels makes measurement and tracking of these balanced performance indicators more important than ever as we strive to improve the quality of nutrient management while communicating performance to local, regional and global communities.

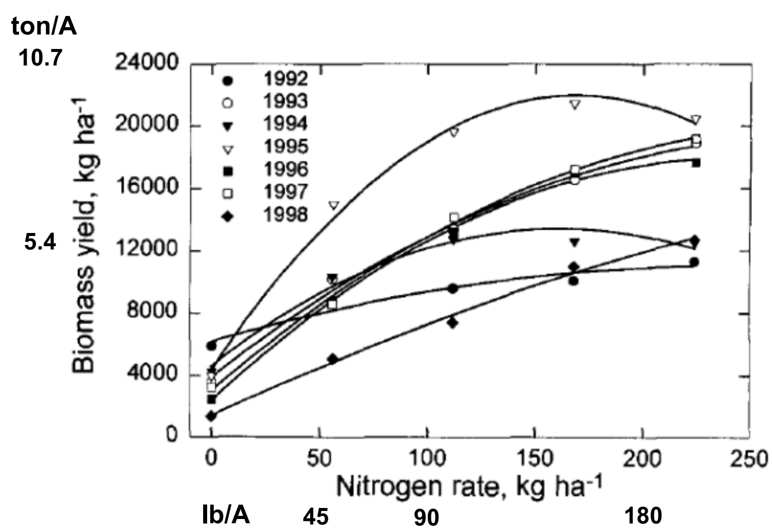
IMPLICATIONS FOR NUTRIENT MANAGEMENT RESEARCH AND EDUCATION

A major challenge to crop producers, their advisers, the fertilizer industry and those conducting research on nutrient management is the development and adoption of nutrient management approaches focused on ecological crop intensification where productivity is increased and the environment is improved. Sustainability of a food, feed, fiber and fuel producing agriculture requires that changes made to increase productivity also contribute positively to environmental impacts … that nitrate and phosphate losses to surface and ground waters are reduced, soil erosion and soil loss from the field are lessened, nitrous oxide and ammonia emissions to the atmosphere are reduced, carbon is sequestered in the soil or at least maintained, and water is used appropriately.

Meeting this challenge will require our best agronomic science and the growers' best agronomic management. Agriculture must capture the production opportunity with good husbandry … not just of production fields, but also of public opinion. One could argue that science has never had a more complete set of "knowledge nuggets" than it has today and that industry has never had a more impressive set of technologies. Perhaps then, the agronomic science most needed is that which guides us to determining which practices and technologies are "best" for a specific farm or field.

Equally important is recognition that relevant agronomic science could be found anywhere in the world. Globalization technology has created, in Thomas Friedman's words, a "flat world" that transcends geopolitical boundaries, not just for business but also for science. Much is to be gained by being open to ideas, approaches, and in some cases even nutrient management algorithms, from other parts of the region, country, or world. However, the extreme opposite is also true … a farmer's own backyard may also be the source of the most relevant agronomic science. Published science is not always clear on nutrient management issues and the answer may only be found through on-farm testing. Today's technology makes this more feasible than ever before.

Figure 4. Biomass response of switchgrass to N fertilization at Stephenville,TX (Muir et al., 2001).



Production of biofuel crops raises many nutrient management questions ranging from the complex, such as the impact of management approaches on the net global warming potential of corn grain systems (Adviento-Borbe et al. 2007), to rather basic ones, such as the nutrient needs of energy crops. For example, switchgrass has been described as a "low input" species, not requiring fertilization or at most, minimal fertilization (Tilman et al., 2006). However, studies show these species can be highly responsive to N fertilization (Figure 4, Muir et al., 2001; Gelderman, et al., 1980; Sanderson et al., 2001) and can remove large quantities of nutrients, especially K though content is extremely variable.

