The Effects of Intensive Maize Agriculture on Landscape, Biodiversity, and Human Life

Corn (Zea mays L.), also known as maize, is a major cash crop grown throughout the world that is used for human consumption, animal feed, and in man-made products. According to the National Corn Growers Association (2013), one bushel of corn (32 pounds) can produce 31.5 pounds of starch, 22.4 pounds of plastic, or 2.8 gallons of fuel ethanol. Corn monoculture driven by increased demand and elevated prices of corn has become a major source of various kinds of pollution, mostly due to unnecessary large inputs of ammonium and nitrate fertilizers. The increased pressure for more intensive corn production has also lead to the destruction of many grassland and prairie ecosystems, as well as the growing preference towards genetically modified corn.

People have presented serious health concerns to the recent uses of corn, i.e. obesity contributed by high fructose corn syrup and the uncertainty raised by genetically modified maize. It is important to remember that while humans have played a major role in the evolution of corn, corn has also played a significant role in shaping our environment and everyday lives.

### Environment
- Nitrogen depletion
- Land, water, and air pollution
- Combating soil nutrient depletion

### Biodiversity
- Diversity of corn
- Plant diversity
- Faunal diversity

### Human Life
- High fructose corn syrup
- Ethanol
- Genetically modified maize

#### In the nutshell
- High demands for corn used in human and animal consumption, biofuel, and bioplastic manufacturing have led to increased corn production resulting in various forms of land, water, and air pollution such as the growing dead zone in the Gulf of Mexico.
- Growing corn in a crop rotation system compared to a continuous corn-growing season can be environmentally and economically beneficial because it requires less nitrogen fertilizer to produce the same corn yield.
- Having a high level of biodiversity gives ecosystems a better chance at withstanding or recovering from disturbances. Having species and genetic diversity also helps to insure natural sustainability.
- The adoptions of high fructose corn syrup and GMO have raised health concerns for obesity and reduction in nutritional value respectively. Recent studies have provided arguments in contradiction.
- Despite the environmental benefits of ethanol, we should consider the economic sustainability after the expiration of federal subsidy given the energy inefficiency of ethanol and the potential increase in world food price.
Nitrogen Depletion

Corn is generally considered to have a high soil fertility requirement to attain maximum yield. While a variety of nutrients is important for overall plant growth and success, nitrogen (N), phosphorus (P), and potassium (K) are the three primary elements necessary for corn to grow. In particular nitrogen, is the element most limiting for crop growth in terrestrial ecosystems in temperate zones and is usually supplied by farmers through routine fertilizer applications (de Solla et al. 2011). Nitrogen is extremely necessary for the production of plant proteins that aid in photosynthesis and the production of the corn “fruit” itself (Taiz and Zeiger 2010). Although corn yield does tend to increase as more usable nitrogen fertilizer is added into the system, it only improves yield up to a certain application amount. Despite this key fact, maize growing farmers continue to exceed the government recommended amount of nitrogen fertilizer applications. According to the U.S. Department of Agriculture assessment of conservation practices in the Upper Mississippi River Basin, 62% of the farmland there requires improved management of fertilizers to address excessive losses of nitrogen and phosphorus (Union of Concerned Scientists 2011).

Land, Water, and Air Pollution Due to Excess Nitrogen

1. Land Pollution: Pesticides and Ammonia in the Soil

Many reptiles lay their eggs in soils associated with agricultural landscapes because, at first glance, it provides a safe environment free of natural predators. However, exposure to toxic pesticides and highly concentrated ammonia fertilizers may pose another risk for these developing embryos; most reptile eggs tend to have a very porous outer covering, allowing for substantial air and water exchange. In one particular study conducted by de Solla et al (2011), they ran a controlled experiment that tested the toxicity of a pesticide and fertilizer regime...
similar to those used in corn production in Ontario on the survivorship of exposed snapping turtle eggs. They found that exposure to high amounts of ammonia (2–3 times the government recommended application rate of 200 kg NH₃–N/ha for corn) resulted in nearly a 100% turtle embryo mortality rate. There is also evidence that the excessive use of certain pesticides such as tefluthrin, may increase deformity rates of exposed turtle embryos (de Solla et al. 2011). Additionally, continuous human exposure to high levels of these toxins can cause irritation to the eyes or skin, harmfully effect one’s endocrine and nervous system, and cause cancer (U.S. Environmental Protection Agency 2012).

