

Fertilizer

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A **fertilizer** (American English) or **fertiliser** (British English) is any material of natural or synthetic origin (other than liming materials) that is applied to soils or to plant tissues (usually leaves) to supply one or more plant nutrients essential to the growth of plants.



A large, modern fertilizer spreader



A Lite-Trac Agri-Spread lime and fertilizer spreader at an agricultural show

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Mechanism

Fertilizers enhance the growth of plants. This goal is met in two ways, the traditional one being additives that provide nutrients. The second mode by which some fertilizers act is to enhance the effectiveness of the soil by modifying its water retention and aeration. This article, like many on fertilizers, emphasises the nutritional aspect. Fertilizers typically provide, in varying proportions:^[1]

- three main macronutrients:
 - Nitrogen (N): leaf growth;
 - Phosphorus (P): Development of roots, flowers, seeds, fruit;
 - Potassium (K): Strong stem growth, movement of water in plants, promotion of flowering and fruiting;
- three secondary macronutrients: calcium (Ca), magnesium (Mg), and sulphur (S);
- micronutrients: copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), boron (B), and of occasional significance there are silicon (Si), cobalt (Co), and vanadium (V) plus rare mineral catalysts.



Six tomato plants grown with and without nitrate fertilizer on nutrient-poor sand/clay soil. One of the plants in the nutrient-poor soil has died.

The nutrients required for healthy plant life are classified according to the elements, but the elements are not used as fertilizers. Instead compounds containing these elements are the basis of fertilisers. The macronutrients are consumed in larger quantities and are present in plant tissue in quantities from 0.15% to 6.0% on a dry matter (DM) (0% moisture) basis. Plants are made up of four main elements: hydrogen, oxygen, carbon, and nitrogen. Carbon, hydrogen and oxygen are widely available as water and carbon dioxide. Although nitrogen makes up most of the atmosphere, it is in a form that is unavailable to plants. Nitrogen is the most important fertilizer since nitrogen is present in proteins, DNA and other components (e.g., chlorophyll). To be nutritious to plants, nitrogen must be made available in a "fixed" form. Only some bacteria and their host plants (notably legumes) can fix atmospheric nitrogen (N₂) by converting it to ammonia. Phosphate is required for the production of DNA and ATP, the main energy carrier in cells, as well as certain lipids.

Micronutrients are consumed in smaller quantities and are present in plant tissue on the order of parts-per-million (ppm), ranging from 0.15 to 400 ppm DM, or less than 0.04% DM.^{[2][3]} These elements are often present at the active sites of enzymes that carry out the plant's metabolism. Because these elements enable catalysts (enzymes) their impact far exceeds their weight percentage.

Classification

Fertilizers are classified in several ways. They are classified according to whether they provide a single nutrient (say, N, P, or K), in which case they are classified as "straight fertilizers." "Multinutrient fertilizers" (or "complex fertilizers") provide two or more nutrients, for example N and P. Fertilizers are also sometimes classified as inorganic (the topic of most of this article) versus organic. Inorganic fertilizers exclude carbon-containing materials except ureas. Organic fertilizers are usually (recycled) plant- or animal-derived matter. Inorganic are sometimes called synthetic fertilizers since various chemical treatments are required for their manufacture.^[4]

Single nutrient ("straight") fertilizers

The main nitrogen-based straight fertilizer is ammonia or its solutions. Ammonium nitrate (NH_4NO_3) is also widely used. About 15M tons were produced in 1981. Urea is another popular source of nitrogen, having the advantage that it is a solid and non-explosive, unlike ammonia and ammonium nitrate, respectively. A few percent of the nitrogen fertilizer market (4% in 2007)^[5] has been met by calcium ammonium nitrate ($\text{Ca}(\text{NO}_3)_2 \cdot \text{NH}_4\text{NO}_3 \cdot 10\text{H}_2\text{O}$).

The main straight phosphate fertilizers are the superphosphates. "Single superphosphate" (SSP) consists of 14–18% P_2O_5 , again in the form of $\text{Ca}(\text{H}_2\text{PO}_4)_2$, but also phosphogypsum ($\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$). Triple superphosphate (TSP) typically consists of 44-48% of P_2O_5 and no gypsum. A mixture of single superphosphate and triple superphosphate is called double superphosphate. More than 90% of a typical superphosphate fertilizer is water-soluble.

Multinutrient fertilizers

These fertilizers are the most common. They consist of two or more nutrient components.

Binary (NP, NK, PK) fertilizers

Major two-component fertilizers provide both nitrogen and phosphorus to the plants. These are called NP fertilizers. The main NP fertilizers are monoammonium phosphate (MAP) and diammonium phosphate (DAP). The active ingredient in MAP is $\text{NH}_4\text{H}_2\text{PO}_4$. The active ingredient in DAP is $(\text{NH}_4)_2\text{HPO}_4$. About 85% of MAP and DAP fertilizers are soluble in water.

NPK fertilizers

NPK fertilizers are three-component fertilizers providing nitrogen, phosphorus, and potassium.

NPK rating is a rating system describing the amount of nitrogen, phosphorus, and potassium in a fertilizer. NPK ratings consist of three numbers separated by dashes (e.g., 10-10-10 or 16-4-8) describing the chemical content of fertilizers.^{[6][7]} The first number represents the percentage of nitrogen in the product; the second number, P_2O_5 ; the third, K_2O . Fertilizers do not actually contain P_2O_5 or K_2O , but the system is a conventional shorthand for the amount of the phosphorus (P) or potassium (K) in a fertilizer. A 50-pound (23 kg) bag of fertilizer labeled 16-4-8 contains 8 lb (3.6 kg) of nitrogen (16% of the 50 pounds), an amount of phosphorus equivalent to that in 2 pounds of P_2O_5 (4% of 50 pounds), and 4 pounds of K_2O (8% of 50 pounds). Most fertilizers are labeled according to this N-P-K convention, although Australian convention, following an N-P-K-S system, adds a fourth number for sulfur.^[8]

Micronutrients

The main micronutrients are molybdenum, zinc, and copper. These elements are provided as water-soluble salts. Iron presents special problems because it converts to insoluble (bio-unavailable) compounds at moderate soil pH and phosphate concentrations. For this reason, iron is often administered as a chelate complex, e.g., the EDTA derivative. The micronutrient needs depend on the plant. For example, sugar beets appear to require boron, and legumes require cobalt.^[9]

Production

Nitrogen fertilizers

Nitrogen fertilizers are made from ammonia (NH_3), which is sometimes injected into the ground directly. The ammonia is produced by the Haber-Bosch process.^[5] In this energy-intensive process, natural gas (CH_4) supplies the hydrogen, and the nitrogen (N_2) is derived from the air. This ammonia is used as a feedstock for all other nitrogen

fertilizers, such as anhydrous ammonium nitrate (NH₄NO₃) and urea (CO(NH₂)₂).

