

# Impact of Ethanol Production on Nutrient Cycles and Water Quality: The United States and Brazil as Case Studies

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## Introduction

Much of the public debate on ethanol is centered on food versus fuel issues and habitat disruption due to conversion of recently unused or perennial grass agricultural lands to cultivate ethanol feedstocks or other currently high-priced commodity crops such as soybeans and wheat. While these are important issues, the use of grain and sugar crops to meet ethanol demands could have substantial negative impacts on water quality and the environment. Alternatively, cellulosic fuel-stocks have the potential to enhance biofuel production and could have positive environmental impacts more consistent with the concept of “green” energy. Technology, infrastructure, policy and political considerations, however, continue to favor ethanol production from grain and sugar crops rather than cellulosic materials.

In the US, ethanol production is focused in the Midwestern states of Illinois, Nebraska,

Iowa, Minnesota, South Dakota, Wisconsin, Kansas, Indiana and Ohio (Figure 9.1). These states are all within the Mississippi River Basin (MRB), which drains to the Gulf of Mexico. The region also has considerable livestock production (i.e. animal feeding operations and confined animal feeding operations). Ethanol production is beginning to expand to population centers on the east and west coasts of the US including areas within watersheds draining to impaired coastal waters such as the Chesapeake Bay. Since ethanol can not be transported through current pipeline systems, construction of additional bio-refineries within these areas is likely.

Dramatic increases in ethanol production and proposals for further increases in production fueled a rise in corn prices during 2007, which led to an almost seven million ha (Mha) increase in corn planted in the U.S. (NASS 2007). Expansion came

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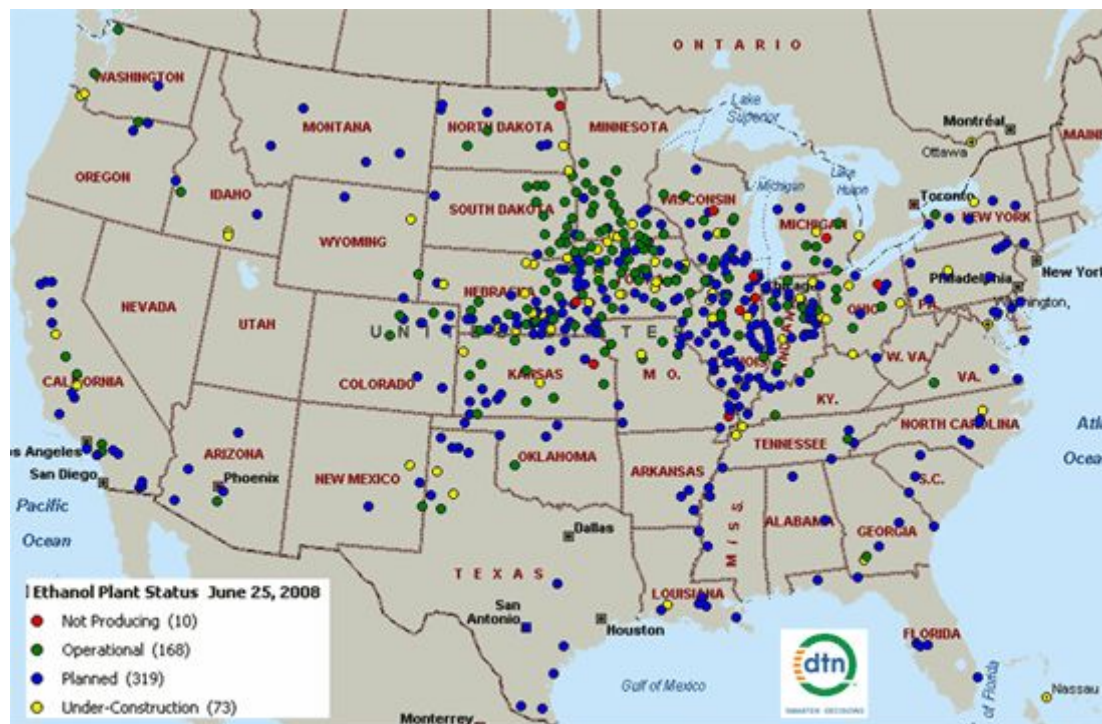


Figure 9.1 Ethanol plant locations in the US as of June, 2008 (Renewable Fuels Association <http://www.ethanolrfa.org/industry/locations/>)

initially from soybean, wheat and cotton acreage and, in combination with increasing world demand and weather conditions, caused increases in the price of all feed, food and fiber crops. Corn, wheat and soybean prices rose to record highs in the U.S. in the first half of 2008 (Table 9.1). The increasing demand for starch and sugar feedstocks for ethanol production also resulted in expanded acreage of sugarcane in warmer climates.

