**The Role of Symbiotic Nitrogen Fixation in Sustainable Production of Biofuels**

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**Abstract**

What type of symbiotic relationship is occurring between the nitrogen fixing bacteria and the legumes? Explain.

With the ever-increasing population of the world (expected to reach 9.6 billion by 2050), and altered life style, comes an increased demand for food, fuel and fiber. However, scarcity of land, water and energy accompanied by climate change means that to produce enough to meet the demands is getting increasingly challenging. Today we must use every avenue from science and technology available to address these challenges. The natural process of symbiotic nitrogen fixation, whereby plants such as legumes fix atmospheric nitrogen gas to ammonia, usable by plants can have a substantial impact as it is found in nature, has low environmental and economic costs and is broadly established. Here we look at the importance of symbiotic nitrogen fixation in the production of biofuel feedstocks; how this process can address major challenges, how improving nitrogen fixation is essential, and what we can do about it.

What is biofuel? (look it up if you are unsure)

**Keywords:** biofuel, legumes, life-cycle analysis, nitrogen fixation

**1. Introduction**

Two of humanity’s major needs are food and energy. With the human population rising at an alarming rate (1 billion increase from present 7.2 billion in the next 12 years (UN estimate)), food security, mainly due to increasing scarcity of land and water resources has become a major political and scientific concern. Ever since humans transitioned from hunter-gatherers to a stable agriculture-based society, improvement of crops has been a major goal. Early farmers observed that land became less productive when planted year after year and concluded that plants absorbed certain nutrients from the soil. In the 1730s, crop rotation was implemented in Europe as a method to improve productivity of major crops. However, it was not until the mid-1800s that the understanding of plant nutrition had advanced enough to realise the importance of added nitrogen and phosphorus to the soil. The German chemist Justus von Liebig was the first to promote the importance of ammonia and inorganic minerals to plant nutrition and developed the first commercial fertiliser by treating phosphate of lime in bone meal with sulphuric acid. Although this failed, because of not being properly absorbed by the crops, it started a trend in fertiliser development. The early fertilisers were mainly based on manures and the effects of many types of manure on plant growth were tested and used. The Rothamsted (UK) Research Station, started at this time by the British entrepreneur John Bennet Lawes and Joseph Gilbert (a student of von Liebig) is still involved in the study of the effect of organic and inorganic fertilisers on crop yield.

Why does it make sense to use stanky manure (poop) to fertilize crops?

However, it was not until the process of atmospheric nitrogen fixation was established, first by Henry Cavendish in 1784, that synthetic fertilisers became widespread. His process was soon replaced by a more efficient Haber-Bosch process, which revolutionised agriculture and won the inventors Fritz Haber and Carl Bosch a Nobel Prize in chemistry (separately in 1918 and 1932!). The process utilises molecular nitrogen (N2, available in abundance (78%) in the atmosphere) and methane (CH4) in an economically sustainable, though environmentally expensive synthesis of ammonia (NH3). The ammonia produced this way is used as a raw material by the modern chemical industry for the production of most of the commonly used fertilisers, such as nitrates. The Haber-Bosch process is one of only three ways in which inert atmospheric N2 is converted to NH3, the other two being biological nitrogen fixation by prokaryotic microbes containing the nitrogenase enzyme complex, and geochemical conversion by lightening. Today crop producers world-wide rely heavily on synthetic fertilisers to enhance plant productivity; this trend seems likely to continue as a steadily rising population needs increased food mass and quality as well as renewable fuel.

What are three problems with using synthetic fertilizers?

Why was Haber-Bosch’s invention such a big deal?

The problem with the “fertiliser scenario” is that plants absorb at any one time only a small percentage of this applied supplement. The majority of it (30% to 50%) [[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4057678/#b1-ijms-15-07380)] is wasted and runs off into waterways, causing environmental pollution on a massive scale (*i.e*., the Mississippi River Delta). In many areas algal blooms and eutrophication are huge problems. In addition the nitrogen in the soil is broken down by soil bacteria, through a process called denitrification, to N2O (nitrous oxide), which reacts with oxygen to give rise to NO (nitric oxide), which in turn reacts with ozone (O3). Natural sources of N20 are soils (contributing 6.6 Tg N/year), oceans, rivers, and estuaries (contributing 5.4 Tg N/year). According to the US Environmental Protection Agency (EPA), N2O has about 294 times higher impact per unit mass (global warming potential) than carbon dioxide and therefore even in small quantities can contribute as GHG in a big way. Application of nitrogenous fertilisers accounts for the majority of N2O emissions. It has been suggested that for every 100 kg of fertiliser N added to the soil, on average 1.25 kg of N is emitted as N2O, which is equivalent in GHG effect to around 600 kg of CO2. The GHGs affect the temperature of the earth by absorbing and emitting radiation within the thermal infrared range (the “Greenhouse Effect”).

Moreover, every step in the production, delivery and application of nitrogen fertiliser requires fossil fuels. Even though formation of fossil fuels is occurring naturally through anaerobic decomposition of buried plants and animals, they are considered non-renewable as they take millions of years to form in large quantities, and reserves are being depleted much faster than new ones are being formed. The world energy consumption has increased dramatically in recent times, growing at the rate of 2.3% each year [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4057678/#b2-ijms-15-07380)]. Unfortunately an estimated 86% of this energy comes from burning of fossil fuels (36% from petroleum, 27% from coal and 23% from natural gas [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4057678/#b2-ijms-15-07380)]. The current demand for oil from fossil fuels is around 85 million barrels per day (about 159 litres per barrel), which is expected to rise to around 106 million barrels per day by 2030 [[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4057678/#b3-ijms-15-07380)]. In addition, burning of fossil fuel is considered to be the largest source of GHG emissions due to human activity, with electricity production (coal combustion), transportation (petrol, diesel and aviation fuel) and industry (gas and coal) being the major culprits.

**Symbiotic Nitrogen Fixation**

Plants of the Leguminosae (legume) family can provide an option for reducing our heavy reliance on nitrogen fertilisers. Legumes are unique in that they have the ability to form a symbiotic relationship with soil bacteria collectively called “Rhizobia.” The bacteria are housed in special root organs called “nodules” where they fix atmospheric nitrogen gas to ammonia, which the plant can use. In return, the bacteria derive plant carbohydrates, mainly for food and the energy they need to perform nitrogen fixation. The importance of this process is enormous as it reduces the plant’s and thus agriculture’s dependence on nitrogen fertilisers. It has been estimated that biological nitrogen fixation produces roughly 200 million tonnes of nitrogen annually [[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4057678/#b4-ijms-15-07380),[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4057678/#b5-ijms-15-07380)].

It would be a huge benefit to humanity and the environment, if all agriculturally important plants could be made to fix nitrogen. This today seems unlikely as the physiological barriers are multi-fold and even despite large advances in knowledge, unknown. With this end in mind a lot of work has been carried out to understand the process of symbiotic nitrogen fixation, which can be thought of as consisting of three components; first, the formation of nodules which provide the correct environment for housing the nitrogen-fixing bacteria; second, the regulation of symbiotic tissue (*i.e.*, nodule numbers) by internal and external factors, and third, the actual conversion of atmospheric nitrogen into ammonia by the invading bacteria using the nitrogenase enzyme complex and its associated biochemical machinery.

How could you use the information in the last two paragraphs to become a billionaire/ Nobel Prize winner?