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Nigeria: Sustainable Agriculture (also Water Scarcity, Populations, Education, Foreign Aid)

Nitrogen-Fixing Microbes: A Renewable, Clean Alternative to Expensive, Environmentally Harmful Nitrate (NO_3) and Ammonium (NH_4) Corn Fertilizers

Located on the west coast of Africa, Nigeria is about twice the size of California. Two hundred twenty million people live in Nigeria – more than any other African nation. Its population is young and growing. Sixty two percent of Nigerians are under the age of twenty-four, and each Nigerian woman gives birth to an average of 4.67 children. Its high birth rate is projected to make Nigeria the world's fourth most populous country by 2050.

Nigerian agriculture is vital to feed its rapidly growing population. Seventy eight percent of Nigerian land is devoted to agriculture. Seventy percent of its labor force works in agriculture, and forty percent of Nigerians live below the poverty line. Primary crops include maize (corn), cassava, yams, oil palm fruit, rice, sorghum, groundnuts, and sweet potatoes (CIA, 2022). Each year, Nigeria produces over eleven million metric tons of corn (Cook, 2022).

Two large scale factors are affecting whether humankind will be able to sustain our global food sources. First, limited agricultural land must produce more food as populations expand. Second, we must do so without harming our soils and surrounding water sources. Fertilizer use – a chief method of producing more food on limited land – can be quite harmful to our environment. Fertilizer has also become very expensive to buy or produce. My paper provides Nigerian corn farmers with a low-cost, renewable, clean alternative to expensive, environmentally harmful nitrate (NO_3) and ammonium (NH_4) fertilizers.

While a balanced diet of fruits, vegetables and proteins is always recommended, this paper focuses specifically on corn's inability to draw nitrogen from the air or soil, and provides a solution to corn's dependency on expensive, environmentally harmful fertilizer for its source of nitrogen.

Corn is a Nigerian baby's first food, introduced at 3 to 6 months in the form of a thin gruel called pap (Public Health Nigeria, 2022). Corn remains an important staple throughout a Nigerian's life. It is calorie-dense and rich in vitamins A, C and E, carbohydrates, dietary fiber, protein, and essential minerals. (Foramfera, 2018).

Corn is a truly global food, essential to people and livestock around the world. The USDA projects the world to produce 1.21 billion metric tons of corn this year (Cook, 2022). Corn can be consumed in a wide variety of ways: as a vegetable (fresh, frozen or canned) alone or mixed into soups, salads or stews. Corn can be ground and mixed with water to make southern grits, Italian polenta, or eastern Africa's ugali. Corn flour or cornmeal are used to make cornbread, tortillas, and corn chips. Corn oil is used in cooking and baking. Corn syrup is used in soft drinks and sweets. Corn starch is used in the food industry as well as in the textile, pharmaceutical, and paper industries (Iowa Corn Growers Assoc., 2022).

Corn is also an important staple for livestock. For example, nearly 40% of corn produced in the United States is used as livestock feed, about half of this for beef and dairy, the other half for poultry and pork (Iowa Corn Growers Assoc., 2022).

Corn is used to make ethanol, a fuel mixed with gasoline to create cleaner-burning fuel for cars. More than 98% of gasoline sold in the U.S. contains ethanol (US Dept of Energy, 2022) and a third of the corn grown in the United States is used to make ethanol (Iowa Corn Growers

Assoc., 2022). According to the Environmental Protection Agency, any gasoline engine (including cars, boats, motorcycles, and other small engines) can use fuel up to 10% ethanol (E10), all cars manufactured after 2001 can use E15, and flexible fuel vehicles can use higher concentrations of ethanol fuels: E20, E30 and E50. The American Lung Association launched its Clean Air Choice campaign to let people know that adding ethanol to gasoline is a renewable way to make fuel burn cleaner and reduce toxic emissions (American Lung Association, 2021). While producing ethanol remains somewhat energy intensive, a 2020 study by Argonne National Laboratory found that substituting corn-based ethanol for gasoline reduces life cycle greenhouse gas emissions by 40% (US Department of Energy, 2022).

Humankind's reliance on corn – as food, feed and fuel – is clear. Just as we depend on corn, corn depends on nitrogen.

Nitrogen is a key plant nutrient. Lack of adequate nitrogen leads to lower crop yield or even crop failure. Farmers add organic (animal manure or compost) and inorganic fertilizer containing nitrate (NO_3) or ammonium (NH_4) to feed corn nitrogen. "Without fertilizer, the world's food production would be cut by 48%. Fertilizer is the fuel that powers modern agriculture" (Temme, 2018).