In 2007, sugarcane covered approximately 7 Mha in Brazil, with about 60% produced in the Southeast region of the country, dominantly in the State of São Paulo. Most of the expansion is occurring in the west part of the State of São Paulo and in the State of Mato Grosso in the Central region of the country, and mostly on pasture areas<sup>1</sup>

(Goldemberg et al. 2008; Martinelli and Filoso 2008). The northeast region of Brazil also produces sugarcane, but no expansion has been observed in this region in the last decades (Martinelli and Filoso 2008). Brazil still has much land available for expansion without increasing food price (Goldemberg et al. 2008)

The sudden and extreme rise (and subsequent decline during late 2008) in demand and price of the major commodities fueled a food versus fuel debate and has indeed had impacts on economic conditions and poverty levels in both developed and developing countries, as well as raised issues about habitat loss and green house gas (GHG) emissions due to expanded crop production. However, the increased extent and intensity of high nutrient input crops,

Table 9.1 June Chicago Board of Trade Commodity Prices for 2006, 2007 and 2008 Futures Prices (near term delivery)  
Wheat prices rose above \$12.00 in March, 2008 Futures Trading

Crop	Jun 06	Jun 07	Jun 08
Corn (\$/bu)	2.50	3.75	7.00
Soybeans (\$/bu)	5.75	7.75	15.00
Wheat (\$/bu)	3.75	5.50	9.00*
Cotton (\$/lb)	0.51	0.53	0.75

largely in response to demand for ethanol, has major implications on nutrient cycles throughout the world. The expansion of intensive, annual crop production onto marginal lands and lands in perennial grasses will result in large increases in nutrient losses to lakes, rivers, and coastal marine ecosystems around the world. In the U.S., this is a particular concern along the Northern Gulf of Mexico (Mississippi-Atchafalaya discharge region) and the Chesapeake Bay.

This paper discusses the potential impacts to nutrient cycling and water quality due to changes in land use, cropping systems, and agricultural intensity due to biofuel expansion. The paper focuses upon the potentially adverse impacts of expanded grain, oilseed, and sugar crop production and/or crop residue harvest on water quality, as well as the potential water quality benefits of perennial grass or waste-based cellulosic ethanol production.

### Impacts of Eutrophication

There are serious concerns about large increases in surface water and groundwater discharge of both N and P (Howarth et al. 2002), because primary production of downstream riverine, lake, estuarine and coastal waters is known to be stimulated by the addition of these nutrients (Ryther and Dunstan 1971; Nixon 1995; Mankin et al. 2003; Howarth and Marino 2006). Nutrient-enhanced primary production, or eutrophication, is a key cause of a rise in estuarine and coastal harmful algal blooms (Paerl 1988, 1997; Richardson 1997), oxygen depletion (i.e. hypoxia), and overall fisheries habitat decline (NRC 2000; Rabalais and Turner 2001). In the U.S., over 60% of the coastal rivers and bays are moderately to severely degraded from nutrient pollution (NRC 2000). While excessive nitrogen (N) loading is the main culprit in coastal eutrophication (Nixon 1995; Boesch et al. 2001), phosphorus (P) pollution leads to severe degradation and impairment of freshwater lakes, rivers and some estuarine and coastal waters, especially those also receiving high N loads (Fisher et al. 1999; Howarth and Marino 2006; Sylvan et al. 2006).