Deposits of sodium nitrate (NaNO₃) (Chilean saltpeter) are also found in the Atacama desert in Chile and was one of the original (1830) nitrogen-rich fertilizers used.^[12] It is still mined for fertilizer.^[13]

There has been technical work investigating on-site (on-farm) synthesis of nitrate fertilizer using solar photovoltaic power, which would enable farmers more control in soil fertility, while using far less surface area than conventional organic farming for nitrogen fertilizer.^[14]

Phosphate fertilizers

All phosphate fertilizers are obtained by extraction from minerals containing the anion PO₄^{3−}. In rare cases, fields are treated with the crushed mineral, but most often more soluble salts are produced by chemical treatment of phosphate minerals. The most popular phosphate-containing minerals are referred to collectively as phosphate rock. The main minerals are fluorapatite Ca₅(PO₄)₃F (CFA) and hydroxyapatite Ca₅(PO₄)₃OH. These minerals are converted to water-soluble phosphate salts by treatment with sulfuric or phosphoric acids. The large production of sulfuric acid as an industrial chemical is primarily due to its use as cheap acid in processing phosphate rock into phosphate fertilizer. The global primary uses for both sulfur and phosphorus compounds relate to this basic process.

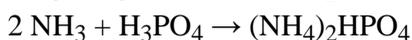
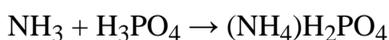
In the nitrophosphate process or Odda process (invented in 1927), phosphate rock with up to a 20% phosphorus (P) content is dissolved with nitric acid (HNO₃) to produce a mixture of phosphoric acid (H₃PO₄) and calcium nitrate (Ca(NO₃)₂). This mixture can be combined with a potassium fertilizer to produce a *compound fertilizer* with the three macronutrients N, P and K in easily dissolved form.^[15]

Potassium fertilizers

Potash is a mixture of potassium minerals used to make potassium (chemical symbol: K) fertilizers. Potash is soluble in water, so the main effort in producing this nutrient from the ore involves some purification steps; e.g., to remove sodium chloride (NaCl) (common salt). Sometimes potash is referred to as K₂O, as a matter of convenience to those describing the potassium content. In fact potash fertilizers are usually potassium chloride, potassium sulfate, potassium carbonate, or potassium nitrate.^[16]

Compound fertilizers

Compound fertilizers, which contain N, P, and K, can often be produced by mixing straight fertilizers. In some cases, chemical reactions occur between the two or more components. For example, monoammonium and diammonium phosphates, which provide plants with both N and P, are produced by neutralizing phosphoric acid (from phosphate rock) and ammonia :



Top users of nitrogen-based fertilizer^[10]

Country	Total N use (Mt pa)	Amt. used for feed/pasture (Mt pa)
China	18.7	3.0
India	11.9	N/A ^[11]
U.S.	9.1	4.7
France	2.5	1.3
Germany	2.0	1.2
Brazil	1.7	0.7
Canada	1.6	0.9
Turkey	1.5	0.3
UK	1.3	0.9
Mexico	1.3	0.3
Spain	1.2	0.5
Argentina	0.4	0.1

Organic fertilizers

The main "organic fertilizers" are peat, animal wastes, plant wastes from agriculture, and treated sewage sludge (biosolids). In terms of volume, peat is the most widely used organic fertilizer. This immature form of coal confers no nutritional value to the plants, but improves the soil by aeration and absorbing water. Animal sources include the products of the slaughter of animals. Bloodmeal, bone meal, hides, hoofs, and horns are typical components.^[1] Organic fertilizer usually contain fewer nutrients, but offer other advantages as well as being appealing to those who are trying to practice "environmentally friendly" farming.

Other elements: calcium, magnesium, and sulfur

Calcium is supplied as superphosphate or calcium ammonium nitrate solutions.

Application

Fertilizers are commonly used for growing all crops, with application rates depending on the soil fertility, usually as measured by a soil test and according to the particular crop. Legumes, for example, fix nitrogen from the atmosphere and generally do not require nitrogen fertilizer.

Liquid vs solid

Fertilizers are applied to crops both as solids and as liquid. About 90% of fertilizers are applied as solids. Solid fertilizer is typically granulated or powdered. Often solids are available as prills, a solid globule. Liquid fertilizers comprise anhydrous ammonia, aqueous solutions of ammonia, aqueous solutions of ammonium nitrate or urea. These concentrated products may be diluted with water to form a concentrated liquid fertilizer (e.g., UAN). Advantages of liquid fertilizer are its more rapid effect and easier coverage.^[1] The addition of fertilizer to irrigation water is called "fertigation".^[16]

Slow- and controlled-release fertilizers

Slow- and controlled-release involve only 0.15% (562,000 tons) of the fertilizer market (1995). Their utility stems from the fact that fertilizers are subject to antagonistic processes. In addition to their providing the nutrition to plants, excess fertilizers can be poisonous to the same plant. Competitive with the uptake by plants is the degradation or loss of the fertilizer. Microbes degrade many fertilizers, e.g., by immobilization or oxidation. Furthermore, fertilizers are lost by evaporation or leaching. Most slow-release fertilizers are derivatives of urea, a straight fertilizer providing nitrogen. Isobutylidenediurea ("IBDU") and urea-formaldehyde slowly convert in the soil to free urea, which is rapidly uptaken by plants. IBDU is a single compound with the formula $(\text{CH}_3)_2\text{CHCH}(\text{NHC}(\text{O})\text{NH}_2)_2$ whereas the urea-formaldehydes consist of mixtures of the approximate formula $(\text{HOCH}_2\text{NHC}(\text{O})\text{NH})_n\text{CH}_2$.

Besides being more efficient in the utilization of the applied nutrients, slow-release technologies also reduce the impact on the environment and the contamination of the subsurface water.^[17] Slow-release fertilizers (various forms including fertilizer spikes, tabs, etc.) which reduce the problem of "burning" the plants due to excess nitrogen. Polymer coating of fertilizer ingredients gives tablets and spikes a 'true time-release' (<http://www.agritab.com>) or 'staged nutrient release' (SNR) of fertilizer nutrients.



Compost bin for small-scale production of organic fertilizer



A large commercial compost operation

Controlled release fertilizers are traditional fertilizers encapsulated in a shell that degrades at a specified rate. Sulfur is a typical encapsulation material. Other coated products use thermoplastics (and sometimes ethylene-vinyl acetate and surfactants, etc.) to produce diffusion-controlled release of urea or other fertilizers. "Reactive Layer Coating" can produce thinner, hence cheaper, membrane coatings by applying reactive monomers simultaneously to the soluble particles. "Multicote" is a process applying layers of low-cost fatty acid salts with a paraffin topcoat.