2. Water Pollution and Dead Zones

Nitrogen, either applied as fertilizer or manure or derived from soil organic matter, can be carried by excess water run off, having the potential to cause detrimental, cascading effects downstream. This is because the soil becomes so saturated with excess nitrogen that the corn plants and other organisms living in the soil do not need it all; if the nitrogen does not bind to or is not taken up by anything, it has a high probability of being leached into water run off during the next heavy rainfall (Helmers et al. 2012). Studies show that up to 33% of the added nitrogen could be lost in subsurface water drainage systems that promote crop yield but also dramatically speed the flow of pollutants into surface waters (Union of Concerned Scientists 2011).

The movement of nitrogen from agricultural fields via drainage waters is a major factor in non-point source pollution of surface waters and ultimately the growing dead zone in the Gulf of Mexico (Helmers et al. 2012) (See Figure 2). As the nitrogen enters the Gulf of Mexico from the Mississippi River outlet, aquatic algae populations explode creating what people refer to as an “algal bloom”. After a few weeks, some of the algae begin to die off.
creating a layer of decomposing organic matter that uses up all of the oxygen in the water. Without oxygen, it makes it very hard for many fish populations to survive, thereby creating extreme detrimental effects on this region’s fishery economy. Additionally, number of studies have documented that NO₃-N concentrations in subsurface drainage from agricultural land commonly exceed the drinking water standard of 10 mg/ L even when government recommended N application rates are followed (Helmers et al. 2012).

3. Air Pollution and Greenhouse Gasses

With a growing human population and the high demand for corn to produce animal feed and ethanol, Midwest farms have transformed from small, two to three acre fields of local production to an intensive production center spanning hundreds upon hundreds of acres. Larger areas of production call for more efficient means of harvesting and redistribution; consider, for example, the use of petroleum fueled tractors to harvest the large fields or the large machinery needed to process and store tons of corn. These factors, along with greater recognition of the environmental consequences of fossil fuels have driven interests in creating more sustainable biofuels. In a comprehensive study done by Hill et al. (2006), they found that corn grain ethanol has the potential to be a better and cleaner fuel source than standard petroleum, however, more policy changes need to be implemented in reducing fertilizer, pesticide, and overall energy usage during the initial stages of production (See the Pros and Cons of Biofuel sidebar).

Excessive use of nitrogen fertilizers and manures in maize agriculture has also played a major role in contributing to the rising atmospheric levels of nitrous oxide (N₂O). This potent greenhouse gas has been shown to deplete parts of the Earth’s ozone (Maharjan and Ventera 2013). When the plants become too saturated with nitrogen to uptake any more, the remaining nutrients can get utilized by the microbes living in the soil. Through the process of denitrification, these heterotrophs convert the nitrate and/or ammonia fertilizer into NO₃- and NO₂-, compounds that are highly reactive and are key drivers in producing the ozone-depleting nitrous oxide (Maharjan and Ventera 2013). Nitrogen fertilizers have also been linked to being a significant source of heat-trapping emissions responsible for global climate change (Union of Concerned Scientists 2011).

ETHANOL: GOOD OR BAD?

Pros:
- Burns cleaner than petroleum; relative to the fossil fuels they displace, produces 12% less greenhouse gasses.
- Yields 25% more energy than the energy invested in its production.

Cons:
- Requires a high agricultural input (fertilizers, pesticides, energy).
- Requires a lot of money to convert corn biomass to ethanol biofuel (corn starches must undergo enzymatic conversion into sugars, yeast fermentation to alcohol, and finally distillation).
- Current corn production (although already very high) would not be able to sustain current gasoline demand.