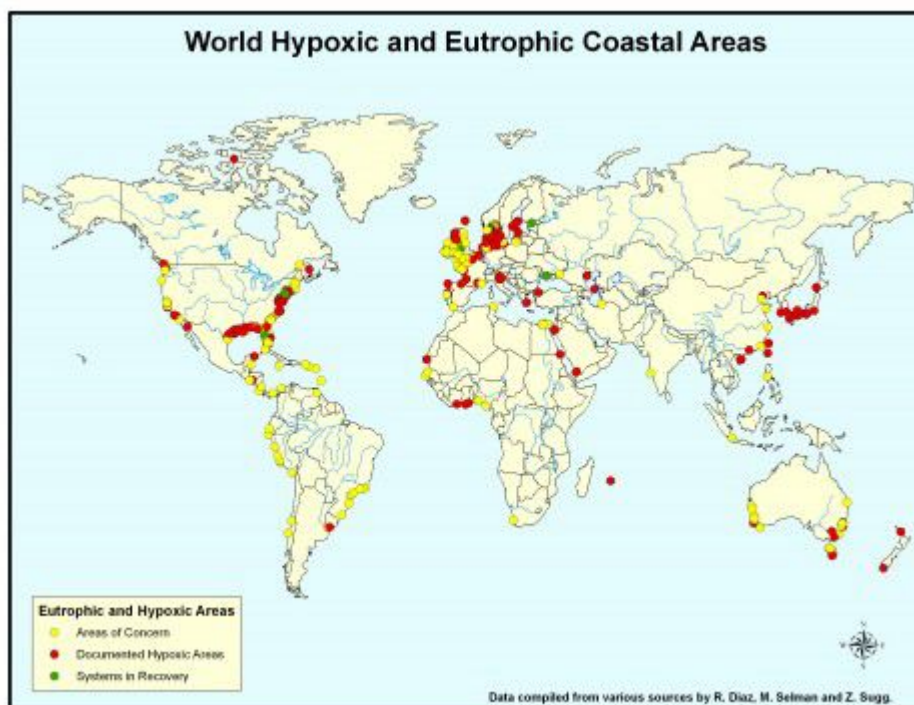
Eutrophication predominately effects the developed world, occurring most commonly in watersheds with intense annual row crop and animal agriculture, as well as intensely urbanized areas (Figure 9.2). Rapidly developing economies (e.g. China and India) also show signs of severe degradation. Thus, biofuel expansion, and associated cropland expansion and intensification, could exacerbate over-enrichment in already impacts waters and accelerate the spread of eutrophication in developing countries.

### Land conversion to row crops in response to ethanol and high commodity prices

Increased demand for grain for ethanol production led to nearly 7 million ha (Mha) increase in corn acreage in the US from 2006 to 2007 (NASS 2007), with much of this increase coming from replacement of soybeans and cotton by continuous corn. Additional acreage came from land currently in the Conservation Reserve Program (CRP), hay, pasture and idle land. In 2007, Wisner et al. (2007) at the Center for Agricultural and Rural Development (CARD) projected 2.9 Mha (7.1 million acres) of CRP land would be converted to corn production and most of the remainder of the expansion would come from conversion of corn-soybean rotations to continuous corn.

High commodity prices caused U.S. farmers to expand production of all these crops to meet the growing demand in 2008; corn, soybean and wheat acreage increased ~5 Mha (12 million ac) between 2006 and 2008. While part of this came from reduced cotton acreage, the geographic distribution of the corn, wheat and soybean acreage makes it unlikely that more than 1 Mha (about 2 million ac) were converted from cotton. As a result, we estimate that about 4 Mha (10 million ac) were converted from idle and conservation lands or pasture and hay. This is substantially different from the land conversion patterns of 2007. The expansion and intensification of row crop production in 2008 appears to indicate the beginning of a longer term response to high commodity prices by displacement of conservation lands and perennial grasses. Water quality impacts

Figure 9.2 Major areas of coastal eutrophication throughout the world.





of this change in conversion pattern will be discussed later in this paper.

In Brazil, the sugarcane acreage expanded by 0.65 Mha in 2007-2008. Most of this (65%) was a conversion of pastures. The remainder of the land was converted from soybean (17%), corn (5%), citrus (5%), and, interestingly enough, 15,546 ha of non-cultivated areas (2.4%). Approximately 80% of this expansion occurred in the southeast region of the country; in the State of São Paulo alone made up approximately 50% of the 0.65 Mha expansion. sugarcane is also expanding to the Center-west region, south of the Amazon region, where most of the tropical savannah (i.e. *Cerrado*) is located. In this region, most of the expansion occurred in the states of Mato Grosso do Sul and Góias. It is important to mention that only ~ 500 hectares of native *Cerrado* was transformed in sugarcane fields, suggesting sugarcane is not replacing the native vegetation, which is highly diverse in terms of plants and animals. Rather, expansion of sugarcane was primarily onto “understocked” pasture lands, which may lead to increased N and P losses both from conversion to cane and increased stocking density on remaining pasture.

### Impact of Land Conversion on Nutrient Loss to Water

*United States.* Corn is an inherently N-inefficient crop, and N loads to downstream aquatic ecosystems from corn-dominated landscapes are typically 20 to 40 kg ha<sup>-1</sup> yr<sup>-1</sup>, the highest of any commodity crop; soybeans lose somewhat less (15-30 kg ha<sup>-1</sup> yr<sup>-1</sup>) (Chesapeake Bay Program 2006). Similarly, average P losses in runoff from corn (2-15 kg ha<sup>-1</sup> yr<sup>-1</sup>) tend to be greater than that from soybean (1-8 kg ha<sup>-1</sup> yr<sup>-1</sup>) (Sharpley and Rekolainen 1997; Carpenter et al. 1998;

Kimball et al. 2001). The loss of P from perennials and hay crops (0.2-2 kg ha<sup>-1</sup> yr<sup>-1</sup>) is generally less than annuals due to decreased runoff volumes and soil loss and lower crop P requirements (Smith et al. 1992; Sharpley et al. 2001).

