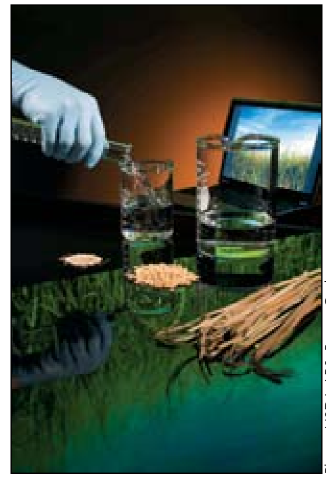
Potential Biofuels Influence on Nutrient Use and Removal in the U.S.

By Paul E. Fixen



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Nutrient use and management will likely be impacted significantly within the next 5 years through grain-based ethanol production. Beyond that time period, another round of major impact may occur as cellulosic biofuel production is commercialized. A major challenge to the fertilizer industry and those conducting research on nutrient management will be the development of nutrient management approaches focused on ecological crop intensification where productivity is increased to meet growing demand and the environment is improved. Failing to take this challenge seriously will likely lead one day to headlines in the media about the "misadventure" of biofuels and the loss of a tremendous opportunity for agriculture.

"*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 around 1500 BC (Johnston and Dawson, 2005). It is 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…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.

Intensified Interest in Yield Improvement

The increased demand for corn can be met by either increasing acres or increasing production per acre. Higher crop prices offer incentive for both. This production-encouraging market comes at a time when biotechnology and genetics industries are promising leaps in genetic yield potential with estimates of 3% per year being made by leading biotechnology companies (Fitzgerald, 2006). **Figure 1** shows what a 3% annual rate of increase looks like projected out to 2020 and contains a table translating the yield increases into additional production relative to 2006. The N, P, and K contained in the additional annual production in 2020 amounts to 18, 21, and 13%, respectively, of the entire current U.S. fertilizer use (average of 2004-2006). If the genetics 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.

Converting genetic potential into harvestable yield should clearly not be taken for granted. Cropping system changes in plant population, fertilization, pest management, tillage, and other cultural practices will likely be necessary on a site-specific basis. The yield drag of increased corn-on-corn acres will need to be overcome. And, it will be critical for sustainability of the resulting modified system that the changes contribute positively to environmental impacts…that nitrate and phosphate losses to surface water and groundwater 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.

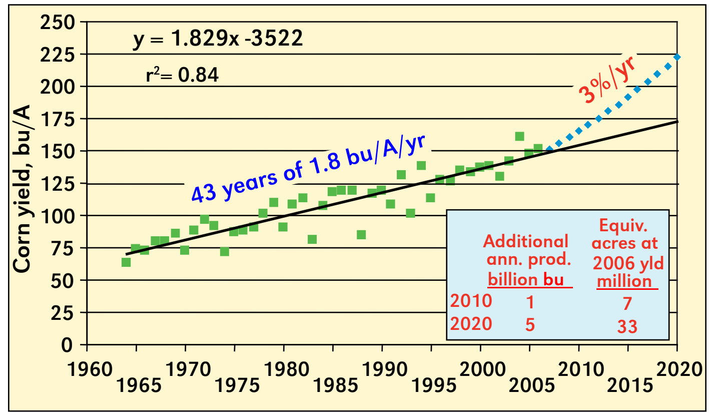

Figure 1. Genetic improvement in corn yields promised by the biotech industry.

Increase in Corn Acreage

A substantial increase in corn acreage is predicted in 2007 and about a 10 to 15% increase over the 2004-2006 average acreage (80.3 million) is anticipated over the next couple years by many. Much of the increase is likely to occur in the traditional corn-soybean rotation region of the Corn Belt, resulting in an increase in corn-on-corn acres. **Table 1** gives an estimate of the impact of a 5 million acre shift of soybeans to corn where use per acre on the new corn area is assumed to be the same as reported in the USDA Ag Chemical Use Survey for the 2 most recent survey years, plus an additional 30 lb N/A to compensate for loss of a soybean previous crop credit.

Table 1. Impact of adding 5 million acres of corn from soybean acreage in the U.S.

	Fertilizer use, 1,000 tons		
Change	N	P_2O_5	K_2O
+5 million acres of corn	405	117	135
-5 million acres of soy	-13	-38	-68
+5 million acres with N adjustment for cont. corn	75	0	0
Net	+467	+79	+68
U.S. fertilizer use (04-06)	12,320	4,570	5,110
% increase	3.8	1.7	1.3

Based on USDA Ag Chemical Use Survey; average of 2003 and 2005 for corn plus 30 lb/A for continuous corn; 2002 and 2004 for soybeans.

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

The fertilizer that would have been applied for soybeans is subtracted from the corn fertilizer. The estimation also accounts for the increased N rate needed for the additional corn-on-corn acres that show up in the second year of the increased corn acreage. Since there are 5 million fewer acres of soybeans to rotate with corn, an increase of 5 million acres of corn results in 10 million acres of corn-on-corn. With these assumptions, a 5 million acre increase in corn results in increases of 3.8, 1.7, and 1.3% in U.S. total fertilizer use over the 2004-2006 average. If 10 million acres shift from soybeans, these values would double.