Combating Soil Nutrient Depletion

Cover Crops and Crop Rotation

Planting a cover crop or switching between crops are grown on a field can help reduce erosion and provide fertilizer uptake year-
round. For example, a soybean-corn crop rotation system requires 25% less nitrate-nitrogen fertilizer than the continuous corn system to produce the same amount of corn yield (Helmers et al. 2012). This is because soybeans, like many other legumes, form a symbiotic relationship with a nitrogen-fixing Rhizobia bacteria. Most plants absorb a majority of their nitrogen in the nitrate (NO3−) form and ammonium (NH4+) form; while the soil may contain a lot of nitrogen, if they are not in a form the plant can utilize, they are not useful to the plant. Rhizobia are able to take these forms of unworkable nitrogen and convert them into ammonia which is then available for the soybean plant to use. In return, the rhizobia is able to thrive with a steady source of carbon in a safe, environment in root nodules created within the soybeans’ roots. This symbiotic relationship makes use of the nitrogen sources already in the soil and helps reduce the necessity for more nitrogen fertilizers.

Additionally, while nitrogen run off is inevitable when N-fertilizer is applied in excess, crop rotation system soils tend to hold onto the nitrate better, saving up to 36% less subsurface nitrogen drainage from getting into the ground water. However, unusually high annual precipitation and reduced drain spacing are also factors that can lead to increased mineral leaching (Helmers et al. 2012). In general, the implementation of cover crops or a crop rotational system has the potential to be a very effective and economic solution to combat soil nutrient depletion and yet less than 1 percent of the Mississippi River Basin’s land utilize these methods due to the demand for more and more corn (Union of Concerned Scientists 2011).

### Biodiversity

that allows the plant to be insect resistant so that the crop would be less likely to suffer from insect damage.

“The [Bt] gene was inserted into the genome of the U.S. corn hybrids using the techniques of biotechnology so that the plants would produce a protein that is selectively toxic to specific insect pests, namely the European corn borer and the corn earworm. Such plants can be called biotechnology derived (i.e., BD plants or crops) to distinguish them from plants bred conventionally by laborious crossing and selection of desirable traits over many years” (Felsot 2002).

Many farmers prefer genetically

### Diversity of Corn

Corn (Zea mays L.), also known as maize originated from Mexico and evolved from a grass called teosinte.

### Genetically Modified Corn

Researchers have developed a genetically modified species of corn known as Bt corn that is used by farmers throughout the United States. Bt stands for Bacillus thuringiensis, an insect pathogen

Figure 3. Evolution of morphology of *Zea mays* from ancestral teosinte (left) to modern corn (right). The middle figure shows possible hybrid of teosinte and corn landraces. (Felsot 2002)
modified corn because it saves them time and money. They can plant the GM corn and expect a return in profit every time because of the high demand for corn. By 2009, over 63% of the total corn crop grown in the United States consisted of genetically modified corn (Suszkiw 2010). As you can see in the figure (from USDA Economic Research Service, Fernandez-Cornejo 2013), genetically modified corn has been available for farmers since 1996 and by 2013, about 76% of total acreage in which corn is planted consists of Bt corn (Fernandez-Cornejo 2013).

Plant Diversity

“The problem with biodiversity does not lie with how crops are bred. Rather, it lies with land management.” (Felsot 2002)

Corn Monoculture

Corn monoculture is when a single crop is grown and cultivated in a specified area. A lot of farms are becoming corn monocultures because of the high demand and therefore price of corn. This is harmful for biodiversity because it reduces the amount of different crops that are grown. Farmers are also increasing the amount of land they are growing corn on which in turn decreases the amount of land local species can grow on. Specifically, grassland and prairie ecosystems are decreasing because of the increase of corn production (Price 2008).