Elobeid et al. (2006) estimated an ethanol-related long term increase of 7.3 Mha (16 million acres) in U.S. Corn, which was used by Simpson et al. (2008) to estimate increases in nutrient losses from agricultural lands due to expansion of corn acres. Simpson et al. (2008) estimated that the 2007 expansion of corn acreage in the MRB would increase annual loads to surface waters by 117 million kg N and 9 million kg P (Table 9.2). The SPARROW model shows very little N and P retention in the Mississippi River (Alexander et al., 2000), thus the majority of these inputs are delivered downstream to the Gulf of Mexico (Alexander et al. 2000; David et al. 2006). Based on 2001-2005 five-year rolling average load of 813,000 t N yr<sup>-1</sup> and 154,000 t P yr<sup>-1</sup>, and assuming 80% of the projected 7.3 Mha of new corn is in the MRB, fluxes to the Gulf of Mexico compared to recent years (Table 9.2) would increase by more than 10% for N and 5% for P (Alexander et al. 2004). This increase must be considered in the context of national goals to decrease N and P loads from the MRB by 40% or more to reduce the size of the area of bottom water hypoxia (< 2 mg dissolved oxygen L<sup>-1</sup>), or “Dead Zone” in the northern Gulf of Mexico (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2001; Rabalais et al. 2002; Scavia et al. 2004; Donner and Scavia 2007). Moreover, the Simpson et al (2008) estimate is likely low, as it does not account for increased fertilizer application rates in response to higher corn prices or increased

Table 9.2 2007 estimated increase in N and P loss in runoff from growing additional 6.5 million hectares (16 million acres) of corn (adapted from Simpson et al. 2008).

	Land area		N loss		P loss	
	10 <sup>6</sup> ha	Avg Kg ha <sup>-1</sup>	Increase 10 <sup>6</sup> kg	Average Kg ha <sup>-1</sup>	Increase 10 <sup>6</sup> kg	
new corn	6.5	33.6	218	3.4	22	
soybean conversion	3.3	25.2	-83	3.4	-11	
CRP conversion	1.6	5.6	-9	0.6	-1	
idle, pasture, hay	1.6	5.6	-9	0.6	-1	
Est. increase in total loss			<b>117</b>		<b>9.0</b>	

nutrient loss from conversion of marginal land to row crop production.

Producers will likely increase fertilizer application rates will likely increase on all corn acres to achieve higher economic optimum yields at much higher corn prices. It is also likely that excess or “insurance” applications of N will increase to assure no risk of yield reduction from N limitation. While N fertilizer costs, fuel and other input costs have risen sharply, the price of corn has risen proportionally faster as indicated by record net profits last year for US grain producers (USDA/ERS 2008), which suggests the impetus and funding to support the application of insurance rates of N still exists. In 2007, Doering (2007) estimated that N application increases by 15% to corn may occur due to these factors.

It is evident that land conversion patterns changed from 2007 to 2008, and 2008 land conversions may be more indicative of a long-term change. Thus we suggest the need to revise the Simpson et al. (2008) estimates

in this volatile and evolving situation. We use the Elobeid et al. (2006) estimate of land conversion used by Simpson et al. (2008), but change the distribution of the conversion among different agricultural land covers/crops to estimate water quality impacts. Based on the 2008 trends, we conclude that about 4.5 Mha (10 million ac) of perennial grasslands and idle lands and about 1 Mha (2 million ac) of cotton have been brought into corn or soybean production. While it is not evident what would be converted to gain the remaining 1.8 Mha (4 million ac), for our calculations, it will be distributed proportionally between grassland (5/6; 1.5 Mha or 3.3 million ac) and cotton (1/6; 0.3 Mha or 0.66 million ac). If the 7.3 Mha (16 million ac) were converted as described above, using the typical nutrient loading rates from Simpson et al. (2008), N and P losses due to conversion of lands to row crops would increase to 170 and 18.9 million kg respectively (Table 9.3), compared to the earlier estimate of 117 and 9.0 million kg (Table 9.2). Eighty percent or more of this land use change is expected to occur in the

