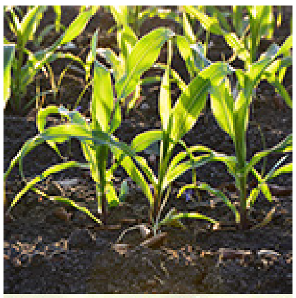
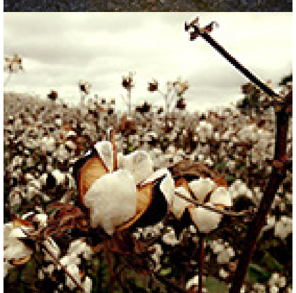
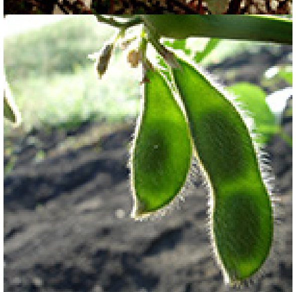
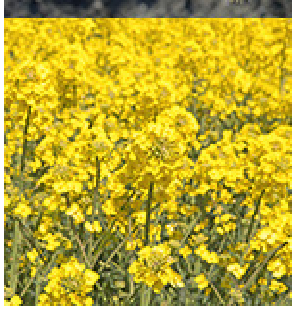
Genetic Engineering and Society Center

Synthetic Microorganisms for Agricultural Use

By 2050, the world's population is estimated to exceed 9 billion people. A challenge to this rising food demand is that crops will have to be grown on the same or less land as today. Additionally, global climate change is causing considerable uncertainty in the ability of the current food production system to adapt to an unknown future.

To address these issues sustainably, scientists from many disciplines have been investigating ways to increase crop yields and prepare for a changing climate. Considerable effort has focused on enhancing the traits of the crop plants themselves, to enhance their growth, make them resistant to disease, or tolerant to environmental stressors like drought or high salinity conditions. Conversely, a growing area of research is looking at how microorganisms, such as bacteria and fungi, influence these plant characteristics.

The relationship between plants and microorganisms is well known. However, researchers are still working to understand the full complexity and extent of interactions between the two groups. We have seen that microbes are important for plant nutrient acquisition, plant growth and protection against disease. Certain types of bacteria are commercially available and used to increase yields and decrease fertilizer use (Farrar et al. 2014).

