Overfertilizing corn undermines ethanol

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Rice University scientists and their colleagues have found that when growing corn crops for ethanol, more means less.

A new paper in today's online edition of the American Chemical Society's journal Environmental Science and Technology shows how farmers can save money on fertilizer while they improve their production of feedstock for ethanol and alleviate damage to the environment.

The research has implications for an industry that has grown dramatically in recent years to satisfy America's need for energy while trying to cut the nation's reliance on fossil fuels.

The team led by postdoctoral researcher Morgan Gallagher as part of her dissertation at Rice discovered that corn grain, one source of ethanol, and the stalks and leaves, the source of cellulosic ethanol, respond differently to nitrogen fertilization.

The researchers found that liberal use of nitrogen fertilizer to maximize grain yields from corn crops results in only marginally more usable cellulose from leaves and stems. And when the grain is used for food and the cellulose is processed for biofuel, pumping up the rate of nitrogen fertilization actually makes it more difficult to extract ethanol from corn leaves and stems.

This happens, they discovered, because surplus nitrogen fertilizer speeds up the biochemical pathway that produces lignin, a molecule that must

be removed before cellulosic ethanol can be produced from corn stems and leaves.

The findings are an important next step in building a sustainable biofuel economy. Plants benefit from some nitrogen from fertilizer to produce the biomolecules they need to grow and function, said Carrie Masiello, an assistant professor of Earth science at Rice and Gallagher's adviser. But for many crops, a little is enough.

"We already know too much fertilizer is bad for the environment. Now we've shown that it's bad for biofuel crop quality too," Masiello said.

While farmers have a clear incentive to maximize grain yields, the research shows a path to even greater benefits when corn residues are harvested for cellulosic ethanol production, she said.

The study, conducted at and in collaboration with the National Science Foundation's W.K. Kellogg Biological Station at Michigan State University (MSU), showed that although feeding the plant more fertilizer increases the grain's cellulose content, grain yield quickly hits a plateau. "The kilograms of grain you get per hectare goes up pretty fast and peaks," Masiello said. At the same time, the researchers found only a modest increase in plant and stem cellulose, the basic component used to produce cellulosic ethanol.

"The implicit assumption has always been that the response of plant cellulose to fertilizer is going to be the same as the grain response, but we've showed this assumption may not always hold, at least for corn," Gallagher said.

Nitrogen fertilization encourages production of lignin within the plant, and without lignin, stalks won't stand. Lignin production comes at the expense of useful cellulose production. The researchers found that lignin

yields from plant residue increased at nearly twice the rate as cellulose in response to nitrogen fertilization, and they said this implies "that residue feedstock quality declines as more nitrogen fertilizer is applied."

Lignin breaks down slowly via bacterial enzymes, and it is expensive to remove by chemical or mechanical processes that create a bottleneck in cellulosic ethanol production. "The ideal cellulosic ethanol crop has no lignin -- except you can't have a plant without it, because it would fall over. Plants need some lignin to maintain structure," said co-author Bill Hockaday, a former Rice postdoctoral researcher and now an assistant professor at Baylor University. "What we want is a low lignin-to-cellulose ratio."

Reducing fertilizer to the bare-bones minimum serves that purpose. "Morgan showed that if you look at kilograms of cellulose per hectare, yields don't increase at the same rate for the grain and the leaves and stems. There's really only a small amount of fertilizer needed if you're cropping strictly for cellulose," Masiello said.

Overfertilization also increases the decomposability of corn residue plowed back into the fields. This implies that soil carbon storage becomes less efficient -- another minus for the environment because storing additional carbon in soil can reduce the atmospheric concentration of carbon dioxide and help crops access soil water.

Issues associated with the runoff of nitrogen from fertilizer into streams and leaching into groundwater are common knowledge, Masiello said. She noted the well-established link between nitrogen fertilizer use in the Mississippi Valley and a "dead zone" -- defined as a lack of life-supporting oxygen -- in the Gulf of Mexico. Nitrate runoff and leaching into drinking water supplies has also been linked to a number of health problems, the researchers wrote.

Finally, Gallagher noted that improving the yield of feedstock for cellulosic ethanol leaves more corn for food. "There's a billion people who are malnourished, so it's ethically questionable to use corn grain for fuel rather than food," she said.

The researchers hope their methods can be transferred to other crops grown for ethanol. Gallagher, who recently earned her doctorate at Rice and is starting a joint postdoctoral stint between Masiello's lab and the NSF agricultural research station at Michigan State, plans to quantify the effects of nitrogen fertilization on switchgrass, which is growing in importance as a biofuel feedstock.

More information: Read the abstract at pubs.acs.org/doi/abs/10.1021/es103252s

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