Table 9.3 Revised estimates of N and P losses reported in Simpson et al. (2008) accounting for 2008 changing pattern of land conversion. Cotton loss estimates from Pease (2007)

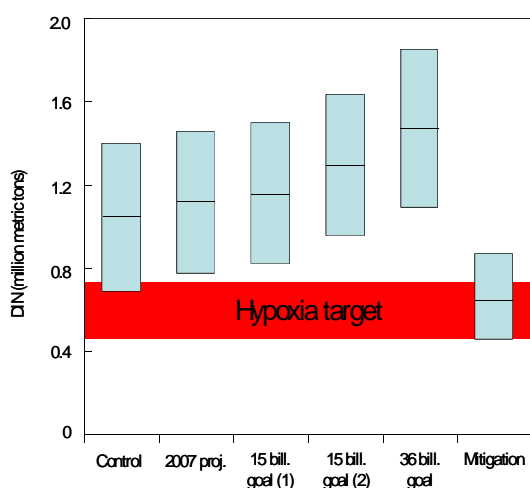
	Land area  10 <sup>6</sup> ha	N loss		P loss	
		Avg Kg ha <sup>-1</sup>	Increase 10 <sup>6</sup> kg	Average Kg ha <sup>-1</sup>	Increase 10 <sup>6</sup> kg
new corn	4.5	33.6	151	3.4	15.3
new soybean	2.7	25.2	68	3.4	9.2
CRP, pasture, hay, & idle converted	6.0	5.6	-33.6	0.6	-3.6
cotton converted	1.2	13.0	-15.6	1.7	-2.0
Est. increase in total loss			<b>170</b>		<b>18.9</b>

MRB draining to the hypoxic Northern Gulf of Mexico.

Donner and Kucharik (2008) also found that increased corn acreage to meet the ethanol Renewable Fuel Standard (RFS) would make it even more difficult to achieve hypoxia target levels for N that have been proposed (Figure 9.3). They used the Agro-IBIS model to compare the impacts of the 2007 corn crop, the 57 billion L yr<sup>-1</sup> (15 billion gal yr<sup>-1</sup>) corn ethanol 2015 RFS target, and the 136 billion L yr<sup>-1</sup> (36 billion gal yr<sup>-1</sup>) 2022 RFS target (ethanol and advanced biofuels) to a control based on average 2004-2006 agricultural land use. Achievement of the 2015 target assumed conversion of soybean and CRP lands to corn under optimistic and pessimistic scenarios regarding both corn and ethanol yields. The analysis indicated a 10-18% increase in dissolved inorganic N (DIN) delivery to the Northern Gulf of Mexico (NGOM) compared with the control. Two scenarios for the achievement of the

2022 goal were also assessed. In the first, they assumed expanded corn production (soybean and CRP conversions) with continuing yield increases and no increases in fertilization rates, as well as harvesting of corn stover to make cellulosic ethanol. This increased effective ethanol yield from about 0.4 to 0.5 L kg<sup>-1</sup> (2.7 - 3.3 gal bushel<sup>-1</sup>), and resulted in a 34% increase in DIN, which is twice the hypoxia target load. The second scenario, which the authors acknowledge is "arguably not realistic", assumes that red meat consumption is reduced by half, which in turn, reduces the crop acreage needed for feed crops such that only a fraction of the former corn and soybean land is planted and the remainder of the non-riparian areas are dedicated to perennial energy crops. They also assume that riparian buffers (capable of removing 35% of the DIN) are planted adjacent to all corn and soybean fields. While the scenario may be unrealistic, it was the most feasible way to meet 2022

Figure 9.3 Simulated annual DIN export by the Mississippi and Atchafalaya Rivers to the Gulf of Mexico in the 2004 – 2006 control and the five ethanol production scenarios. The blue box represents the 5 – 95% confidence interval range of annual DIN export based on 1981 – 2000 climate variability (the horizontal line represents the annual mean). In red is the estimated level of DIN export required to achieve the federal goal of reducing the hypoxic zone to <5,000 km<sup>2</sup>; the upper bound is the federally recommended 30% reduction in mean DIN flux and the lower bound is the 55% reduction in mean DIN flux thought necessary to account for variability in climate and ocean dynamics (Donner and Kucarik, 2008).



RFS target while coming close to achieving the NGOM hypoxia target.

It is apparent that the acreage of row crop production, particularly corn and soybeans, will remain high to support the increased demand for corn for ethanol and increased demand for animal feed. Given the high N and P losses typically associated with a corn-soybean rotation and the expansion of these crops onto lands that are likely less productive and more prone to loss, it is essential to accelerate implementation of conservation measures to reduce nutrient losses.