Foliar application

Foliar fertilizers are applied directly to leaves. The method is almost invariably used to apply water-soluble straight nitrogen fertilizers and used especially for high value crops such as fruits.^[1]

Chemicals that affect nitrogen uptake

Various chemicals are used to enhance the efficiency of nitrogen-based fertilizers. In this way farmers can limit the polluting effects of nitrogen run-off. Nitrification inhibitors (also known as nitrogen stabilizers) suppress the conversion of ammonia into nitrate, an anion that is more prone to leaching. 1-Carbamoyl-3-methylpyrazole (CMP), dicyandiamide, and nitrapyrin (2-chloro-6-trichloromethylpyridine) are popular. Urease inhibitors are used to slow the hydrolytic conversion of urea into ammonia, which is prone to evaporation as well as nitrification. The conversion of urea to ammonia catalyzed by enzymes called ureases. A popular inhibitor of ureases is N-(n-butyl)thiophosphoric triamide (NBPT).

Overfertilization

Careful fertilization technologies are important because excess nutrients can be as detrimental.^[18] Fertilizer burn can occur when too much fertilizer is applied, resulting in drying out of the leaves and damage or even death of the plant.^[19] Fertilizers vary in their tendency to burn roughly in accordance with their salt index.^[20]

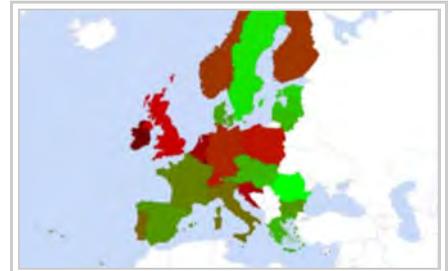


Fertilizer burn

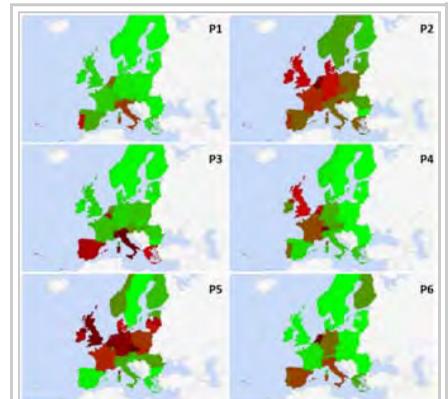
Statistics

Conservative estimates report 30 to 50% of crop yields are attributed to natural or synthetic commercial fertilizer.^{[16][21]} Global market value is likely to rise to more than US\$185 billion until 2019.^[22] The European fertilizer market will grow to earn revenues of approx. €15.3 billion in 2018.^[23]

Data on the fertilizer consumption (http://data.worldbank.org/indicator/AG.CON.FERT.ZS/countries?order=wbapi_data_value_2007%20wbapi_data_value&sort=desc&display=default) per hectare arable land in 2012 are published by The World Bank.^[24] For the diagram below values of the European Union (EU) countries have been extracted and are presented as kilograms per hectare (pounds per acre). The total consumption of fertilizer in the EU is 15.9 million tons for 105 million hectare arable land area^[25] (or 107 million hectare arable land according to another estimate^[26]). This figure equates to 151 kg of fertilizers consumed per ha arable land on average for the EU countries. Interestingly, mainly in those countries where fertilizers are consumed a lot also plant growth product are sold more than in others. (See P5 in thumbnail "Pesticide categories" maps on the right.)

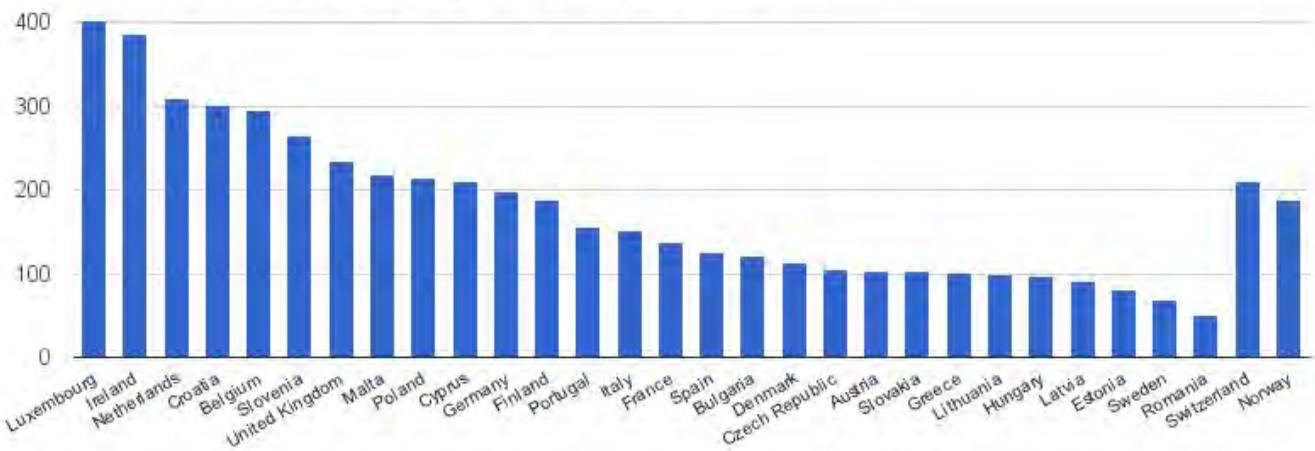


The map displays the statistics of fertilizer consumption (https://docs.google.com/spreadsheets/d/1HzGIIAHphyw13AO2-S_aXDAS0VLL4IU6V19fVptSnjs/pubchart?oid=478882198&format=interactive) in western and central European countries from data published by The World Bank for 2012.



Pesticide categories,^[27] EUROSTAT. P5= Plant growth regulators. The red/green scale represents high/low pesticide sales per arable land.

Fertilizer consumption (kg/ha), The World Bank 2012



Environmental effects

Water

Agricultural run-off is a major contributor to the eutrophication of fresh water bodies. For example, in the US, about half of all the lakes are eutrophic. The main contributor to eutrophication is phosphate, which is normally a limiting nutrient; high concentrations promote the growth of cyanobacteria and algae, the demise of which consumes oxygen.^[28] Cyanobacteria blooms ('algal blooms') can also produce harmful toxins that can accumulate in the food chain, and can be harmful to humans.^{[29][30]}

The nitrogen-rich compounds found in fertilizer runoff are the primary cause of serious oxygen depletion in many parts of oceans, especially in coastal zones, lakes and rivers. The resulting lack of dissolved oxygen greatly reduces the ability of these areas to sustain oceanic fauna.^[31] The number of oceanic dead zones near inhabited coastlines are increasing.^[32] As of 2006, the application of nitrogen fertilizer is being increasingly controlled in northwestern Europe^[33] and the United States.^{[34][35]} If eutrophication *can* be reversed, it may take decades before the accumulated nitrates in groundwater can be broken down by natural processes.



