Productivity and nitrogen retention tradeoffs in bioenergy grasslands

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Most biofuel in the United States is produced from corn grain; however, corn typically requires high levels of nitrogen fertilizer. Also, corn grain biofuels compete with other important uses for corn, such as human food and animal feed. Perennial grassland cropping systems may someday be managed as an alternative source of biofuel that requires fewer fertilizer inputs. This alternative biofuel can also reduce competition with food crops because land that is unsuitable for row crops may be used for perennial grasslands. The diversity and types of plant species present in grasslands, in addition to fertilizer management, may affect rates of nitrogen loss as well as aboveground biomass production.

A study by UW-Madison researchers with the Great Lakes Bioenergy Research Center (GLBRC) found that there may be a tradeoff between biomass production and nitrogen retention in perennial grasslands managed for biofuels. In their study, fertilized switchgrass had higher productivity but also higher nitrogen pollution potential than more diverse perennial grasslands.

Nitrogen losses, often high in agriculture because of nitrogen fertilizer application, have both economic and environmental consequences. At $0.52 to $1.24 per pound of nitrogen, nitrogen fertilizer is an expensive input, yet most crops cannot use the majority of applied nitrogen before it is lost from the ecosystem. Crops with higher nitrogen use efficiency may reduce nitrogen losses and improve farmer profits.

The environment is also negatively affected by excess nitrogen. Nitrous oxide, a greenhouse gas which has an effect on global warming that is about 300 times stronger than carbon dioxide, may be emitted at higher rates from soils with too much nitrogen. Nitrate leaching, especially problematic in fertilized cropland, causes algae blooms in water bodies that can lead to oxygen depletion and eventually "dead-zones" such as the one found in the Gulf of Mexico each year. In addition, nitrate can contaminate drinking water supplies, leading to the fatal condition known as "blue baby syndrome."

Brianna Laube Duran, Chris Kucharik, and Randy Jackson of the UW-Madison Department of Agronomy and GLBRC compared nitrous oxide emissions, potential nitrate leaching, and biomass production from fertilized (50 lbs N/acre/year applied in mid- to late-May) and unfertilized plots of three perennial grassland bioenergy cropping systems: monoculture switchgrass; a native grass mix of Canada wildrye, Indian grass, big bluestem, little bluestem, and switchgrass; and a native prairie mix of 18 grasses and forbs. All were planted in 2008 at the UW-Madison Arlington Agricultural Research Station. The soils at this site are highly productive Plano silt loams formed under the Empire Prairie. The native prairie system contained native species such as Canada wildrye, prairie coneflower, and wild bergamot, as well as non-natives such as Kentucky bluegrass. Measurements were performed during the 2011 and 2012 field seasons. Each year, after all field measurements were complete (late-September 2011 and late-August 2012), the aboveground biomass was harvested to ground level, dried, and weighed to estimate aboveground production.

Diversity effects on nitrogen losses

Fertilized switchgrass had up to seven times higher nitrous oxide emissions and up to six times higher potential nitrate leaching than the fertilized polycultures of native grasses and prairie. Unfertilized switchgrass also had higher nitrous oxide emissions than the unfertilized polycultures. Because polycultures are more diverse, they may contain species that can access different nitrogen reserves in the soil or utilize nitrogen at different times of year. A monoculture, which contains only one species, can only access certain reserves of nitrogen at certain times during the season. Greater access to nitrogen reserves should reduce soil nitrogen in polycultures, which may reduce nitrogen losses because less nitrogen is available to be lost. Diverse cropping systems are also more likely than monocultures to contain one or more plant species that have high nitrogen uptake, again reducing the amount of nitrogen left in the soil.

In this experiment, the addition of cool-season grasses into the polycultures may have reduced nitrogen losses compared to the monoculture switchgrass, a warm-season grass. The cool-season grasses, such as Canada wildrye, were growing and utilizing nitrogen early in the season. This likely reduced soil nitrogen,

Polycultures included native grasses like Canada wildrye.

leading to less nitrous oxide emissions and potential nitrate leaching at the beginning of the growing season. Switchgrass grows most rapidly later in the season and does not use as much early-season soil nitrogen, allowing for greater nitrogen losses from the soil.