Increasing Local Ecosystems to Help with Biodiversity

Within ecosystems, when there are a variety of different plants growing in the area, then biodiversity is high and is more likely to increase than decrease. When there is homogeneity, or environmental sameness, then biodiversity is reduced within the ecosystem. On farms with high crop diversity, there tends to be a larger number of birds, butterflies, beetles, and spiders than on farms with only one type of crop being grown (Dale, V. H. et al 2010). However in an experiment done in Iowa by Matt Liebman, Mathew J. Helmers, Lisa A. Schulte, and Craig A. Chase (2013), if farmers grow one crop at a time in their fields, they can increase local biodiversity, improve soil and water conservation, and nutrient retention, by keeping strips of prairie land as a buffer between cropland. They determined that diversifying the croplands of monoculture farms with strips of local prairie ecosystems of native plants would greatly help with the conservation of soil, water, and biodiversity.

Faunal Diversity

One of the issues that have come up in the debate around using genetically modified crops is how it might affect faunal diversity and the surrounding ecosystems. There has been some long term experiments conducted about the effects of Bt corn on animals in the environment including arthropods, soil invertebrates and microorganisms.
Effect of Bt Corn on Arthropods

Edwin P. Alcantara (2012) conducted a four year-long experiment in the Philippines to determine if Bt corn affected communities of arthropods on commercial farms and adjacent riparian areas. Arthropods were counted visually on commercial farms that planted Bt corn and non-Bt corn as well as riparian areas near the farms. After collecting data and looking at principal response curves and analysis of variance, the results showed that there were no adverse effects of Bt corn on the diversity of arthropods. Arthropod diversity was similar in Bt corn and non-Bt corn areas and riparian areas (Alcantara 2012).

Effects of Bt Corn on Soil Ecosystems

Isik Icoz and Guenther Stotzky (2008) analyze the effect that Bt crops have on soil ecosystems and if the genetically modified crops change the soil chemistry in a way that changes the ecosystem. They gathered information from other papers and previous experiments to determine if there are any negative effects on soil-dwelling invertebrates like earthworm and woodlouse, as well as soil microorganisms like bacteria, fungi, and algae. Table 1 shows effect of Bt corn on soil-dwelling invertebrates. As you can see, there is no real effect on earthworms, woodlouse, pillbugs, sowbugs, collembolas, or mites. But there is an effect on nematodes. Table 2 shows the same information but it is about soil microorganisms. Some microorganisms are negatively affected by the change in soil brought upon by Bt corn.
Table 1. Modified table based on information found on Table 1 from Icoz & Stotzky (2008). It summarizes the effect of Cry proteins from *Bacillus thuringiensis* (an insect pathogen and what Bt stands for in Bt corn) on soil-dwelling invertebrates.

<table>
<thead>
<tr>
<th>Organism</th>
<th>Effect of Bt Corn on Organism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthworm (5 different species/communities)</td>
<td>In 6 experiments, there was no significant effect on mortality and weight.</td>
</tr>
<tr>
<td>Woodlouse (<em>Porcellio scaber</em>)</td>
<td>In 3 of 4 experiments, there was no significant effect. In one experiment, they ate more non-Bt corn than Bt corn.</td>
</tr>
<tr>
<td>Pillbug (<em>Armadillidiidum nasatum</em>) and Sowbug (<em>Trachelipus rathkii</em>)</td>
<td>One experiment determined that there were no adverse effects on survival and growth.</td>
</tr>
<tr>
<td>Collembola (2 species) and Mites (<em>Oppia nites</em>) and natural communities</td>
<td>In 8 of 9 experiments, there was no significant effect. In one experiment, there was a lower abundance of collembola and a higher abundance of mites under Bt corn.</td>
</tr>
<tr>
<td>Nematodes (3 different species) and natural populations</td>
<td>In 4 of 11 experiments, there was no negative effect on communities. In the other 7 experiments, there were changes in the community structure.</td>
</tr>
</tbody>
</table>