Runoff of soil and fertilizer during a rain storm



An algal bloom caused by eutrophication

Nitrate pollution

Only a fraction of the nitrogen-based fertilizers is converted to produce and other plant matter. The remainder accumulates in the soil or lost as run-off.^[36] High application rates of nitrogen-containing fertilizers combined with the high water solubility of nitrate leads to increased runoff into surface water as well as leaching into groundwater, thereby causing groundwater pollution.^{[37][38][39]} The excessive use of nitrogen-containing fertilizers (be they synthetic or natural) is particularly damaging, as much of the nitrogen that is not taken up by plants is transformed into nitrate which is easily leached.^[40]

Nitrate levels above 10 mg/L (10 ppm) in groundwater can cause 'blue baby syndrome' (acquired methemoglobinemia).^[41] The nutrients, especially nitrates, in fertilizers can cause problems for natural habitats and for human health if they are washed off soil into watercourses or leached through soil into groundwater.

Soil

Acidification

Nitrogen-containing fertilizers can cause soil acidification when added.^{[42][43]} This may lead to decreases in nutrient availability which may be offset by liming.

Accumulation of toxic elements

Cadmium

The concentration of cadmium in phosphorus-containing fertilizers varies considerably and can be problematic.^[44] For example, mono-ammonium phosphate fertilizer may have a cadmium content of as low as 0.14 mg/kg or as high as 50.9 mg/kg.^[45] This is because the phosphate rock used in their manufacture can contain as much as 188 mg/kg

cadmium^[46] (examples are deposits on Nauru^[47] and the Christmas islands^[48]). Continuous use of high-cadmium fertilizer can contaminate soil (as shown in New Zealand)^[49] and plants.^[50] Limits to the cadmium content of phosphate fertilizers has been considered by the European Commission.^{[51][52][53]} Producers of phosphorus-containing fertilizers now select phosphate rock based on the cadmium content.^[28]

Fluoride

Phosphate rocks contain high levels of fluoride. Consequently, the widespread use of phosphate fertilizers has increased soil fluoride concentrations.^[50] It has been found that food contamination from fertilizer is of little concern as plants accumulate little fluoride from the soil; of greater concern is the possibility of fluoride toxicity to livestock that ingest contaminated soils.^{[54][55]} Also of possible concern are the effects of fluoride on soil microorganisms.^{[54][55][56]}

Radioactive elements

The radioactive content of the fertilizers varies considerably and depends both on their concentrations in the parent mineral and on the fertilizer production process.^{[50][57]} Uranium-238 concentrations range can range from 7 to 100 pCi/g in phosphate rock^[58] and from 1 to 67 pCi/g in phosphate fertilizers.^{[59][60][61]} Where high annual rates of phosphorus fertilizer are used, this can result in uranium-238 concentrations in soils and drainage waters that are several times greater than are normally present.^{[60][62]} However, the impact of these increases on the risk to human health from radionuclide contamination of foods is very small (less than 0.05 mSv/y).^{[60][63][64]}

Other metals

Steel industry wastes, recycled into fertilizers for their high levels of zinc (essential to plant growth), wastes can include the following toxic metals: lead^[65] arsenic, cadmium,^[65] chromium, and nickel. The most common toxic elements in this type of fertilizer are mercury, lead, and arsenic.^{[66][67][68]} These potentially harmful impurities can be removed; however, this significantly increases cost. Highly pure fertilizers are widely available and perhaps best known as the highly water-soluble fertilizers containing blue dyes used around households, such as Miracle-Gro. These highly water-soluble fertilizers are used in the plant nursery business and are available in larger packages at significantly less cost than retail quantities. There are also some inexpensive retail granular garden fertilizers made with high purity ingredients.

Trace mineral depletion

Attention has been addressed to the decreasing concentrations of elements such as iron, zinc, copper and magnesium in many foods over the last 50–60 years.^{[69][70]} Intensive farming practices, including the use of synthetic fertilizers are frequently suggested as reasons for these declines and organic farming is often suggested as a solution.^[70] Although improved crop yields resulting from NPK fertilizers are known to dilute the concentrations of other nutrients in plants,^{[69][71]} much of the measured decline can be attributed to the use of progressively higher-yielding crop varieties which produce foods with lower mineral concentrations than their less productive ancestors.^{[69][72][73]} It is, therefore, unlikely that organic farming or reduced use of fertilizers will solve the problem; foods with high nutrient density are posited to be achieved using older, lower-yielding varieties or the development of new high-yield, nutrient-dense varieties.^{[69][74]}

Fertilizers are, in fact, more likely to solve trace mineral deficiency problems than cause them: In Western Australia deficiencies of zinc, copper, manganese, iron and molybdenum were identified as limiting the growth of broad-acre crops and pastures in the 1940s and 1950s.^[75] Soils in Western Australia are very old, highly weathered and deficient in many of the major nutrients and trace elements.^[75] Since this time these trace elements are routinely added to

fertilizers used in agriculture in this state.^[75] Many other soils around the world are deficient in zinc, leading to deficiency in both plants and humans, and zinc fertilizers are widely used to solve this problem.^[76]

Changes in soil biology

High levels of fertilizer may cause the breakdown of the symbiotic relationships between plant roots and mycorrhizal fungi.^[77]

Energy consumption and sustainability

In the USA in 2004, 317 billion cubic feet of natural gas were consumed in the industrial production of ammonia, less than 1.5% of total U.S. annual consumption of natural gas.^[78] A 2002 report suggested that the production of ammonia consumes about 5% of global natural gas consumption, which is somewhat under 2% of world energy production.^[79]

Ammonia is produced from natural gas and air.^[80] The cost of natural gas makes up about 90% of the cost of producing ammonia.^[81] The increase in price of natural gases over the past decade, along with other factors such as increasing demand, have contributed to an increase in fertilizer price.^[82]

Contribution to climate change

The greenhouse gases carbon dioxide, methane and nitrous oxide are produced during the manufacture of nitrogen fertilizer. The effects can be combined into an equivalent amount of carbon dioxide. The amount varies according to the efficiency of the process. The figure for the United Kingdom is over 2 kilogrammes of carbon dioxide equivalent for each kilogramme of ammonium nitrate.^[83] Nitrogen fertilizer can be converted by soil bacteria to nitrous oxide, a greenhouse gas.