Interestingly, nitrogen losses were approximately the same in the native grasses and prairie cropping systems, even though the prairie was more diverse and contained different species. Therefore, a certain level of diversity may be needed to reduce nitrogen losses, but a further increase in diversity may have no effect. In the native grasses, greater amounts of switchgrass and other warm-season grasses (e.g. big bluestem and Indian grass) were correlated with a reduction in potential nitrate leaching. Warm-season grasses are highly productive and have extensive root systems, so they are likely to have enhanced uptake of soil nitrate. Duran explains, "A mix of cool- and warm-season grasses in a bioenergy cropping system may be important in retaining nitrogen across the entire growing season and, by reducing fertilizer losses, may also enhance economic efficiency."

Fertilizer application is expected to increase nitrogen loss by adding nitrogen in a more mobile form to the system. Following this expectation, fertilized switchgrass had higher nitrous oxide emissions and potential nitrate leaching than unfertilized switchgrass. Prairie also had higher nitrous oxide emissions when fertilized. However, nitrous oxide emissions were only slightly higher in fertilized compared to unfertilized native grasses, and fertilizer did not increase potential nitrate leaching in either polyculture. Again, the polycultures included cool-season species that prosper early in the growing season and may better utilize excess fertilizer nitrogen applied at the start of the season. In contrast, warm-season switchgrass does not grow readily at the time of spring nitrogen application.

Diversity effects on productivity

The most diverse cropping system, the native prairie, had the lowest aboveground productivity, while monoculture switchgrass had the highest productivity. Switchgrass was, in part, chosen as a potential bioenergy cropping system for its relatively high productivity, so the researchers were not surprised by its high productivity in monoculture. The polycultures contained less switchgrass, which may explain the lower biomass production. On these productive soils, planting more grasses and including highly productive grass species (e.g. switchgrass, big bluestem, Canada wildrye) may increase polyculture biomass.

Fertilization affected both crop and weed growth differently among the treatments. Polyculture treatments responded to fertilization with greater growth of planted species. In the monoculture switchgrass stands, fertilizer seemed to encourage weed growth but did not increase crop yield. The lack of fertilizer effect in switchgrass may be due to early-season weed encroachment and subsequent herbicide application in the fertilized switchgrass plots in 2012. Following herbicide application, dry conditions may have lead to patchy switchgrass growth and low biomass production. Duran says, "These results emphasize the importance of biodiversity in resisting weed invasion. Though fertilizer was applied at the same time in the monoculture and polycultures, early-season native species were already established in the polycultures, minimizing the growth of weed species."

Tradeoffs

There are many factors besides nitrogen loss to consider when choosing a perennial bioenergy cropping system type, including potential for carbon sequestration, fuel-use requirements, soil type and fertility, and climate. Based on this study, land managers will also have to decide whether the differences in nitrous oxide emissions and potential nitrate leaching among these cropping systems are ecologically and economically significant. For example, in this study, fertilized switchgrass emitted almost two pounds of nitrous oxide per acre more than unfertilized prairie. Because nitrous oxide has a stronger global warming effect than carbon dioxide, this is equivalent to the global warming effect of 587 pounds of carbon dioxide per acre. However, fertilized switchgrass also produced 2.6 tons of biomass per acre more than unfertilized prairie.

This study shows that diverse bioenergy grasslands may help reduce nitrogen pollution, especially when fertilizer is used, but there may be a tradeoff with biomass production. These results may also be applicable to grasslands in the Conservation Reserve Program land as well as pasture systems. Future work will need to study these tradeoffs on soils that are less fertile than those used for this research, as bioenergy cropping systems may be relegated to marginal lands to minimize competition with food crops.

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