Potential Biofuels Influence on the Fertilizer Market

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"*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 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.

Use of corn for ethanol production has been skyrocketing with a 20% increase last season and a projected increase of another 30% for the 2006-07 season, exceeding 15% of the entire U.S. corn crop (Pottorf, 2006). This puts even greater pressure on world coarse grain stocks, estimated at 12% of total use for the 2005/06 crop year, a 30-year low, and part of a 10-year trend of steady declines in spite of several phenomenal global crop years (Collins, 2006). Increased corn demand has lead to substantial increases in corn prices. Corn prices over the last eight years have averaged $2.05/bu while predicted average CBOT prices for the next three years are in the range of $3.17 to $3.63/bu (Karst, 2006). Such a price jump across the 11 billion bushel U.S. corn crop translates to an additional $11 billion in gross revenue to corn producers.

The impact of higher corn prices will be far-reaching and likely include: more corn acres and fewer acres of some other crops; changes in government farm programs; a shift in attitudes and management emphasis; livestock industry shifts in feeding, revenues, and perhaps geography; transportation challenges; and input industry implications, including for the fertilizer industry. Those implications are the focus of this paper.

Intensified Interest in Yield Improvement

The increased demand for corn can be met by either increasing acres or increasing production per acre. Higher prices offer incentive for both. This production-encouraging market comes at a time when biotechnology and genetics industries are promising leaps in yield potential with estimates of 3% per year being made by leading biotechnology companies (Fitzgerald, 2006). The significance of this projection can be better appreciated by considering the history of yield improvement.

Figure 1 was created based on the concept offered recently by Cassman et al. (2006). It illustrates that 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 decidedly linear rate of 1.8 bu/A/yr with no sign of a recent increase in rate, as some have suggested. Figure 2 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. The N, P and K contained in the additional annual

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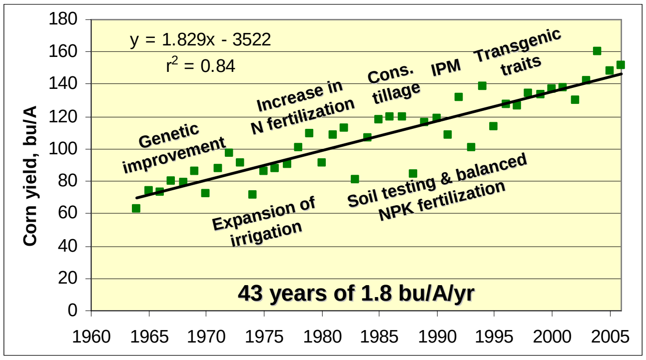
[1] *Proceedings of the 2007 Fluid Forum. Feb. 18-20, 2007. Scottsdale, AZ. Fluid Fertilizer Foundation, 2805 Claflin Road, Suite 200, Manhattan, KS 66502.*

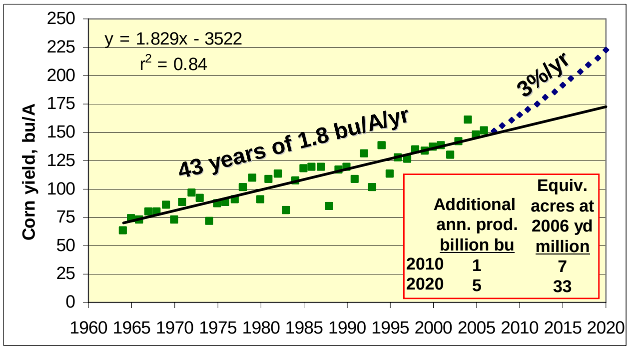
production in 2020 amounts to 18, 21, and 13% respectively of the entire current U.S. fertilizer use (average of 2004-2006). If the genetics industry can deliver on the promised increased genetic potential, and if agronomic researchers, educators, crop advisers, and growers can convert that genetic potential into bushels in the bin, we will indeed be in the midst of a revolution, not experienced since the hybridization of corn.

Figure 1. U.S. corn yields, 1964 to 2006.



Concept by Cassman, 2006

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



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 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 in used appropriately. Indeed, 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 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.

Increase in Corn Acreage

A substantial increase in corn acreage is predicted in 2007 and about a 10% increase over the 2004-2006 acreage 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. Evaluation of fertilizer use practices on corn and soybeans is useful in understanding the impact of these changes on fertilizer consumption. Table 1 shows the U.S. average fertilizer rates as

Table 1. Fertilizer use per acre as reported in the USDA Ag Chemical Use Survey.

Crop	Crop years	Use, lb/A/yr N	P_2O_5	K_2O
Corn	2003, 2005	132	47	54
Soybeans	2002, 2004	5.1	15	27
Rotation avg		69	31	41
Removal avg	2005, 2006	163	47	48

reported in the most recent USDA Ag Chemical Use Survey for corn and soybeans. The average fertilizer use for a corn/soybean rotation would be 69+31+41 ($N+P_2O_5+K_2O$, lb/A/yr). These P and K rates are less than average removal for the 2005 and 2006 crop years.