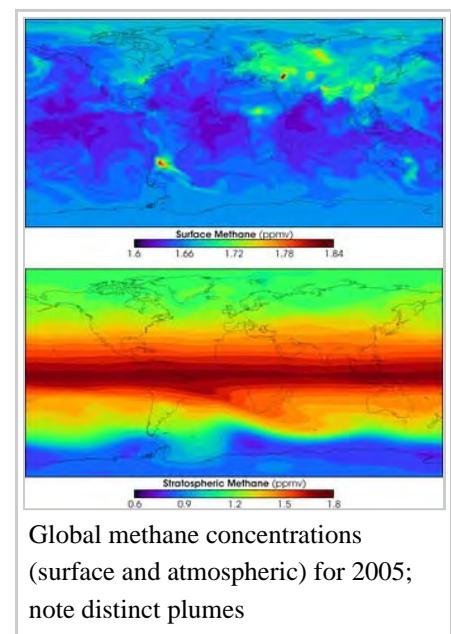
Atmosphere

Through the increasing use of nitrogen fertilizer, which was used at a rate of about 110 million tons (of N) per year in 2012,^{[84][85]} adding to the already existing amount of reactive nitrogen, nitrous oxide (N₂O) has become the third most important greenhouse gas after carbon dioxide and methane. It has a global warming potential 296 times larger than an equal mass of carbon dioxide and it also contributes to stratospheric ozone depletion.^[86] By changing processes and procedures, it is possible to mitigate some, but not all, of these effects on anthropogenic climate change.^[87]

Methane emissions from crop fields (notably rice paddy fields) are increased by the application of ammonium-based fertilizers. These emissions contribute to global climate change as methane is a potent greenhouse gas.^{[88][89]}

Regulation

In Europe problems with high nitrate concentrations in run-off are being addressed by the European Union's Nitrates Directive.^[90] Within Britain, farmers are encouraged to manage their land more sustainably in 'catchment-sensitive farming'.^[91] In the US, high concentrations of nitrate and phosphorus in runoff and drainage water are classified as non-point source pollutants due to their diffuse origin; this pollution is regulated at state level.^[92]



Oregon and Washington, both in the United States, have fertilizer registration programs with on-line databases listing chemical analyses of fertilizers.^{[93][94]}

History

Management of soil fertility has been the preoccupation of farmers for thousands of years. Egyptians, Romans, Babylonians, and early Germans all are recorded as using minerals and or manure to enhance the productivity of their farms.^[9] The modern science of plant nutrition started in the 19th century and the work of German chemist Justus von Liebig, among others. John Bennet Lawes, an English entrepreneur, began to experiment on the effects of various manures on plants growing in pots in 1837, and a year or two later the experiments were extended to crops in the field. One immediate consequence was that in 1842 he patented a manure formed by treating phosphates with sulphuric acid, and thus was the first to create the artificial manure industry. In the succeeding year he enlisted the services of Joseph Henry Gilbert, with whom he carried on for more than half a century on experiments in raising crops at the Institute of Arable Crops Research.^[95]



Founded in 1812, Mirat, producer of manures and fertilizers, is claimed to be the oldest industrial business in Salamanca (Spain).

The Birkeland–Eyde process was one of the competing industrial processes in the beginning of nitrogen based fertilizer production.^[96] This process was used to fix atmospheric nitrogen (N_2) into nitric acid (HNO_3), one of several chemical processes generally referred to as nitrogen fixation. The resultant nitric acid was then used as a source of nitrate (NO_3^-). A factory based on the process was built in Rjukan and Notodden in Norway, combined with the building of large hydroelectric power facilities.^[97]

The 1910s and 1920s witness the rise of the Haber process and the Ostwald process. The Haber process produces ammonia (NH_3) from methane (CH_4) gas and molecular nitrogen (N_2). The ammonia from the Haber process is then converted into nitric acid (HNO_3) in the Ostwald process.^[98] The development of synthetic fertilizer has significantly supported global population growth — it has been estimated that almost half the people on the Earth are currently fed as a result of synthetic nitrogen fertilizer use.^[99]

The use of commercial fertilizers has increased steadily in the last 50 years, rising almost 20-fold to the current rate of 100 million tonnes of nitrogen per year.^[100] Without commercial fertilizers it is estimated that about one-third of the food produced now could not be produced.^[101] The use of phosphate fertilizers has also increased from 9 million tonnes per year in 1960 to 40 million tonnes per year in 2000. A maize crop yielding 6–9 tonnes of grain per hectare (2.5 acres) requires 31–50 kilograms (68–110 lb) of phosphate fertilizer to be applied; soybean crops require about half, as 20–25 kg per hectare.^[102] Yara International is the world's largest producer of nitrogen-based fertilizers.^[103]

Controlled-nitrogen-release technologies based on polymers derived from combining urea and formaldehyde were first produced in 1936 and commercialized in 1955.^[17] The early product had 60 percent of the total nitrogen cold-water-insoluble, and the unreacted (quick-release) less than 15%. Methylene ureas were commercialized in the 1960s and 1970s, having 25% and 60% of the nitrogen as cold-water-insoluble, and unreacted urea nitrogen in the range of 15% to 30%.

In the 1960s, the Tennessee Valley Authority National Fertilizer Development Center began developing sulfur-coated urea; sulfur was used as the principal coating material because of its low cost and its value as a secondary nutrient.^[17] Usually there is another wax or polymer which seals the sulfur; the slow-release properties depend on the degradation of the secondary sealant by soil microbes as well as mechanical imperfections (cracks, etc.) in the sulfur. They typically provide 6 to 16 weeks of delayed release in turf applications. When a hard polymer is used as the secondary coating, the properties are a cross between diffusion-controlled particles and traditional sulfur-coated.

See also

- Agroecology
- Circulus (theory)
- Fertigation
- Food and Agriculture Organization
- History of organic farming
- Milorganite
- Phosphogypsum
- Soil defertilisation