Table 2 shows a second scenario in which 5 million acres of additional corn results from acreage shifts of crops other than soybeans. It is assumed that these will be lower yielding acres and therefore receive lower fertilizer rates than the acres coming from soybeans. Though enterprise budgets will likely influence which crops will contribute the acres, in this analysis the contributions are based on available acreage and an acreage-weighted average fertilizer rate calculated to subtract from the fertilizer applied to the new corn acres. Crops contributing acres were wheat, cotton, sorghum, and barley. Since the fertilizer rate differences between corn and the crops contributing the corn acres are smaller, the impact of this scenario on fertilizer use is less than when soybeans were contributing the new corn acreage.

Table 2. Impact of adding 5 million acres of corn taken from non-soybean crop acreage.

	Fertilizer use, 1,000 tons		
Change	N	P_2O_5	K_2O
+5 million acres of corn[1]	288	88	50
-5 million acres of crops[2]	169	58	37
Net	119	29	13
U.S. fertilizer use (04-06)	12,320	4,570	5,110

[1]Assuming lower corn yields (130 bu/A) receiving lower than average fertilizer use. (115+35+20, N+ P_2O_5+ K_2O, lb/A). N as 130 bu/A*1.2 lb/bu – 41=115.
[2]Based on Ag Chemical Use Survey acreage-weighted average fertilizer rates for winter wheat (0.53), cotton (0.23), sorghum (0.15), and barley (0.09).

Table 3. Nutrient content of corn stover.

	lb/dry ton		
Parameter	N	P_2O_5	K_2O
Range in 8 estimates of "typical"[1]	9-22	3.6-8.0	16-46.5
Average	19	5.7	32
	In 75 million tons of stover:		
1,000 tons	713	214	1,200
% of U.S. fertilizer use per year (04-06)	5.8	4.7	23

[1]U.S. and Canada sources

Table 4. Impact of changing from corn grain to corn grain + stover harvest.

	Removal, lb/A/yr		
Harvested portion	N	P_2O_5	K_2O
Grain, 150 bu/A	135	57	41
Stover, 3.5 t/A	67	20	112
Stover, 1.4 t/A[1]	27	8	45
Total (grain + 40% of stover)	162	65	86
Change, %	20	14	110

[1]Assuming 40% of stover can be removed sustainably. Estimates for average sustainable levels vary at least from 33 to 50%.

Harvest of Crop Residues and Energy Crops

The production of ethanol from cellulosic biomass occurs today only on a pilot basis, but progress is being made towards commercialization. If cellulosic ethanol production does become a commercial reality as many experts are predicting, the impact on the fertilizer industry and nutrient cycling could be large, especially for K. Corn stover is expected to be a major initial feedstock due in part to a plentiful supply, with current sustainable availability estimated at 75 million tons per year (Perlack et al., 2005). The nutrient content of this stover is difficult to predict due to the wide range in "typical" nutrient concentrations reported in the literature (**Table 3**). Nutrient content of stover entering a biorefinery could be even more variable due to variation in foliar leaching during crop senescence, extent of weathering in the field, or harvest techniques. For the calculations made in this paper, eight reported "typical" stover nutrient concentrations reported in the literature were simply averaged as shown in **Table 3**. Using these average figures, the 75 million tons of harvestable corn stover would contain nutrients equivalent to 6%, 5%, and 23% of annual U.S. fertilizer sales of N, P_2O_5, and K_2O, respectively.

Table 4 compares the nutrient removal in grain and stover for a 150 bu/A corn crop (average yield for U.S. for 2005 and 2006). Assuming that on average 40% of the stover can be harvested sustainably and maintain soil quality, stover harvest increases nutrient removal by 20, 14, and 110% for N, P_2O_5, and K_2O respectively over grain-only harvest.

Thinking in terms of biorefinery capacity helps visualize how a commercial cellulosic industry might get started. Though the bioenergy literature indicates considerable uncertainty in commercial scale details, an 80 million gallon refinery seems to be in the central range of the capacities presented as does an estimate of 80 gallons of ethanol per dry ton of stover (**Table 5**). Therefore, a reasonable estimate of the stover demand for a refinery is a million tons of stover…10 refineries would require 10 million tons per year or 6 to 7 million acres supplying corn stover.

Once cellulosic ethanol production is commercialized, energy crops such as switchgrass or miscanthus (elephant grass) are bound to enter the scene in short order. These are often described as "low input" species, not requiring fertilization or at most, minimal fertilization (Tilman et al., 2006). However, studies show these species are highly responsive to N fertilization (Muir et al., 2001; Sanderson et al., 2001) and can remove large quantities of nutrients, especially K (**Table 6**), though content is extremely variable. Rainfall during leaf senescence can markedly reduce plant K concentration.