Table 2. Modified table based on information found on Table 2 from Icoz & Stotzky (2008). It summarizes the effect of Cry proteins from *Bacillus thuringiensis* (an insect pathogen and what Bt stands for in Bt corn) on the diversity of microbes and other organisms in the soil.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Cultural bacteria, fungi, and/or protozoa</td>
<td>In the majority of 9 different experiments, there were no significant differences in the population size, but there was a difference in numbers.</td>
</tr>
<tr>
<td>Rhizosphere bacterial communities</td>
<td>In 2 different experiments, there was no significant effect on community population, but there was a change in community structure.</td>
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<tr>
<td>Microbial mass</td>
<td>In the 4 of 10 different experiments, there was not significant effect. In the other 6 experiments, the population size of fungi or bacteria was slightly lower with Bt corn than without Bt corn.</td>
</tr>
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</table>
United States, the world’s largest corn producer and exporter, generated $274 million tons in total maize production (FAOSTAT 2013). By November 2013, 5.2 billion bushels of corn were used for animal feed while 4.9 billion bushels were used to alcohol production for fuel use (ERS 2013). Corn is processed for utilization through one of two techniques: dry-milling or wet-milling. Dry-millers aim to process corn into corn grits, meal and another co-product, corn bran, which is added to animal feed as a source of fiber. Wet millers separate corn into four components: starch, gluten, fiber and germ (Rose et al. 2013), and produce high fructose corn syrup (HFCS), ethanol and industrial alcohol (ERS 2013). As corn penetrates into agricultural, food and energy industries, issues raised by corn are no longer merely affect the biosphere but also the human society.

**High Fructose Corn Syrup**

US sugar consumption has increased since 1970s. Sugar-sweetened soft drinks and bakery goods contribute greatly to total sugar intake. Sugar-sweetened beverage (SSB) alone takes up approximately 43% of added sugar consumption (Beghin & Jensen 2008) and has taken the place of milk consumption in children and adolescents (Morgan 2013). Recent studies have shown that elevated sugar consumption, intake from HFCS in particular, is associated with obesity (body mass index (BMI) ≥30 kg/m²) and type 2 diabetes. Some research linked obesity and type 2 diabetes with decline in cognitive skills. People who are obese and metabolically abnormal experienced fastest cognition decline. Individuals whose type 2 diabetes’ conditions are poorly controlled also exhibits decline in cognition function (Lakhan & Kirchgessner 2013). As obesity prevails among each age group, the size of sugar-sweetened beverage has been regulated in New York and warning should be labelled on the package of SSB. Furthermore, a fructose index was established to study the correlation between fructose consumption and cardiovascular diseases (Ha et al. 2013).

However, Feinman and Fine argued in Fructose in perspective that we cannot safely conclude that the insulin resistance could be induced by high fructose as suggested in many previous studies. The experiments are
conducted under high total carbohydrate and failed to eliminate the confounding factor. Ha and her research team argued that many studies are conducted in animals whose metabolic pathways are different from that of human therefore the result cannot be safely translated to human.

High fructose corn syrup’s most common form, HFCS 55, contains 55% of fructose and 45% glucose. HFCS as a cheaper sweetener has substitute for sugar which contains sucrose and is made from sugarcane and beets. US farm policies have favored the substitution of high fructose corn syrup (Beghin & Jensen 2008). Trade restrictions and production quota are imposed on sugar and hence the domestic sugar price is raised. From 1963 to 2005, the corn price in real term has declined faster than the real sugar price. HFCS became a more attractive alternative sweetener as the price level of HFCS is consistently lower than that of table sugar.

Even though the price level of corn was elevated by the ethanol production, the food processing industry has developed specialized technology to utilize high fructose corn syrup as an input; for instance, besides sweetening food, HFCS can increase shelf-life of bakery goods. Therefore, food policy is unlikely to influence the composition of sweeteners used in manufactured food industries (Beghin & Jensen 2008).