References

1. Dittmar, Heinrich; Drach, Manfred; Vosskamp, Ralf; Trenkel, Martin E.; Gutser, Reinhold; Steffens, Günter (2009). "Fertilizers, 2. Types". *Ullmann's Encyclopedia of Industrial Chemistry*. doi:10.1002/14356007.n10_n01. ISBN 3527306730.
2. "AESL Plant Analysis Handbook – Nutrient Content of Plant". Aesl.ces.uga.edu. Retrieved 11 September 2015.
3. H.A. Mills; J.B. Jones Jr. (1996). *Plant Analysis Handbook II: A practical Sampling, Preparation, Analysis, and Interpretation Guide*. ISBN 1-878148-05-2.
4. J. Benton Jones, Jr. "Inorganic Chemical Fertilizers and Their Properties" in *Plant Nutrition and Soil Fertility Manual*, Second Edition. CRC Press, 2012. ISBN 978-1-4398-1609-7. eBook ISBN 978-1-4398-1610-3.
5. Smil, Vaclav (2004). *Enriching the Earth*. Massachusetts Institute of Technology. p. 135. ISBN 9780262693134.
6. "Summary of State Fertilizer Laws" (PDF). EPA. Retrieved 14 March 2013.
7. "Label Requirements of specialty and other bagged fertilizers". Michigan Department of Agriculture and Rural Development. Retrieved 14 March 2013.
8. "National Code of Practice for Fertilizer Description & Labelling" (PDF). Australian Government Department of Agriculture, Fisheries and Forestry. Retrieved 14 March 2013.
9. Heinrich W. Scherer. "Fertilizers" in *Ullmann's Encyclopedia of Industrial Chemistry*. 2000, Wiley-VCH, Weinheim. doi:10.1002/14356007.a10_323.pub3 (https://dx.doi.org/10.1002%2F14356007.a10_323.pub3)
10. *Livestock's Long Shadow: Environmental Issues and Options*, Table 3.3 (ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e03.pdf). Retrieved 29 June 2009. United Nations Food and Agriculture Organization.
11. http://fert.nic.in/page/production-inputs
12. "Supplemental technical report for sodium nitrate (crops)". *www.ams.usda.gov*. Retrieved 6 July 2014.
13. "Caliche Ore". *www.sqm.com*. Retrieved 6 July 2014.
14. Du, Z.; Denkenberger, D.; Pearce, J.M. (2015). "Solar photovoltaic powered on-site ammonia production for nitrogen fertilization". *Solar Energy*. **122**: 562–568. Bibcode:2015SoEn..122..562D. doi:10.1016/j.solener.2015.09.035.
15. EFMA (2000). "Best available techniques for pollution prevention and control in the European fertilizer industry. Booklet No. 7 of 8: Production of NPK fertilizers by the nitrophosphate route." (PDF). *www.fertilizerseurope.com*. European Fertilizer Manufacturers' Association. Retrieved 28 June 2014.
16. Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker, Manik Dhanorkar, Kalyani Paranjape "The Fertilizer Encyclopedia" 2009, John Wiley & Sons. ISBN 9780470410349. Online ISBN 9780470431771. doi:10.1002/9780470431771 (https://dx.doi.org/10.1002%2F9780470431771)
17. J. B. Sartain, University of Florida (2011). "Food for turf: Slow-release nitrogen". *Grounds Maintenance*.
18. "Nitrogen Fertilization: General Information". Hubcap.clemson.edu. Retrieved 17 June 2012.
19. "Avoiding Fertilizer Burn". Improve-your-garden-soil.com. Retrieved 17 June 2012.
20. "Understanding Salt index of fertilizers" (PDF). Archived from the original (PDF) on 28 May 2013. Retrieved 22 July 2012.
21. Stewart, W.M.; Dibb, D.W.; Johnston, A.E.; Smyth, T.J. (2005). "The Contribution of Commercial Fertilizer Nutrients to Food Production". *Agronomy Journal*. **97**: 1–6. doi:10.2134/agronj2005.0001.
22. Ceresana, Market Study Fertilizers - World, May 2013, http://www.ceresana.com/en/market-studies/agriculture/fertilizers-world/
23. "Market Study Fertilizers - Europe". Ceresana.com.
24. http://data.worldbank.org/indicator/AG.CON.FERT.ZS/countries?order=wbapi_data_value_2007%20wbapi_dat:sort=desc&display=default
25. "Archived copy". Archived from the original on 6 October 2014. Retrieved 2011-10-19.
26. Arable land
27. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_fm_salpest09&lang=en

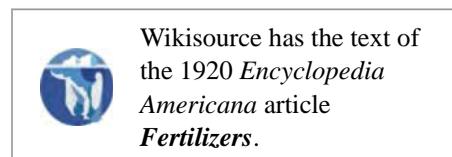
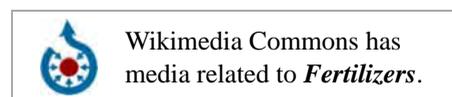
28. Wilfried Werner "Fertilizers, 6. Environmental Aspects" Ullmann's Encyclopedia of Industrial Chemistry, 2002, Wiley-VCH, Weinheim. doi:10.1002/14356007.n10_n05 (https://dx.doi.org/10.1002/14356007.n10_n05)
29. http://www.toledofreepress.com/2014/08/02/donot-drink-water-advisory-issued-for-city-of-toledo/
30. Schmidt, JR; Shaskus, M; Estenik, JF; Oesch, C; Khidekel, R; Boyer, GL (2013). "Variations in the microcystin content of different fish species collected from a eutrophic lake". *Toxins (Basel)*. **5**: 992–1009. doi:10.3390/toxins5050992. PMC 3709275 . PMID 23676698.
31. "Rapid Growth Found in Oxygen-Starved Ocean 'Dead Zones'" (http://www.nytimes.com/2008/08/15/us/15oceans.html), NY Times, 14 August 2008
32. John Heilprin, Associated Press. "Discovery Channel :: News – Animals :: U.N.: Ocean 'Dead Zones' Growing". Dsc.discovery.com. Retrieved 25 August 2010.
33. Van Grinsven, H. J. M.; Ten Berge, H. F. M.; Dalgaard, T.; Fraters, B.; Durand, P.; Hart, A.; ... & Willems, W. J. (2012). "Management, regulation and environmental impacts of nitrogen fertilization in northwestern Europe under the Nitrates Directive; a benchmark study" (PDF). *Biogeosciences*. **9**: 5143–5160. Bibcode:2012BGeo....9.5143V. doi:10.5194/bg-9-5143-2012. Retrieved 3 July 2014.
34. "A Farmer's Guide To Agriculture and Water Quality Issues: 3. Environmental Requirements & Incentive Programs For Nutrient Management". *www.cals.ncsu.edu*. Retrieved 3 July 2014.
35. State-EPA Nutrient Innovations Task Group (2009). "An Urgent Call to Action – Report of the State-EPA Nutrient Innovations Task Group" (PDF). *water.epa.gov*. Retrieved 3 July 2014.
36. "Eutrophication of Lakes". *Eutrophication: Causes, Consequences and Control*: 55–71. doi:10.1007/978-94-007-7814-6_5.
37. C. J. Rosen; B. P. Horgan (9 January 2009). "Preventing Pollution Problems from Lawn and Garden Fertilizers". Extension.umn.edu. Retrieved 25 August 2010.
38. "Fertilizer-N use efficiency and nitrate pollution of groundwater in developing countries". *Journal of Contaminant Hydrology*. **20**: 167–184. doi:10.1016/0169-7722(95)00067-4.
39. "NOFA Interstate Council: The Natural Farmer. Ecologically Sound Nitrogen Management. Mark Schonbeck". Nofa.org. 25 February 2004. Retrieved 25 August 2010.
40. "Roots, Nitrogen Transformations, and Ecosystem Services". *Annual Review of Plant Biology*. **59**: 341–363. doi:10.1146/annurev.arplant.59.032607.092932.
41. Knobeloch, L; Salna, B; Hogan, A; Postle, J; Anderson, H (2000). "Blue Babies and Nitrate-Contaminated Well Water". *Environ. Health Perspect.* **108**: 675–8. doi:10.1289/ehp.00108675. PMC 1638204 . PMID 10903623.
42. "Eutrophication: More Nitrogen Data Needed". *Science*. **324**: 721–722. Bibcode:2009Sci...324..721S. doi:10.1126/science.324_721b.
43. "Phosphorus Solubility in Response to Acidification of Dairy Manure Amended Soils". *Soil Science Society of America Journal*. **72**: 238. doi:10.2136/sssaj2007.0071N.
44. McLaughlin, M. J.; Tiller, K. G.; Naidu, R.; Stevens, D. P. (1996). "Review: the behaviour and environmental impact of contaminants in fertilizers". *Soil Research*. **34**: 1–54. doi:10.1071/sr9960001.
45. Lugon-Moulin, N.; Ryan, L.; Donini, P.; Rossi, L. (2006). "Cadmium content of phosphate fertilizers used for tobacco production" (PDF). *Agron. Sustain. Dev.* **26**: 151–155. doi:10.1051/agro:2006010. Retrieved 27 June 2014.
46. Zapata, F.; Roy, R.N. (2004). "Use of Phosphate Rocks for Sustainable Agriculture: Secondary nutrients, micronutrients, liming effect and hazardous elements associated with phosphate rock use". *www.fao.org*. FAO. Retrieved 27 June 2014.
47. Syers JK, Mackay AD, Brown MW, Currie CD (1986). "Chemical and physical characteristics of phosphate rock materials of varying reactivity". *J Sci Food Agric*. **37** (11): 1057–1064. doi:10.1002/jsfa.2740371102.
48. Trueman NA (1965). "The phosphate, volcanic and carbonate rocks of Christmas Island (Indian Ocean)". *J Geol Soc Aust.* **12**: 261–286. Bibcode:1965AuJES..12..261T. doi:10.1080/00167616508728596.
49. Taylor MD (1997). "Accumulation of Cadmium derived from fertilizers in New Zealand soils". *Science of Total Environment*. **208**: 123–126. doi:10.1016/S0048-9697(97)00273-8.
50. Chaney, R.L. (2012). "Food safety issues for mineral and organic fertilizers". *Advances in Agronomy*. **117**: 51–99. doi:10.1016/b978-0-12-394278-4.00002-7.
51. Oosterhuis, F.H.; Brouwer, F.M.; Wijnants, H.J. (2000). "A possible EU wide charge on cadmium in phosphate fertilisers: Economic and environmental implications." (PDF). *dare.uvu.vu.nl*. Retrieved 27 June 2014.
52. Fertilizers Europe (2014). "Putting all the cards on the table" (PDF). *www.fertilizerseurope.com*. Retrieved 27 June 2014.
53. Wates, J. (2014). "Revision of the EU fertilizer regulation and cadmium content of fertilisers". *www.iatp.org*. Retrieved 27 June 2014.
54. Loganathan, P.; Hedley, M.J.; Grace, N.D. (2008). "Pasture soils contaminated with fertilizer-derived cadmium and fluorine: livestock effects.". *Reviews of Environmental Contamination and Toxicology*. **192**: 29–66. doi:10.1007/978-0-387-71724-1_2.
55. Cronin, S. J.; Manoharan, V.; Hedley, M. J.; Loganathan, P. (2000). "Fluoride: A review of its fate, bioavailability, and risks of fluorosis in grazed-pasture systems in New Zealand". *New Zealand Journal of Agricultural Research*. **43**: 295–3214. doi:10.1080/00288233.2000.9513430.