However, fertilizer is expensive, and its cost continues to rise rapidly. Just prior to the war in Ukraine, fertilizer had made up about a third of a corn farmer's total costs. Fertilizer prices were on the rise driven by high demand and tight supply of many fertilizer ingredients. Prices were expected to nearly double in 2022, bringing fertilizer costs to 45% or more of total corn growing costs (Thiesse, 2021).

Since the war in Ukraine began, the price and availability of fertilizer has become even more dire. The world has come to realize just how dependent it is on Russia's exports of both fertilizer and fossil fuels. Farmers are attempting to buy nitrogen fertilizer from other suppliers, but it is difficult given Russia's dominance in the market. As countries attempt to make their own fertilizer, they discover how fossil fuel intensive the nitrogen fertilizer manufacturing process is.

Russia remains the world's largest exporter of nitrogen fertilizer (nitrogen fertilizers make up four-fifths of fertilizer worldwide). Russia is also the second largest exporter of phosphorus and potassium fertilizers (which make up 16 and 3 percent of worldwide fertilizers, respectively). In 2021, Russia exported $12.5 billion in fertilizer or 15.1% of worldwide exported fertilizers. The United States, by comparison, had a $6.2 billion fertilizer *deficit*, meaning it imported $6.2 billion more fertilizer than it exported.

Early this year, the Associated Press interviewed farmers in Kenya whose fertilizer prices had increased to five times to what they were before the war. One farmer reported that, "Continuing to work the land would yield nothing but losses." (Kaviti, 2022). Many agricultural challenges – weather; plant disease; insect, worm or rodent invasion – lie largely outside a farmer's control. It is disheartening to think that fertilizer use – one of the few variables farmers could historically control – is now a farmer's greatest worry.

In addition to being costly, fertilizer is also harmful to our soils, water, and air. Rain carries fertilizers into our streams and rivers causing algae blooms that suffocate fish. "Worldwide fertilizer-linked pollution is responsible for more than 500 dead zones: places so toxic that nothing lives. One of the largest is where the Mississippi River empties into the Gulf of Mexico. It's the size of New Jersey" (Temme, 2018).

The amount of nitrate in water is an important water-quality indicator. The EPA has set a maximum allowed amount of N and NO3 in drinking water. Fertilizer runoff has been linked to acid rain, the suffocation of fish and other marine life, amphibian mortality and deformations as well as blue baby syndrome in infants (Ketterings, 2003).

Nitrogen fertilizer manufacturing is energy intensive and a significant producer of greenhouse gasses. "Ammonia used in fertilizer is currently produced by the Haber-Bosch method which reacts molecular nitrogen with hydrogen at high temperatures (over 400 Celsius). The production of ammonia is responsible for 2% of the world's annual energy consumption" (Brundeen, 2021). Fritz Haber and Carl Bosch, invented this method of producing ammonia (NH3) in the early 1900's. After ammonia is made into nitrogen fertilizer, additional fossil fuels are needed to transport the fertilizer to farms around the world.

A small portion of chemical fertilizer decomposes into nitrous oxide (N_2O). According to the EPA, N_2O – a greenhouse gas that stays in the atmosphere for 114 years – is 300 times more potent than carbon dioxide (CO_2). Seven percent of U.S. greenhouse gas emissions are N_2O and three-quarters of this is generated from agricultural activities such as the use of nitrogen fertilizers (EPA, 2021). Accordingly, one company estimates that the decomposition of fertilizer is responsible for about 5% of global warming (Temme, 2018).

With no way to feed corn plants nitrogen, other than expensive, environment-harming fertilizer, farmers attempt to apply just enough fertilizer to yield healthy corn crops. This application is both a science and art. Cornell's College of Agriculture and Life Sciences provides a table recommending fertilizer rates for corn but also warns that nitrogen fertilizers can be lost in wet weather and recommends accessing nitrogen use by examining the crop in hindsight (CALS, 2022).

Surprisingly, the nitrogen that corn plants need to grow occurs naturally and abundantly. Nearly 80% of our atmosphere is made up of nitrogen. Nitrogen gas (N_2) is chemically stable though and remains inaccessible to most crops, including crops in the grass family such as corn (Ketterings, 2003).

A few crops – such as legumes – can access and absorb atmospheric nitrogen thanks to bacteria on their roots. This process of adding atmospheric N_2 to the soil is called biological N fixation, or nitrogen fixing (Ketterings, 2003). Legumes such as alfalfa, lentils, peas, peanuts, soybeans and clover automatically add nitrogen to soil while both growing and decomposing. So, clover is often planted in lawns; legumes such as soybeans or alfalfa are often rotated or planted with corn.