Today's elevated crop and fertilizer prices create a greater economic penalty for over or under estimating nutrient needs and for nutrient losses. Economic justification for precision fertilizer application, fertilizer efficiency enhancement, soil testing, plant analysis, soil or plant imaging, on-farm strip trials, omission plots, and other forms of decision support is great indeed. Investing in determination of right source, rate, time and place for inputs is the right economic response as well as the right response for the future of biofuel crop production. Nutrient management researchers and educators need to be prepared to support growers and their advisers in making that investment.

SUMMARY

The increased value of agriculture resulting from the development and expansion of the biofuels industry may well mark the end of a 25-year era – an era that was dominated by the mindset that the abundant production of North American agriculture is a problem. Perhaps, biofuels and the array of co-product opportunities that is appearing along with it offers a new mindset where sustainable development of the real potential of modern agriculture to harness the sun's energy in meeting food, feed, fiber, and fuel needs becomes the focus. Such a mindset is ripe with opportunity for agriculture provided the steps taken are not only good business moves, but grounded in science-based sustainable practices leading to efficient and effective nutrient management and resource utilization.

REFERENCES

Adviento-Borbe, M.A.A., M.L. Haddix, D.L. Binder, D.T. Walters, and A. Dobermann. 2007. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. Global Change Biol. 13: 1972-1988. doi:10.1111/j. 1365-2486. 2007. 01421.x

Brouder, S. M. and J.J Volenec. 2007. Impact of climate change on crop nutrient and water use efficiencies. Proceedings No. 609. International Fertilizer Society, York, UK. 1-32.

Cassman, K.G., Eidman, V., and Simpson, E. 2006. Convergence of agriculture and energy: Implications for research and policy. CAST Commentary QTA 2006-3.

Cassman, K.G. and A.J. Liska. 2007. Food and fuel for all: realistic or foolish? On line at http://www3.interscience.wiley.com/cgi-bin/fulltext/114283521/PDFSTART.

Fales, S.L., J.R. Hess, and W.W. Wilhelm. 2007. Convergence of agriculture and energy: II. Producing cellulosic biomass for biofuels. CAST Commentary QTA 2007-2.

Fairchild, D. 2007. Precision agriculture, apple pie, motherhood and other good "stuff". Proceedings of the InfoAg 2007 Conference. On line at http://www.infoag.org/2007/.

Fitzgerald, A. 2006. 300 bushels per acre corn yield no longer a pie-in-sky goal. Des Moines Register, Dec. 10.

Fixen, P.E. 2007. Potential biofuels influence on nutrient use and removal in the U.S. Better Crops 91(2):12-14.

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. 2007. Current and potential U.S. corn stover supplies. Agron. J. 99:1-11.
Gelderman, R., P.Carson, D. Beck, B. Nettleton, and E.J. Williamson. 1980. Effect of nitrogen carryover on switchgrass forage production – Wheeler Site. Eastern South Dakota Progress Report. Agric. Exp. Sta., South Dakota State Univ.

IPNI. 2007. A global framework for best management practices for fertilizer use. BMP and Nutrient Use Efficiency Working Group. Inter. Plant Nutrition Institute. Norcross, GA.

Johnston, A.E. and Dawson, C.J. 2005. *Phosphorus in Agriculture and in Relation to Water Quality*. Agricultural Industries Confederation, Peterborough, UK.

Muir, J. P., Sanderson, M.A., Ocumpaugh,W.R., Jones, R.M. and Reed, R.L. 2001. Biomass Production of 'Alamo' Switchgrass in Response to Nitrogen, Phosphorus, and Row Spacing. Agron. J. 93:896-901.

Sanderson, M.A., Jones, R.M., McFarland, J.M., Stroup, J., Reed, R.L. and Muir, J.P. 2001. Nutrient Movement and Removal in a Switchgrass Biomass–Filter Strip System Treated with Dairy Manure. J. Environ. Qual. 30:210–216.

Tilman, D., Hill, J. and Lehman, C. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314: 1598-1600.