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Chemistry in a coffee cup: does coffee waste contain key elements for plant growth?

Infosheet 3: History of fertilizers

At the turn of the 20th century, agriculture was transformed by the discovery of how to make **ammonia** out of thin air: the Haber Bosch process that combines nitrogen, which makes up 78% of the Earth's atmosphere, with hydrogen to give ammonia (NH_3).[1]

$$N_2 + 3H_2 \leftrightharpoons 2NH_3$$

This process is key, since plants need inorganic nitrogen compounds to grow. They can't take up gaseous N_2 from the air and 'fix' it, that is, split the two nitrogen atoms apart and incorporate them into other compounds. Some plants, especially many legumes, host bacteria in special structures in their roots called nodules, and these bacteria can fix nitrogen. It has been known for a very long time that these plants improve the soil. For this reason, they have been important in traditional agriculture around the world, for example, the 'three sisters' crop system used by Native Americans.[2] Otherwise, after a while, the nitrogen compounds in the soil can be used up, and they need to be replenished in the form of fertilizers. But how did we learn what compounds plants need to grow?

The little lumps on the roots of this bean plant are the nodules that host the nitrogen-fixing bacteria. The nodules are like little chemical factories, where nitrogen 'fertilizer' is produced from nitrogen gas in the air.
Image: Foxy Tigre/Wikimedia Commons, CC BY 2.0

Until the middle of the 19th century, there was a dispute about the importance of nitrogen for crop production. The 19th-century German chemist Justus von Liebig incorrectly calculated that plants obtained all the nitrogen they needed for growth from rain, and that the key to increasing crop **yields** was to add minerals, including potassium, calcium, and magnesium. This was shown to be wrong by Sir John Bennett Lawes, an English landowner and entrepreneur, who, in 1843, started the world's first formal agricultural experiment,[3] which is still running today and is the longest-running experiment of any kind anywhere in the world.[4] Lawes used a piece of land called Broadbank Field[2] on his family estate at Rothamsted in Hertfordshire, just north of London, to establish plots of land **fertilized** in different ways. Lawes's experiments, carried out in collaboration with a chemist, Sir Joseph Gilbert, established once and for all that adding nitrogen fertilizer increased crop yields. The plots with added nitrogen, potassium, and phosphorus, or with added farmyard manure, yielded two to three times more wheat per **hectare** than the unfertilized plot, and this difference has persisted for over 150 years.

Lawes showed that nitrogen fertilizers were crucial for improving **crop** production, but where was the extra nitrogen to come from? In the middle of the 19th century, there were three main sources of natural mineral deposits: **nitrates** from Chile, ammonia as a byproduct of turning coal into coke, and seabird droppings (guano) from the Pacific coast of South America. All three sources were limited, however.

Seabird and bat droppings (guano, white substance on the rock) are high in nitrates and used to be a very valuable commodity that was traded around the world. It is still collected for this purpose today in some areas.
Image: Jose C Silva/flickr, CC BY 2.0

This is why the Haber–Bosch process was the saviour of food production in the early 20th century. The Canadian scientist Vaclav Smil estimated that, at the end of the 20th century, only half the world's population could be fed were it not for the Haber–Bosch process.[1]

Glossary

Ammonia: a colourless gas with a strong odour, with the formula NH_3, used in fertilizers and cleaning products.

Fertilizer: a substance applied to soil or land to promote plant growth.

Hectare: a metric unit of area equal to 10 000 m^2 (approximately 2.47 acres).

Nitrates: salts of nitric acid, used especially as fertilizers.

Crops: plants grown for food or other agricultural purposes.

Yields: the amounts of product obtained from a process or reaction.

References

[1] Krebs J (2013) *Food. A Very Short Introduction.* Oxford University Press. ISBN: 978-0199661084

[2] Preston RD (1941) The Rothamsted Field experiments on the growth of wheat. *Nature* **147**: 583–584. doi: 10.1038/147583a0

[3] Learn about the Rothamsted Research Station: https://www.era.rothamsted.ac.uk/site/rothamsted

[4] Read about the traditional 'three sisters' crop system: https://www.nal.usda.gov/collections/stories/three-sisters