Table 2 shows what might be viewed as a typical situation for the central Corn Belt and what switching from a corn/soybean rotation to corn/corn does to N fertilizer use and nutrient removal. A 5% yield decline is assumed for corn on corn compared to corn following soybeans. Research tends to show that decline often being closer to 10%, but the assumption is made here that farmers focused on this system with access to the latest technologies, using the most suited fields, will be able to minimize the corn on corn yield penalty. This scenario results in a 134% increase in fertilizer N use for the rotation, a 13% increase in P removal, and a 24% <u>reduction</u> in K removal. This would imply that switching to corn on corn would reduce K fertilizer use. However, this is not likely due to the common practice of applying at least a portion of the soybean fertilizer needs to the corn crop. Also, the increased crop residue levels may lead to increased tillage which will reduce soil K stratification, likely resulting in a drop in measured soil test K levels and a positive influence on K use.

Table 2. Impact of changing from corn/soybean to corn/corn rotation in the central Corn Belt

		Rotation average annual			
		Fertilizer	Removal, lb/A		
Crop	Yield, bu/A	N, lb/A[2]	N	P_2O_5	K_2O
Corn/soy	165/50	142/5 = 74	170	53	55
Corn/corn	157[1]	173	141	60	42
Change,%		+134	-17	+13	-24

[1] 5% yield penalty assumed. [2] 1.1x yd – 40 (if following soy).

Table 3. Impact of adding 5 million acres of corn from soybean acreage in the U.S.

	Fertilizer Use, 1000 tons		
Change	N	P_2O_5	K_2O
+ 5 million acres of corn	330	117	135
- 5 million acres of soy	-13	-38	-68
Net	+317	+79	+68

Based on USDA Ag Chemical Use Survey; average of 2003 & 2005 for corn and 2002 and 2004 for soybeans.

A more likely scenario is depicted in Table 3 where use per acre on the new corn area is assumed to be the same as reported in the USDA Survey. In other words, the new corn acres are fertilized as is the past. It is also assumed that the first 5 million acres comes from soybean ground so the fertilizer that would have been applied for soybeans is subtracted from the corn fertilizer. Table 4 goes a step further and assumes that farmers increase N rate on the new corn acres by 30 lb/A to compensate for the loss of soybean previous crop credit. It 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 adjustments made, a 5 million acre increase on corn results in increases of 3.8, 1.7, and 1.3% in U.S. total fertilizer use.

Table 4. Impact of adding 5 million acres of corn from soybean acreage in the U.S.

	Fertilizer Use, 1000 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 & 2005 for corn plus 30 lb/A for continuous corn; 2002 and 2004 for soybeans.

It is plausible that within the next 5 years, a second 5 million acres of additional corn could develop. The impact of this additional acreage on fertilizer use is estimated in Table 5. It is assumed that these will be lower yielding acres and therefore receive lower fertilizer rates than the first 5 million acres. Also, these acres will likely not come from soybeans but rather from wheat, cotton, sorghum, and barley. 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. Since the fertilizer rate differences between corn and the crops contributing the corn acres are smaller, the impact of the second 5-million acre increase on fertilizer use is less than for the first 5 million acres.

Table 5. Impact of adding a 2nd 5 million acres of corn taken from several crops.

	Fertilizer Use, 1000 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
% increase	1.0	0.6	0.3

[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-39=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).

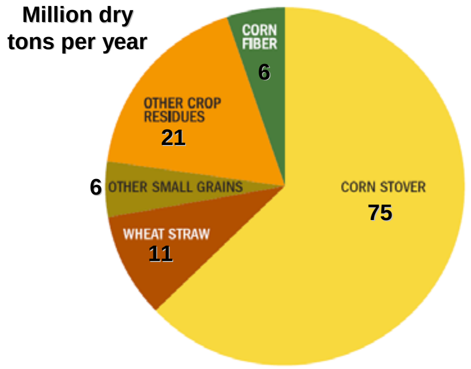
Harvest of Crop Residues and Energy Crops

The production of ethanol from cellulosic biomass occurs today only on a pilot basis but progress is being made towards commercialization. A few indications:

- For over a year, Iogen Corporation has been operating an 800,000 gallon/year demonstration scale facility in Ottawa, Canada producing ethanol from wheat straw. This facility represents the final proving stage prior to full-scale commercial biorefineries each designed to process annually more than 1.5 million dry tons of crop residues into 100 million gallons of ethanol (Hettenhaus, 2006).
- Abengoa Energy is constructing a one-ton-per-day pilot plant to make ethanol from distiller dry grains and corn stover in York, Nebraska, expected to be operational in 2007. (Hettenhaus, 2006).
- In 2007, Iogen plans to initiate construction of a 20 million gallon commercial plant in Idaho’s Snake River Valley to make ethanol from wheat straw with operation anticipated by 2009.
- DuPont and Broin have created a partnership that has announced plans to add cellulose to an existing corn ethanol plant facility in Iowa (Hettenhaus, 2006).
- Bruce Jamerson, President of VeraSun Energy, indicated in January of 2007 that full commercialization of biomass ethanol production is still 3-5 years in the future.