Current US policy promotes voluntary participation in conservation programs and the 2008 fiscal crisis will limit available funding, so it is unrealistic to expect major increases in conservation implementation. Increases in N and P losses to the Gulf of Mexico were observed in both 2007 and 2008 and should continue under current policy and fiscal conditions (N. Rabalais, personal communication, 2008). Even if conservation implementation were accelerated, it is unlikely that a corn-soybean rotation could be grown on lands previously in perennials without a substantial increase in N and P loss.

*Brazil.* Annual N fertilizer application to Brazilian sugarcane varies from 60 to 100 kg N ha<sup>-1</sup>. Assuming an average of 80 kg N ha<sup>-1</sup> yr<sup>-1</sup> and assuming that this rate is applied evenly in all 0.65 Mha of new sugarcane, the 2007 sugarcane expansion results in a new input of ~ 53 million kg N ha<sup>-1</sup> yr<sup>-1</sup>. However, it is important to consider that pastures are rarely fertilized in Brazil and soybean, due to the high rates of biological nitrogen fixation, does not receive high amounts of mineral N fertilizer. If we instead assume average rates of N for crops that were replaced, and assume that these rates were used evenly among the crop areas, expansion results in a net total of ~ 40 million kg N ha<sup>-1</sup> yr<sup>-1</sup>.

Based on several studies about N fertilizer efficiency in sugarcane, Martinelli and Filoso (2008) concluded that most of the losses of N occurred to the atmosphere. Approximately 40% of the urea that is applied is volatilized either from the soil or from the leaves during senescence and during sugarcane burnings. By difference we estimated that another 20% is lost via denitrification either in the form of N<sub>2</sub>O or N<sub>2</sub>. Leaching losses of nitrogen in sugarcane fields are not as high as for corn, but are higher than



pasture or hay, typically between 10 to 15 kg N ha<sup>-1</sup> yr<sup>-1</sup>.

There is another important source of potential impact on the aquatic system, which is the production of liquid effluents by the ethanol production. A series of effluents are produced during the transformation of sugarcane into ethanol. The most important is the vinasse, a organic-matter rich effluent with high concentrations of nitrogen and potassium. Each liter of ethanol produces ~10 to 12 liters of vinasse, thus Brazil's 2007 ethanol production (20 billion liters) created 200 billion L of vinasse.

Approximately two decades ago the vinasse was discarded in rivers, lakes and reservoirs (Goldemberg et al. 2008). This highly labile effluent led to hypoxia, causing fish killings in several occasions. Brazilian federal law has prohibited the dumping of vinasse to any water body since 1978, and the effluent is now returned to the field as fertilizer. However, the handling, storage, and transport of this effluent are complex and accidents do occur, resulting in vinasse spills to rivers, lakes and reservoirs. Additionally, the continued use of vinasse as a fertilizer and the high nutrient concentrations has raised concerns about toxic levels of potassium in the soil and ground water. In the beginning of 2005, the environment agency of the State of São Paulo (CETESB) soil potassium concentrations may not exceed 5% of the cation exchange capacity of the soil. In these areas, vinasse may only be applied to replace the potassium that is extracted by the sugarcane (185 kg K<sub>2</sub>O). Therefore, there is the potential danger that areas over-fertilized with vinasse may have problems of soil salinization and ground water contamination.

### **Potential for Further Conversion of CRP Land to Row Crops in the US**

About 10 Mha of CRP land will have become eligible for renewal or release between 2007 and 2010. Not all of this land would be suitable for row crop production and most would be less productive than adjacent cropland. Estimates of the amounts of CRP land that could be converted to row crops range from ~ 4.5-10 Mha (10-24 million ac) (A. Templeton, DTN, July 17, 2008, Omaha). The lower end of this range is consistent with the revised assumptions from Simpson et al. (2008) as presented in Table 9.3. If the upper end of the suggested range of CRP were converted (total of 10 million ha), N and P losses would increase by 154 million and 15.4 million kg, respectively, or nearly double that which is reported in Table 9.3.