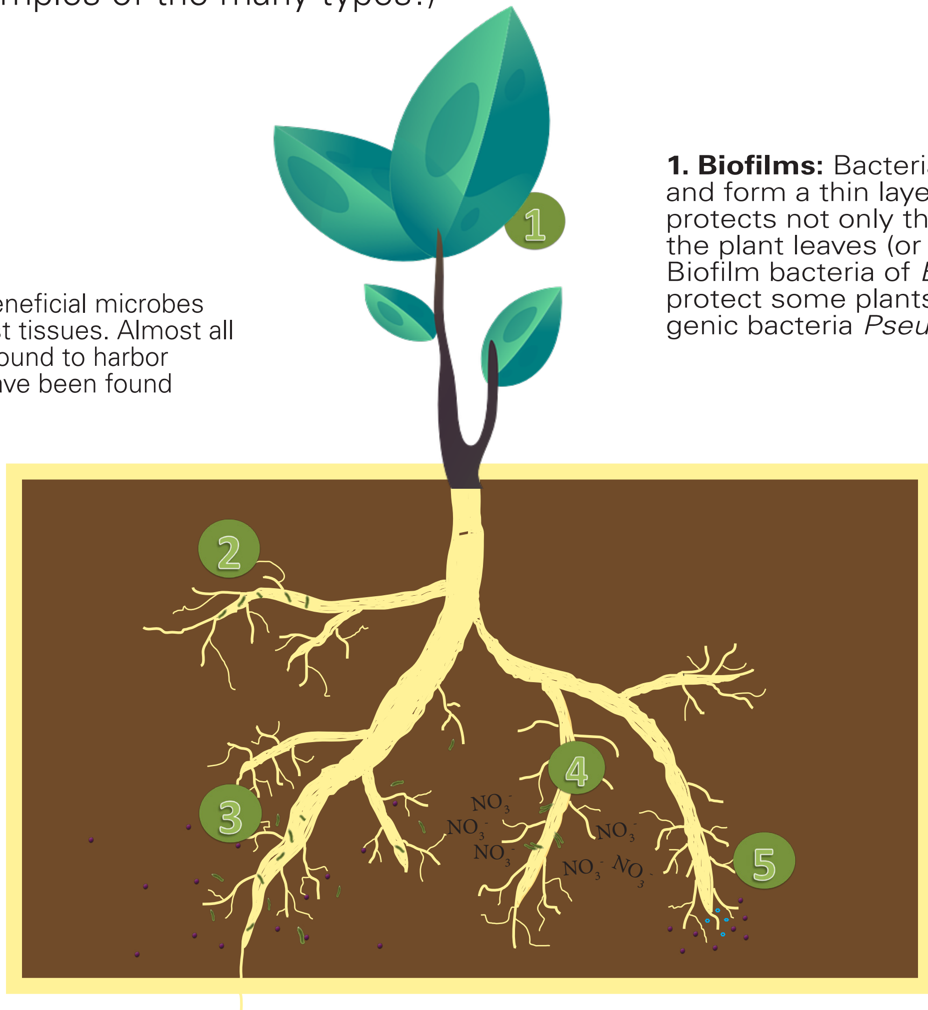
Synthetic biology may be able to create a suite of microorganisms that will benefit crops in various ways (see Table 1). A type of genetic engineering, synthetic biology can be described as the "repurposing and redesign of biological systems for novel purposes or applications" (Marner 2009). Scientists are trying to design microbes that will perform reliably and target specific plant/microbe interactions. This issue brief describes current research on the topic and discusses issues that may arise should a synthetic microbe become available for environmental release.

Potential Benefits
Reduced use of synthetic fertilizer, enhanced plant growth, increased plant protection, increased plant nutrition, tolerance to environmental stressors
Potential Concerns
Uncertain ecological effects, cost/ownership of technology, regulation, public perception/acceptance, limited knowledge of plant/microbe relationships

Table 1. Benefits and concerns around the use of synthetic microorganisms in agriculture. See page 3 for expanded discussion.

Types of Plant/Microbial Interactions

(Just a few examples of the many types!)



1. Biofilms: Bacteria can congregate and form a thin layer of film that protects not only the bacteria but also the plant leaves (or roots) it sticks to. Biofilm bacteria of *Bacilus subtilis* protect some plants from the pathogenic bacteria *Pseudomonas*.

2. Endophytes: Beneficial microbes that live within host tissues. Almost all plants have been found to harbor endophytes and have been found throughout plants.

3. Phytohormone production: Bacteria respond to and can influence the types of hormones produced by the plant, which can have effects on plant growth.

4. Nutrient acquisition: Many microorganisms produce compounds and minerals as by-products that are useful for plant nutrition. For example, nitrifying bacteria converts ammonium to nitrate, which can then be taken up by the plant.

5. Rhizodeposition: Plants deposit compounds into soil around the roots which alters the surroudning microbial community through attraction or repulsion. However this type of signaling varies by both plant species and microorganisms present in the soil.

Why use synthetic biology?

The goal of using synthetic biology is to create microbes with known functions that will act reliably and specifically. This can be accomplished by creating new organisms, by using parts of genomes from different species, or by reducing the genomes of existing species. For example, reducing the genome of *Streptomyces avermitillis* by 18.5% led to an increased production of antibiotics (Komatsu et al. 2010). Creating genome-reduced microbes can reduce complexity and the production of unwanted products and enhance the desired metabolic pathways.