**Ethanol**

Ethanol is produced from corn or sugarcane and added to gasoline to reduce carbon monoxide emissions (Griffin 2013). Ethanol is a step towards cleaner energy source and a less dependent partnership on crude oil. However, government support for ethanol will slice a larger share of US domestic corn production. The percentage of corn production used for ethanol use grew from 0.5% in 1980 (Bandyopadhyay et al. 2013) to almost 43% in 2013 (ERS 2013). Moreover, the energy inefficiency of corn-based ethanol requires vehicle drivers to purchase more ethanol than gasoline to run the same mileage; a unit of ethanol is 37% less efficient than the same amount of gasoline (Griffin 2013). With the growing ethanol demand DC, the new equilibrium corn price PC’ is elevated above the original equilibrium price PC as indicated in Figure 5 (Du et al. 2009).

Some study has shown that the $0.51 per gallon federal subsidy is appealing to corn producers however the subsidy policy will generate inefficiency in resources allocation and limit social benefits (Gardner 2007). Du et al. (2008) confirmed that the federal subsidy on ethanol will result in a significant deadweight loss. On the other side, researchers believed that the federal subsidies has increased relative world corn prices, made the US corn more attractive on global corn market and hence benefited US exporters (Cui et al. 2011).

Ethanol supposedly should result substantially lower energy price at the pump as the gas station and reduce carbon footprint. However, the real benefits of US ethanol policy are disappoint. The gas price benefit is actually 0.2 cents per gallon and we haven’t seen much about reducing greenhouse gases emission. Yet the unintended impacts on the skyrocketed world and US food price are significant (Griffin 2013). As indicated by Figure 6, Iowa ethanol producers has an estimated $0.60 per gallon margin for 2009 and 2010. During the drought in the first half of 2012, the corn price increased sharply due to the limited supply of corn and since corn is a major component of ethanol production, margin for Iowa ethanol producers remained at a near zero level for most of 2012 (Biofuels Issues and
Trends, 2012). After the US ethanol federal subsidy expired in January 2012 (Griffin 2013), the sustainability of ethanol production needs to be carefully reconsidered.

Genetically modified maize
In United States, 90% of corn planted is genetically modified maize (Adoption of Genetically Engineered Crops in the U.S. 2013). Genetically modified crops are designed to be herbicide or insecticide resistant and widely grown in the field. The introduction of transgenic crops has been a controversial issue.

The initial intention of genetically modified crops was to increase productivity and furthermore food quality. GMOs promote sustainable agriculture as they reduce the requirement for agricultural inputs and cut down the burning of fossil fuels in response to the lower market demand for herbicide and pesticides (Buiatti et al. 2013). The adoption of Bt corn could reduce the annual pesticide usage in European by 5.2 tons (Venneria et al. 2008). Edgerton et al. (2013) studied several commercial transgenic Bt corn cultivars and discovered that Bt transgenic insect resistant corn cultivars exhibits a significant higher average crop yield and 67% less damaged than unprotected corns. As GMOs are presumed to increase food quality, the study by Venneria et al. (2008) who researched nutritional composition of GM maize showed that there is no significant difference between nutrition components. The insertion of Bt gene does not affect the level of fatty acids, lutein, zeaxanthin, β-cryptoxantina, total phenols contents, and hydrophilic and lypophilic antioxidant activity.

Meanwhile one major health concern that is raised by GMOs is the introduction of genes that are foreign to human diet. Recent research suggested that microRNAs from plants accumulated in mammalian blood but the research failed to point out that the accumulation was only observed in rats who ingest an equivalent of 33kg raw rice in human diet. Since the introduction of commercial genetically modified crops in 1996, there isn’t any toxicity reports (Buiatti et al. 2013). But the uncertainty of safety issues put GMOs in dilemma in the marketplace. Consumers prefer to purchase GM Free products in the interest of environmental protection and personal health security (Bawa and Anilakumar 2013).


Hill, J. et al. (2006). Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. PNAS. 103.