A small California-based company, Pivot Bio, believes naturally occurring nitrogen-fixing bacteria for corn has become dormant by a century of synthetic chemical fertilizer use. Incredibly, Pivot Bio has been able to identify microbes that are both 1) attracted to corn roots and 2) contain nitrogen-fixing DNA. Pivot Bio mapped "trillions of interactions between living organisms in the soil to identify the rare microbes with the right internal DNA software to produce nitrogen." (Pivot Bio, 2022). After they identified these tiny nitrogen factories, Pivot Bio's began growing nitrogen-fixing microbes by fermentation in an inexpensive sugar-water solution (Havens, 2021).

In 2019, Pivot Bio began commercially working with farmers to replace their nitrogen fertilizer with inexpensive nitrogen-fixing microbes. This field work is ongoing.

Farmers simply add Pivot Bio's nitrogen-fixing microbes to their soil when they plant corn seed. When the corn plant begins to grow, the microbes attach themselves to the corn plant's roots and feed off a waste the corn plant produces called exudates. This gives the microbes the energy they need to start pulling nitrogen (N_2) from the atmosphere and converting

it into ammonia (NH_3) – a form of nitrogen that both the microbes and corn plant can absorb. The microbes absorb some of the nitrogen, while the corn plant absorbs the excess nitrogen produced by the microbes.

Microbes remain attached to the corn roots due to their symbiotic relationship. Rain does not wash them away, nor do they volatilize (as fertilizers do) into toxic nitrous oxide. Until now, farmers could only dream of having a nitrogen source that is weatherproof.

When the corn plant dies at the end of the growing season, the microbe's food source also dies, and the microbes diminish or die off. The soil and surrounding water sources do not become contaminated as might be the case with heavy fertilizer use.

Farmers no longer need to buy, apply and reapply nitrogen fertilizer. Less testing is also required. Each corn plant absorbs only the nitrogen it requires to grow. Nitrogen-producing microbes are a more reliable, cost-effective, and environmentally friendly method of delivering plant nutrition (Mower telephone interview, 2022).

Decreasing or eliminating nitrogen fertilizer has immediate environmental benefits for the farming soils and surrounding waterways. Removing the need to manufacture ammonia by the energy-intense Haber-Bosch method will reduce energy consumption and greenhouse gasses by 2% worldwide (Brundeen, 2021).

In summary, corn is a versatile food, vital to feeding people and livestock around the globe. Corn is also used to make ethanol, which is mixed with gasoline to make a cleaner-burning fuel. Just as we depend on corn, corn depends on nitrogen. Nitrogen is plentiful in our atmosphere, but plants cannot absorb atmospheric nitrogen without the help of microbes that live symbiotically on their roots. Pivot Bio believes a century of fertilizing corn plants has made nitrogen-fixing microbes for corn (and many other crops) dormant. Pivot Bio has had great success identifying these microbes and growing them in inexpensive sugar-water. Replacing costly, environmentally damaging fertilizer with eco-friendly, naturally occurring microbes has recently begun to benefit corn crops in the United States.

Pivot-Bio's discovery is particularly well-timed as the war in Ukraine is causing the entire world to look elsewhere for a nitrogen source for its crops. Countries looking to manufacture nitrogen fertilizer themselves by the well-established Haber-Bosch method, have found that the high cost of fossil fuels (also caused by the war in Ukraine) makes the energy-intensive process too expensive.

Corn is an important crop and food source for Nigeria's young and growing population. I recommend bringing Nigeria's corn farmers the technology of nitrogen-fixing microbes by partnering with organizations such as Thrive whose mission is to create "a self-sufficient Africa that feeds itself and the world" (Thrive Agric, 2022). Several Nigerian Government initiatives may be helpful as well including the Agriculture Promotion Policy (APP), Nigeria-Africa Trade and Investment Promotion Program, and Nigeria Erosion and Watershed Management Project (NEWMAP). The goal of these programs is to increase agricultural productivity to meet domestic demand as well as promote sustainable management of natural resources and rehabilitation of degraded lands (Food and Agriculture Organization of the United Nations, 2022).

Pivot Bio's mission is to replace all nitrogen fertilizer with microbes that adhere to the crop's root system and feed the crop nitrogen as they need it (Temme, 2018). The discovery of nitrogen-fixing corn microbes and the elimination of harmful fertilizers makes me very optimistic about the future of our global food security and the sustainability of our planet.

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