Engineered synthetic bacteria and fungi are not meant to replace or alter existing soil microbial communities. Rather, scientists are working to develop single or multiple synthetic microbes to promote benefits to crop plants reliably and be functionally resilient under different environmental conditions. Early work on synthetic microbes focused on the production of biofuels and other industrial products, but now is being expanded for other applications.

Potential Benefits

Decreased synthetic fertilizer use
Scientists are working to develop nitrogen-fixing bacteria for a wider number of crops. Bacterial inoculation of wild rice increased plant biomass equivalent to 40kg N/ha application of nitrogen fertilizer (Baldani et al. 2000).

Enhanced plant growth
Plant growth promoting bacteria (PGPB) can drastically increase biomass of plants. *Enterobacter* sp. inoculated poplar seedlings increased biomass by 55% (Rogers et al. 2012). PGPB could be used to increase yields and decrease fertilizer usage.

Increased plant protection
Beneficial microbes can protect crops from pathogenic bacteria, reducing disease incidence and/or virulence (Farrar et al. 2014). This is especially important when pathogens evolve resistance to natural plant defence mechanisms.

Increased plant nutrition
In addition to nitrogen, microbes can provide an array of nutrients that are beneficial to growth and health.

Tolerance to environmental stressors
Some bacteria, like *Burkholderia phytofirmans*, can help protect several crops, like maize, wheat, and grapes, against drought by increasing water-use efficiency (Farrar et al. 2014). Research is also being conducted into ways to enhance plant tolerance to high saline conditions. Other *Burkholderia* spp. can help reduce stress response in plants, promote plant growth and produce nitrogen as a by-product. These species may be important for reducing the use of chemical fertlizers.

Potential Concerns

Uncertain ecological effects
How synthetic organisms will behave in nature is an open question. Once synthetic bacteria are released, they cannot be recalled. Research into how these microbes will affect the environment and whether or not they can be safely released will be important before any field releases are conducted.

Cost/ownership of technology
Cost is currently unclear. Corporations, non-profits and universities are developing synthetic microbes for agriculture that may be distributed with an as-yet unknown cost structure. Products available may require single (self-replicating) or periodic applications.

Regulation
No genetically engineered microorganism has been approved for environmental release in the United States. Concerns about horizontal gene transfer between microbes and other environmental effects may affect their regulation.

Public acceptance/perception
Significant public concern exists about genetically modified organisms currently used in agriculture. It is unclear whether an engineered bacteria used to help grow crops would be acceptable or unacceptable to consumers.

Limited knowledge about plant/microbe relationships
The depth and breadth of plant/microbe interactions remains unknown. In some cases, a bacteria is beneficial to one plant, but harmful to another. The full range of possible interactions needs to be explored prior to release.

The Genetic Engineering and Society Center at NC State University hosted a workshop on synthetic biology governance in 2013, funded by the Alfred P. Sloan Foundation. The workshop goals were to use specific proposed applications of synthetic biology to discuss research priorities, governance needs, and societal implications ahead of technology deployment. One group focused on using synthetic biology to improve and expand upon existing nitrogen fixing relationships between plants and bacteria. Some of the major themes that emerged from this discussion include: whether or not there is a societal need for this technology, the impacts of altering plant evolutionary processes (e.g., if N-fixing is beneficial, why don't more plants exhibit this symbiotic relationship?), whether current regulatory systems are adequate to handle the complexity this new technology could introduce, and various potential environmental effects, such as gene flow to other organisms, impacts to soil health and preventing nitrogen pollution from currently-used synthetic fertilizers. The report with a full description of the workshop and outcomes is available online at https://research.ncsu.edu/ges/files/2014/04/Sloan-Workshop-Report-final-ss-081315-1.pdf.

References and Resources:

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This issue brief has been produced by the Genetic Engineering and Society Center at NC State University, whose mission is to serve as a hub of interdisciplinary research & analysis and inclusive dialogue surrounding opportunities and challenges associated with genetic engineering and society.

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