56. Wilke, B.M. (1987). "Fluoride-induced changes in chemical properties and microbial activity of mull, moder and mor soils". *Biology and Fertility of Soils*. **5**: 49–55. doi:10.1007/BF00264346.
57. Mortvedt, JJ; Beaton, JD. "Heavy Metal And Radionuclide Contaminants In Phosphate Fertilizers". Retrieved 16 July 2014.
58. "Radiation Protection:Fertilizer and Fertilizer Production Wastes". US EPA. 2012. Retrieved 17 July 2014.
59. Khater, A. E. M. (2008). "Uranium and heavy metals in phosphate fertilizers" (PDF). *www.radioecology.info*. Retrieved 17 July 2014.
60. NCRP (1987). *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources*. National Council on Radiation Protection and Measurements. pp. 29–32. Retrieved 17 July 2014.
61. Hussein EM (1994). "Radioactivity of phosphate ore, superphosphate, and phosphogypsum in Abu-zaabal phosphate". *Health Physics*. **67** (3): 280–282. doi:10.1097/00004032-199409000-00010. PMID 8056596.
62. Barisic D, Lulic S, Miletic P (1992). "Radium and uranium in phosphate fertilizers and their impact on the radioactivity of waters". *Water Research*. **26** (5): 607–611. doi:10.1016/0043-1354(92)90234-U.
63. Hanlon, E. A. (2012). "Naturally Occurring Radionuclides in Agricultural Products". *edis.ifas.ufl.edu*. University of Florida. Retrieved 17 July 2014.
64. Sharpley, A. N.; Menzel, R. G. (1987). "The impact of soil and fertilizer phosphorus on the environment". *Advances in Agronomy*. **41**: 297–324. doi:10.1016/s0065-2113(08)60807-x.
65. Wilson, Duff (3 July 1997). "Business | Fear In The Fields – How Hazardous Wastes Become Fertilizer – Spreading Heavy Metals On Farmland Is Perfectly Legal, But Little Research Has Been Done To Find Out Whether It's Safe | Seattle Times Newspaper". *Community.seattletimes.nwsourc.com*. Retrieved 25 August 2010.
66. "Waste Lands: The Threat Of Toxic Fertilizer". *Pirg.org*. 3 July 1997. Retrieved 25 August 2010.
67. *mindfully.org*. "Waste Lands: The Threat of Toxic Fertilizer Released by PIRG Toxic Wastes Found in Fertilizers Cat Lazaroff / ENS 7may01". *Mindfully.org*. Retrieved 25 August 2010.
68. Zapata, F; Roy, RN (2004). *Use of phosphate rocks for sustainable agriculture* (PDF). Rome: FAO. p. 82. Retrieved 16 July 2014.
69. Davis, D.R.; Epp, M.D.; Riordan, H.D. (2004). "Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999". *Journal of the American College of Nutrition*. **23**: 669–682. doi:10.1080/07315724.2004.10719409.
70. Thomas, D. (2007). "The mineral depletion of foods available to us as a nation (1940–2002) – A Review of the 6th Edition of McCance and Widdowson". *Nutrition and Health*. **19**: 21–55. doi:10.1177/026010600701900205.
71. Jarrell, W.M.; Beverly, R.B. (1981). "The Dilution Effect in Plant Nutrition Studies". *Advances in Agronomy*. **34**: 197–224. doi:10.1016/s0065-2113(08)60887-1.
72. Fan, M. S.; Zhao, F. J.; Fairweather-Tait, S. J.; Poulton, P. R.; Dunham, S. J.; McGrath, S. P. (2008). "Evidence of decreasing mineral density in wheat grain over the last 160 years.". *Journal of Trace Elements in Medicine and Biology*. **22**: 315–324. doi:10.1016/j.jtemb.2008.07.002.
73. Zhao, F. J.; Su, Y. H.; Dunham, S. J.; Rakszegi, M.; Bedo, Z.; McGrath, S. P.; Shewry, P. R. (2009). "Variation in mineral micronutrient concentrations in grain of wheat lines of diverse origin.". *Journal of Cereal Science*. **49**: 290–295. doi:10.1016/j.jcs.2008.11.007.
74. Saltzman, A.; Birol, E.; Bouis, H. E.; Boy, E.; De Moura, F.F.; Islam, Y.; Pfeiffer, W. H. (2013). "Biofortification: progress toward a more nourishing future". *Global Food Security*. **2**: 9–17. doi:10.1016/j.gfs.2012.12.003.
75. Moore, Geoff (2001). *Soilguide - A handbook for understanding and managing agricultural soils* (PDF). Perth, Western Australia: Agriculture Western Australia. pp. 161–207. ISBN 0 7307 0057 7.
76. "Zinc in Soils and Crop Nutrition". *Scribd.com*. 25 August 2010. Retrieved 17 June 2012.
77. Carroll and Salt, Steven B. and Steven D. (2004). *Ecology for Gardeners*. Cambridge: Timber Press. ISBN 9780881926118.
78. Aleksander Abram; D. Lynn Forster (2005). "A Primer on Ammonia, Nitrogen Fertilizers, and Natural Gas Markets". Department of Agricultural, Environmental, and Development Economics, Ohio State University: 38.
79. IFA – Statistics – Fertilizer Indicators – Details – Raw material reserves, (2002–10) (http://www.fertilizer.org/ifa/statistics/indicators/ind_reserves.asp)
80. Appl, Max (2000). *Ullmann's Encyclopedia of Industrial Chemistry, Volume 3*. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA. pp. 139–225. doi:10.1002/14356007.o02_o11. ISBN 9783527306732.
81. Sawyer JE (2001). "Natural gas prices affect nitrogen fertilizer costs". *IC-486*. **1**: 8.
82. "Table 8—Fertilizer price indexes, 1960–2007".
83. Sam Wood; Annette Cowie (2004). "A Review of Greenhouse Gas Emission Factors for Fertiliser Production". IEA Bioenergy IEA Bioenergy.
84. FAO (2012). *Current world fertilizer trends and outlook to 2016* (PDF). Rome: Food and Agriculture Organization of the United Nations. p. 13. Retrieved 3 July 2014.
85. "An Earth-system perspective of the global nitrogen cycle". *Nature*. **451**: 293–296. Bibcode:2008Natur.451..293G. doi:10.1038/nature06592.