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 (Figure 3). The nutrient content of this stover is difficult to predict due to the wide range in “typical” nutrient concentrations reported in the literature (Table 6). 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 6. Using these average figures, the 75 million tons of

Figure 3. Current sustainable availability of cellulosic biomass from agricultural lands.



Perlack et al., 2005

Table 6. Nutrient content of corn stover.

Parameter	lb/dry ton		
	N	P_2O_5	K_2O
Range in 8 estimates of "typical"*	9-22	3.6-8.0	16-46.5
Average	19	5.7	32

* *U.S. and Canada sources.*

In 75 million tons of stover:

1000 tons	713	214	1200
% of U.S. fertilizer use per yr (04-06)	5.8	4.7	23

Table 7. Impact of changing from corn grain to corn grain + stover harvest.

Harvested portion	Removal, lb/A/yr		
	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*	27	8	45
Total (grain + 40% of stover)	162	65	86
Change, %	20	14	110

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

Table 8. Potential demand for corn stover for cellulosic ethanol production in U.S.

	Million acres at[2]		Removal, 1000 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 (1600 mil gal)	14.2	11.2	160	38	400

[1] Assuming 80 million gallon biorefinery feasible size; 80 gallons/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.

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 7 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 the 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 8). Therefore, a reasonable estimate of the stover demand for a refinery is a million tons of stover and 10 refineries would require 10 million tons per year with each refinery needing 6 to 7 million acres supplying corn stover.

Once cellulosic ethanol production is commercialized, energy crops such a switchgrass 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 (Figure 4; Muir et al., 2001; Sanderson et al., 2001) and can remove large quantities of nutrients, especially K (Table 9), though content is extremely variable. Rainfall during leaf senescence can markedly reduce plant K concentration.

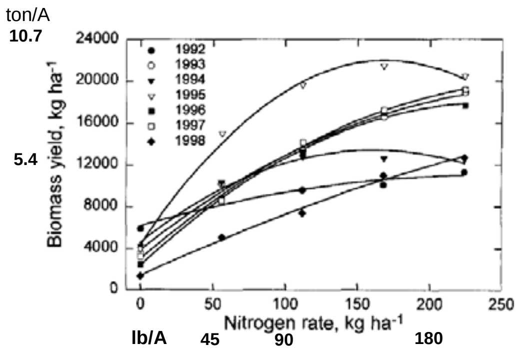
Table 10 illustrates what 5 and 10 million acres of switchgrass at either 4 or 8 tons per acre looks like in terms of fertilizer N use and P and K removal. At the assumed K content of 46 lb K_2O/ton, 10 million

Table 9. Nutrient content of switchgrass.

Crop	Yield, tons/A	Fertilizer	Removal, lb/A		
		N, lb/A	N	P_2O_5	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.

Figure 4. Biomass response of switchgrass to N fertilization at Stephenville, TX.



Muir et al., 2001.

Table 10. Switchgrass from CRP grass and cropland pasture for cellulosic ethanol.

Million acres[1]	Yield T/A	Fert. N 1000 T	Crop removal, 1000 Tons			
			100%		50%[2]	
			P_2O_5	K_2O	P_2O_5	K_2O
5	4	188	89	460	45	230
5	8	375	178	920	89	460
10	4	375	178	920	89	460
10	8	750	356	1840	178	920

[1] Approximately 25 million acres of CRP are in grasses and 68 million acres in in cropland pasture. [2] Assuming 50% of removal is replaced by fertilization.

acres of 8 T/A switchgrass would remove a quantity of K equivalent to 36% of total current U.S. K fertilizer 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. The right two columns in Table 10 show 50% of removal to reflect this situation and may be more realistic estimates. 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 is 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 the production fields, but not necessarily the fields it came from because they may not have the greatest agronomic need.

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 here.

Summary

A summary of reference points for the potential impact of biofuels on fertilizer use is offered in Table 11. 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. Table 11 rather clearly shows that fertilizer use will likely be impacted significantly within the next five years through grain-based ethanol production. Beyond that time period, another round of major impact can be expected as cellulosic biofuel production is commercialized. I do not have the expertise to make even remotely reliable predictions of the scale of future biofuel production. Instead, what this paper has attempted to do is connect reference points of biofuel growth to fertilizer use impact and potential opportunities.

Table 11. Reference points for the potential impact of biofuels on fertilizer use in U.S.

	1000 tons			% of annual U.S. fertilizer (04-06)		
Ethanol source	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Grain 5 mil acres	467	79	68	3.8	1.7	1.3
Grain 2nd 5 mil acres	119	29	13	1.0	0.6	0.3
10 refineries - stover	80	29	200	0.6	0.6	3.9
Switchgrass,10 mil ac, 8 t/A	750	178	920	6.1	3.9	18.0
Total	1416	315	1201	11.5	6.9	23.5

The development and expansion of the biofuels industry may well mark the end of an era in agriculture; an era that began in the 1980s with LISA (Low Input Sustainable Agriculture) and the publication of *Alternative Agriculture* by the National Research Council (1989). It was an era dominated by the mindset that production was the problem and input reduction was 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 the fertilizer industry 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.

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