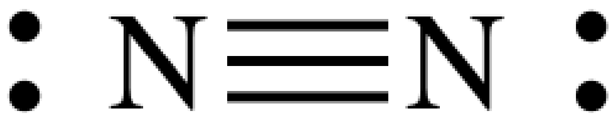
GMO sustainability frontier: Helping crops acquire their own nitrogen

It comprises 78 percent of our atmosphere, yet it enters and leaves your lungs unchanged. That's partly because the triple bond holding its two atoms together is really hard to break up, and that's why most plants don't do anything with it either.

Molecular nitrogen (N_2) has loads of chemical energy packed into that triple bond, and nature has ways to break it up. In a process called *nitrogen fixation*, energy is consumed to convert atmospheric N_2 into compounds like ammonia (NH_3), ammonium (NH_4^+), and nitrate (NO_3^-), which plants are equipped to utilize in their growth. Physical forces that can do this include volcanism and lightning strike, but certain bacteria and certain archaea also can fix nitrogen using an the enzyme *nitrogenase*, which breaks up N_2 and adds hydrogen, producing ammonia. In another process, called *nitrification*, soil bacteria can convert ammonia to nitrate, which plants love, though plants also can utilize ammonium, the ionic form of ammonia.



Despite these mechanism, however, nitrate is not concentrated enough in most soils to produce the kind of agricultural yields needed to support the human population —plus the livestock that many humans prefer as a source of protein. Consequently, farmers must enrich soils with nitrogen fertilizers, which go into the roots of plants where they're needed, but also end up in places where they're not wanted. Furthermore, their production is costly and energy consuming.

So this raises a question: Might we instead use our biotechnology to enable food crops to fix their own nitrogen?

The answer is yes; people are working on it with potential benefits not only in terms of cost, but also in terms of environmental stewardship. But, somewhat analogous new generation nuclear power, advocates of nitrogen fixation biotech are also tasked to win over the public in a political and cultural landscape that has been plagued with an intense distrust of any biotechnology.

Climate change issues

Fertilizers can be synthetic or, for lack of a better term, *natural*, and use of either category of fertilizer entails tradeoffs of pluses and minuses. When it comes to synthetic fertilizers, for instance, they have enabled dramatic yields of staple crops in large-scale agriculture, but the quantity of energy that goes into producing them and putting them into the soil is staggering. It's roughly two percent of all of the energy that human civilization consumes and that's with a high carbon footprint, since the machinery for putting them into soil is powered by fossil fuels. For this reason, biotechnology aimed at making staple crops like cereals capable of nitrogen fixation, thereby eliminating the need for fertilizer, is emerging a pathway to a green, more sustainable future.

Two basic strategies

The direct approach for making plants self-fertilizing is a transgenic strategy. You give them the *nitrogenase* gene from bacteria. It's not as simple as just banging the gene into the plant genome though, *nitrogenase* is a complex enzyme whose activity is obstructed by oxygen, which is plentiful in plant cells and must be kept away from the enzyme. There are tricks that can be adapted from cyanobacteria and other organisms that produce *nitrogenase* in high-oxygen environments, but researchers need to work out which trick is optimal, and this includes deciding where exactly to put the gene—in the cell's nuclear genome, or in the chromosomes of the cells mitochondria (the energy organelles) or chloroplasts (organelles of photosynthesis)?

The indirect approach is to leave nitrogen fixation to microorganisms, but make that happen inside the plant, instead of the soil. Certain plants, particularly legumes (includes soybeans, peas, beans, alfalfa, clover, peanuts, beans, lentils, and carob), already fix nitrogen, not within their own cells, but through a symbiosis with nitrogen-fixing bacteria. But imagine if this capability could be transferred into cereal crops, such as wheat. Doing this is a major goal of the John Inness Centre in Norwich, UK, where researchers are using the indirect approach with the goal of producing wheat that can outgrow any wheat, and without fertilizer to boot.

Cereal crops actually do have their own symbiotic bacteria that live in various nooks and crannies in the plant, so some researchers are working on transferring the *nitrogenase* gene into those bacteria. However the thrust of the Inness Centre strategy for nitrogen fixing wheat is to make the wheat attract bacteria from soil that have nitrogen fixation already, the kind of bacteria that live symbiotically inside legumes. The tactic involves manipulation of the wheat's gene expression causing the plant to sense the presence of the nitorgen-fixing bacteria and take them inside nodules in the roots. Within a few years, it's anticipated that this could lead to nitrogen fixation, in wheat, and also corn and canola.

Advantages for big and small agriculture

Nitrogen fixing cereals could be extremely valuable for big farms, since they would avoid the need for massive amounts of fertilizer and that entails, but economics is just one factor.

"Through combining scientific excellence with strategic relevance that we can address the major societal and environmental challenges that lie ahead," said Professor Dale Sanders, the John Inness Centre Director.

The carbon footprint of growing these staple crops would be reduced dramatically, along with environmental issue, such as those connected with nitrate runoff. Potentially, the technology could also help small farmers to compete, since they also could avoid the expensive fertilizers as well as the needed safety measures to contain them. As for organic farms that already avoid synthetic fertilizers but use manure, compost, or other methods, they also would stand to benefit from nitrogen fixing wheat. The risk of coliform bacterial infection associated with manure fertilization is not exclusive to organic farms, since manure is also used in some conventional farming. But the infection risk is nevertheless statistically higher among organic farmers, and it's plausible that some organic farms would consider replacing their cereals with engineered nitrogen fixing varieties. This is true, particularly for nitrogen fixing wheat developed with GE methods, rather than through transgenic approaches, since farmers could still be organic-certified, even in areas, such as in the EU, with strong restrictions on GM crops. To be sure, the distinction between transgenic and GE may not be rational in terms of safety, but it can affect how a product develops by affecting the legal and political environment. And as the technology advances it could end up being a win-win scenario for parties with differing perspectives on biotech policy.

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