86. "Human alteration of the nitrogen cycle, threats, benefits and opportunities" (http://www.initrogen.org/fileadmin/user_upload/2007_docs/2007-N-joint-policy-brief.pdf) UNESCO – SCOPE Policy briefs, April 2007
87. Roy, R. N.; Misra, R. V.; Montanez, A. (2002). "Decreasing reliance on mineral nitrogen-yet more food" (PDF). *AMBIO: A Journal of the Human Environment*. **31** (2): 177–183. doi:10.1579/0044-7447-31.2.177. Retrieved 3 July 2014.
88. Bodelier, Paul, L.E.; Peter Roslev³, Thilo Henckel¹ & Peter Frenzel¹ (November 1999). "Stimulation by ammonium-based fertilizers of methane oxidation in soil around rice roots". *Nature*. **403** (6768): 421–424. Bibcode:2000Natur.403..421B. doi:10.1038/35000193. PMID 10667792.
89. Banger, K.; Tian, H.; Lu, C. (2012). "Do nitrogen fertilizers stimulate or inhibit methane emissions from rice fields?". *Global Change Biology*. **18** (10): 3259–3267. doi:10.1111/j.1365-2486.2012.02762.x.
90. European Union. "Nitrates Directive".
91. Defra. "Catchment-Sensitive Farming".
92. "Polluted Runoff: Nonpoint Source Pollution". EPA. Retrieved 23 July 2014.
93. "Washington State Dept. of Agriculture Fertilizer Product Database". Agr.wa.gov. 23 May 2012. Retrieved 17 June 2012.
94. <http://www.regulatory-info-sc.com/> Washington and Oregon links
95. This article incorporates text from a publication now in the public domain: Chisholm, Hugh, ed. (1911). ""article name needed". *Encyclopædia Britannica* (11th ed.). Cambridge University Press.
96. Aaron John Ihde (1984). *The development of modern chemistry*. Courier Dover Publications. p. 678. ISBN 0-486-64235-6.
97. G. J. Leigh (2004). *The world's greatest fix: a history of nitrogen and agriculture*. Oxford University Press US. pp. 134–139. ISBN 0-19-516582-9.
98. Trevor Illtyd Williams; Thomas Kingston Derry (1982). *A short history of twentieth-century technology c. 1900-c. 1950*. Oxford University Press. pp. 134–135. ISBN 0-19-858159-9.
99. Erisman, Jan Willem; MA Sutton, J Galloway, Z Klimont, W Winiwarter (October 2008). "How a century of ammonia synthesis changed the world" (PDF). *Nature Geoscience*. **1** (10): 636–639. Bibcode:2008NatGe...1..636E. doi:10.1038/ngeo325. Retrieved 22 October 2010.
100. Glass, Anthony (September 2003). "Nitrogen Use Efficiency of Crop Plants: Physiological Constraints upon Nitrogen Absorption". *Critical Reviews in Plant Sciences*. **22** (5): 453–470. doi:10.1080/713989757.
101. Commercial fertilizers increase crop yields [1] (<http://www.theglobaleducationproject.org/earth/food-and-soil.php>). Accessed 9 April 2012.
102. Vance, Carroll P; Uhde-Stone & Allan (2003). "Phosphorus acquisition and use: critical adaptations by plants for securing a non renewable resource". *New Phytologist*. Blackwell Publishing. **157** (3): 423–447. doi:10.1046/j.1469-8137.2003.00695.x. JSTOR 1514050.
103. "Mergers in the fertiliser industry". *The Economist*. 18 February 2010. Retrieved 21 February 2010.

External links

- Nitrogen for Feeding Our Food, Its Earthly Origin, Haber Process (<http://shakahara.com/nitrogen.shtml>)
- International Fertilizer Industry Association (IFA) (<http://www.fertilizer.org>)
- Agriculture Guide, Complete Guide to Fertilizers and Fertilization (<http://www.agricultureguide.org/a-complete-guide-to-fertilization-and-choosing-best-fertilizers/>)
- 4R's Nutrient Stewardship program from The Fertilizer Institute (<http://www.nutrientstewardship.com/>)



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