### **Feeding of Dried Distillers Grains and Solubles**

Most attention is appropriately focused on the water quality impacts of expanded and intensified row crop production. However, a byproduct of grain-based ethanol, Dried Distillers Grains and Solubles (DDGS), may have an indirect impact as a supplement to livestock feed. Dried distillers grains typically contain 0.8-0.9% P, and have been used as a minor supplement in feed for decades, with distilleries providing the DDGs. Phosphorus levels of 0.33-0.36% are desired in dairy and beef diets, and many dairies have feed rations with 0.45 - 0.45% P. Recent research indicates that recommended P requirements for beef and dairy cattle should be decreased (Erickson et al. 2002). This research shows that reducing dietary P from conventional levels (0.35% or more) to diets with no supplemental P (0.25%) improved animal P use efficiency, reduced the P excreted in manure, and did not adversely affect animal performance. The U.S.

Department of Agriculture Natural Resources Conservation Service (NRCS) has established a national practice standard for feed management for dairy, and many state NRCS offices are implementing dairy feed management aimed at reducing P to, or below 0.30-0.40% for dairy cows (NRC 2001).

The rapidly expanding supply of DDGs (each liter of grain ethanol creates about 1203 tons of DDGs) has lowered the price of the material, and it is being used in dairy and beef diets throughout the country at rates of 15-25% to dairy and 30-45% for beef rations. The pervasiveness of DDGs in livestock feed appears very likely to erode progress in managing P in dairy and beef feed and will make government incentive and cost-share payments to improve feed management more expensive and less attractive to farmers. Inclusion of the high-P manure that will come from livestock fed with distiller's grains will increase the land area needed for agronomic use of the manures (per unit mass), which will exacerbate nutrient management planning in counties already short of adequate crop land for agronomic use of available manure N and P (Kellogg et al. 2000; NRC 2003).

### **Options and Sustainability Recommendations**

The transition from row crops to perennial grasses using tools such as the CRP has the greatest potential to achieve major reductions in N and P loss (Baker et al. 2005). However, The high price of corn due to ethanol expansion provides a disincentive for cropland retirement or conversion to perennials. The costs of land retirement programs to the public will have to increase to maintain enrollment, though it is doubtful that they can increase sufficiently to compete with increased demand for corn

and other row crops. This will likely discourage establishment of perennial crops, including those to be grown for cellulosic ethanol, unless the value of cellulosic crops can be increased through multiple revenue streams. In summary, the demand for corn to support grain-based ethanol production will reduce acreage in CRP, perennials or idle land and will make future conversions to low-impact uses more expensive and less likely. This is opposite to what is recommended as one of the most effective ways to reduce N and P loss to ground and surface waters for the Northern Gulf of Mexico (Committee on Environment and Natural Resources, 2000)

While there is potential for cellulosic-based ethanol using perennial grasses, fast growing woody species, and plant wastes, the infrastructure and technology to produce cellulosic ethanol is not yet operational or economically viable. For one, fermentation of cellulosic biomass is more energetically and financially costly. Secondly, assurance of an adequate supply is difficult. While millions of hectares of corn exist to supply grain-based facilities, the 23,000 to 44,000 ha (50,000 to 100,000 ac) needed in a concentrated area to grow enough perennial grass or woody material to support a 190 ML yr<sup>-1</sup> facility does not exist. While these factors combine to favor grain rather than cellulosic ethanol production, cellulosic-based production provides a long-term option that can generate multiple revenue streams for the farmer while providing a wide range of ecosystem services, which has the added benefit of improved ground and surface water quality (Jordan et al. 2007). Perennial grasses require less N and P fertilizer than corn and their extensive root system make them more efficient nutrient users than most annuals, so nutrient losses

to water are substantially lower than that seen in corn systems.

The use of corn stover and other crop and forestry residues in cellulosic ethanol production is also being promoted (Doering, 2007). However, removal of crop residues should only be done when soil erosion and associated N and P loss would not be exacerbated. Additionally, residue harvesting will accelerate reductions in soil organic matter content, which has the potential to reduce long-term productivity, increase runoff and N and P losses, and contribute to global warming as this could deplete existing soil C levels.

The use of switchgrass as a cellulosic feedstock for ethanol production may offer substantial environmental benefits over a corn grain-stover energy strategy. Switchgrass is a warm season perennial native prairie grass that produces large amounts of biomass in its top growth and in an extensive, deep root system. It takes two to three growing seasons without harvesting to establish switchgrass. Once established, it can grow for 20 years or more without replanting, if properly managed. Thus, incentives will be needed to compensate the farmer during the two-year transition with no harvest. As with other cellulosic feedstocks, it will be necessary to locate ethanol production facilities near areas of switchgrass production. However, switchgrass can be grown on marginal lands or as a buffer, under recommended fertilization rates, with far less potential for nutrient loss than corn. It can also be grown instead of corn or soybeans on productive lands with 75-90% reductions in N and P losses, which could generate marketable credits in a nutrient discharge permit cap and trade program.