At the assumed content of 46 lb K_2O/ton, 10 million acres of switchgrass yielding 8 tons/A would remove a quantity of K equivalent to 36% of total current U.S. fertilizer K

Table 5. Potential demand for corn stover for cellulosic ethanol production in U.S.

	Million acres at[2]		Removal, 1,000 tons		
Biorefineries[1]	1.4 t/A	1.8 t/A	N	P_2O_5	K_2O
10 (800 mil gal)	7.1	5.6	80	29	200
20 (1,600 mil gal)	14.2	11.2	160	58	400

[1]Assuming 80 million gallon biorefinery feasbile size; 80 gal/dry ton; 1 million tons stover/refinery (estimates range from 60 to 100 gal/ton).
[2]Assuming 40% or 50% of stover can be removed sustainably.

Table 6. Nutrient content of switchgrass.

Crop	Yield, tons/A	Fertilizer N, lb/A	Removal, lb/A N	Removal, lb/A P_2O_5	Removal, lb/A K_2O
Range in estimates[1]	1	–	13-28	4.5-13	12-66
Average	1	–	22	8.9	46
Low yield switchgrass	4	75[2]	88	36	184
High yield switchgrass	8	150[2]	176	72	368

[1]U.S. sources. [2]Typical N application rates.

Table 7. Reference points for the potential impact of biofuels on fertilizer use in the U.S.

Ethanol source	1,000 tons N	1,000 tons P_2O_5	1,000 tons K_2O	% of annual U.S. fertilizer (04-06) N	% of annual U.S. fertilizer (04-06) P_2O_5	% of annual U.S. fertilizer (04-06) K_2O
Corn grain – 7.5 mil acres from soy[1]	701	119	102	5.7	2.6	2.0
Corn grain – 2.5 mil acres from non-soy crops[1]	60	15	7	0.5	0.3	0.1
10 refineries – stover (10 mil tons)[2]	80	29	200	0.6	0.6	3.9
Biomass crops, 10 mil acres, 6 t/A[3]	550	134	690	4.5	2.9	13.5
Total	1,391	297	999	11.3	6.5	19.5

[1]Net increase in fertilizer use.

[2]Nutrient removal; 16% of sustainably collectable stover based on 1995-2000 production with no change in tillage (Graham et al., 2007).

[3]Crops such as switchgrass or Miscanthus; 50% of removal for P and K; 110 lb N/A.

consumption. However, deep rooted perennial crops often do not receive nutrient applications at removal rates due to the soils they are sometimes grown on, the ability to tap soil nutrient reserves not measured in routine soil tests, and grower resistance to application of the large rates involved. Even if the content estimate is off by 50% and growers only replace 50% of the P and K removed, it's still a lot of nutrients that will be transported from the field to biorefineries.

The question remains of what large nutrient removal by biomass crops and crop residue harvest means to the fertilizer industry. At first glance, it appears to represent a potentially large increase in fertilizer demand following the logic that nutrients are being removed from fields that will indeed eventually need replacement. Yet when one considers the fate of the nutrients being removed, the vision of these removed nutrients as raw material for a new fertilizer source or sources appears. At least some of the N and P moving to biorefineries will very likely end up entering the livestock feed industry as is the case with grain-based ethanol production, but the K accumulating will have limited value for that use. It will go somewhere, and the likely place is back to production fields, but not necessarily the fields it came from.

It appears it would be wise for the fertilizer industry to further explore with the bioenergy industry the potential for partnerships based on the concept of biomass nutrients as fertilizer co-products. Early discussions, before commercialization, may be beneficial to allow consideration of how processes might be modified to accommodate fertilizer co-product production while also increasing ethanol production efficiency. Brazil learned long ago how to make a fluid fertilizer (venasse) from the nutrients resulting from processing of sugarcane into ethanol. Perhaps there is a corollary with cellulosic ethanol production.

A summary of reference points for the potential impact of biofuels on fertilizer use is offered in **Table 7**. It considers the March 30 USDA Prospective Plantings Report which indicated that corn plantings are expected to be 10.1 million acres above the 2004-2006 average and soybeans and cotton 7.1 and 2.3 million acres, respectively, below the 3-year average. This table does not include the impact higher crop prices and accelerated development of crop genetic potential might have on nutrient management across all planted acres, which of course could be quite large in itself. The across-the-table impact will likely be felt on both fertilizer product use and on the knowledge-based services associated with using those products effectively. Though corn to fertilizer price ratios are not greatly different today than they have been in the past, the economic penalty for over or underestimating need or for nutrient loss is much greater with \$4 corn/\$0.40 N than it was with \$2 corn/\$0.20 N. Economic justification for precision fertilizer application, fertilizer efficiency enhancement, soil testing, plant sampling, 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 plant nutrients is a low risk, high potential benefit proposition for both the pocket book and the environment.

The development and expansion of the biofuels industry may well mark the end of a 25-year era in agriculture – an era that was dominated by the mindset that production is a problem and input reduction is the solution. 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. BC

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