Switchgrass will also sequester carbon, increase soil organic matter and improve soil quality through its extensive, deep root system. Tufekcioglu et al. (2003) found that switchgrass in a riparian buffer had eight times the below ground biomass and up to 55% more total soil organic carbon than adjacent cropped fields. This sequestered organic carbon in a continuous perennial crop could be sold as carbon credits, while the above ground biomass growth would be sold for ethanol production. Finally, switchgrass improves soil quality relative to row crops, and long-term production of switchgrass will improve soil productivity and increase future yield potential should the land be returned to row crops. This could have the added benefit of making farmers eligible for payments under U.S. Department of Agriculture's Conservation Stewardship Program.

Based on the discussion above, it appears that, if technological and infrastructure constraints are overcome, the opportunity for income from multiple revenue sources generated through the provision of a range of ecosystem services could make switchgrass and other perennial grasses economically competitive with commodity row crops.

In Brazil, the long term sustainability of the sugarcane ethanol will depend on law enforcement. There are a set of environmental laws or compromises that if obeyed will reduce the potential impacts of the industry on water quality. For instance, there is an environmental protocol signed by the government of the State of São Paulo and sugarcane mills to end sugarcane burnings in 2014. The current law requires an end to the practice by 2021. If the protocol is adhered to, the sugarcane industry in the State will move toward enhanced environmental sustainability.

Regarding soil and water quality, the sugarcane industry should think to reduce considerably the volume of vinasse which is produced. There are already technologies for this, but they are expensive and require a series of adaptations in the industrial plant itself.

### Conclusions

Grain-based ethanol production is expanding rapidly and is the primary factor leading to major expansion of corn and soybean acreage, largely at the expense of CRP, idle lands, pasture and hay, as well as some cotton in the U.S. and elsewhere. Increased corn acreage and increased fertilizer application rates due to corn prices will increase N and P losses to streams, rivers, lakes, and coastal waters, particularly the Northern Gulf of Mexico and Atlantic coastal waters downstream of expanding production areas. Both nutrient and hypoxia monitoring are already showing the effects of this increase, which was clearly exacerbated by the Mississippi flood of 2008 (N. Rabalais, *personal communication*). It is critical that a broad suite of conservation measures, particularly nutrient management, are rigorously implemented on new or more intensively managed corn lands, particularly under continuous corn production (Simpson and Weammert 2007). Adoption of innovative new practices and production technologies (Simpson et al. 2004) also needs to be accelerated to partially offset increases in nutrient losses due to expanded and intensified grain production. Future harvest of corn stover for cellulosic ethanol production would increase erosion (i.e. sedimentation) and nutrient loads from corn land.

It is apparent that meeting both the RFS targets and reducing nutrient loads to

NGOM sufficiently to reduce hypoxia will require much more drastic change than just improved management of current row crops (Donner and Kucharik 2008). It will be necessary to redesign the agricultural landscape by using buffers and/or wetlands wherever intensive row crops are grown and to make perennial-based cellulosic ethanol economically viable so perennials can be grown on both productive and marginal lands. It may also be necessary to reduce the amount of grains and oilseeds needed for animal feed, if both renewable, clean transportation fuel and water quality goals are to be met.

Dried distiller's grain from grain fermentation are rapidly becoming available for use in animal rations, particularly for dairies, and, due to their high P content, will increase P content in manures, which will further enhance the mobility in runoff of P applied in these manures (Kleinman et al. 2002; Sharpley et al. 2005). The use of DDGs in livestock and poultry rations should not be done in a manner that increases N and P manure contents from levels achieved using current feed management practices

The development of efficient and competitive fermentation technologies and supporting infrastructure to allow development of a perennial grass or waste-based cellulosic ethanol industry could provide a long-term sustainable approach to ethanol production. However, it may be more feasible to use biomass directly to generate electricity and energy rather converting it to a liquid fuel. A cellulosic renewable energy approach could provide multiple ecosystem services including energy, carbon sequestration, improved water quality and fisheries habitat, and improved soil quality and productivity.

The current focus on ethanol production is centered on the food versus fuel debate. While this is understandable, there are serious environmental consequences from the implementation of current ethanol policies, throughout the world. Much of the current environmental concern focuses either on habitat loss or GHG emission during land clearing and tillage operation.

We conclude that continuing the current direction in ethanol production, particularly with the focus remaining on grain and sugar crops as primary feedstocks, has serious implications for coastal water quality and will almost certainly worsen, already serious hypoxic conditions in many locations around the world.

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