

3.4 Results

Results are presented below for each country, stakeholder, and implementation strategy, starting with the US. All monetary values are in 2005 USD and future values are estimated using a 5% discount rate (Nordhaus, 2007). The percentage losses or gains are all reported relative to the BAU scenario.

3.4.1 United States

3.4.1.1 RE 50% scenario

Farmers – Under the 100% FBMP, 100% EEF and 50/50 implementation strategies, farmers reduce their net 20-year fertilizer costs per hectare by 2.6%, 2.5% and 2.4%, respectively, relative to BAU. In comparison, farmers stand to lose approximately 10% of their corn revenue if they simply reduce their fertilizer application rates in response to the RE target without increasing their use of FBMPs and/or EEFs (Vitosh et al. 1995).

Fertilizer industry – Under all the implementation strategies, fertilizer industry profits do not increase relative to BAU. However, it is still in the fertilizer industry's interest to respond in some form to the policy target, otherwise they could lose considerably more. For example, if the fertilizer industry does nothing in response to the RE 50%, they stand to lose 4.2% of their 20-year profit per hectare. If they invest in the 100% FBMP strategy, this loss is reduced to 3.1%, and it is reduced even further under the 50/50 and 100% EEF strategies (to 2.4% and 1.7% losses, respectively). However, given the range

Seeded Content – Fertilizer – Wikipedia
<https://en.wikipedia.org/wiki/Fertilizer>

A **fertilizer** ([American English](#)) or **fertiliser** ([British English](#); [see spelling differences](#)) 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](#).

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 [sulfur](#) (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.

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 fertilizers. 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 (e.g., K, P, or N), 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. [Urea](#) is another popular source of nitrogen, having the advantage that it is 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

Main article: [Labeling of fertilizer](#)

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]

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 sulfuric 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]

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%.

of potential EEF price and cost premiums in 2035 (14%-26% for price, 6%-17% for cost of production – Table 3.3), it is possible (at the 5% confidence level) that the fertilizer industry will actually profit from the 100% EEF strategy (Section 3.5.1 discusses in detail the range of FBMP and EEF prices and production costs exist that let industry profit while still allowing farmers to reduce their fertilizer costs relative to BAU).

Figure 6a summarizes our estimates of the economic impacts of the RE 50% scenario on both farmers and the fertilizer industry.

Environment – Achieving the RE 50% target reduces agricultural N pollution by 2.5 Tg N over 20 years, which we estimate results in environmental benefits of \$46 billion (Figure 3.7, Table 3.5), dwarfing fertilizer industry losses of \$0.7-1.2 billion and farmer savings of \$1-1.2 billion (Table 3.5). The environmental benefits of achieving the RE 50% target dominate because the cost of N losses to society (from \$8.2 to \$39.4 kg N⁻¹ depending on the Nr species) vastly outweigh the cost of N fertilizer (\$0.75 kg N⁻¹ in 2010, and projected to increase to \$0.96 kg N⁻¹ in 2035 – Table 3.1a). The savings from reduced NO₃⁻ losses eclipse the other environmental benefits for two reasons (highlighted in Table 3.4a): it has the highest IPCC emission factor (30% compared to 1.3% for N₂O and 5% for NO_x and NH₃), and the highest average damage costs (\$39.4 kg NO₃⁻N⁻¹, compared to \$24.6 kg NO_x-N⁻¹, \$13.7 kg NH₃-N⁻¹ and \$8.2 kg N₂O-N⁻¹).

3.4.1.2 RE 60% scenario

Farmers – While farmers’ fertilizer costs increase slightly relative to BAU over the 20-year period of analysis using the 100% FBMP strategy (1.4%), they decrease by 2.7% under the 50/50 scenario, and 6.8% under the 100% EEF scenario. In comparison, farmers stand to lose approximately 20% of their corn revenue if they simply reduce their fertilizer application rates in response to the RE target without increasing their use of FBMPs and/or EEFs (Vitosh et al. 1995).

Fertilizer industry – Similar to the RE 50% scenario, industry profits do not increase relative to the BAU scenario. And yet, the costs of inaction considerably outweigh the costs of action: industry stands to lose 11% of their 20-year profit per hectare if they do nothing in response to the policy target. These losses are reduced by almost half to 5.6% following the 100% EEF strategy, to 4.3% following the 50/50 strategy, and to 2.9% following the 100% FBMP strategy. Nevertheless, similar to the RE 50% scenario, the range of potential EEF price and cost premiums in 2035 (11%-24% for price, 6%-18% for cost of production – Table 3.3), allows for the possibility that the fertilizer industry actually profits from the 100% EEF strategy.

Figure 3.6b captures the economic impacts of the RE 60% scenario on both farmers and the fertilizer industry.

Environment - Achieving the RE 60% target reduces agricultural N pollution by 6.4 Tg N over 20 years, which equates to environmental benefits of \$115 billion (Figure 3.7,

3.4.2 China

3.4.2.1 RE 20% scenario

Farmers - Under the 100% FBMP, 100% EEF, and 50/50 implementation strategies, farmers reduce their net 20-year fertilizer costs by 1.5%, 8.4%, and 5% respectively, relative to BAU. In comparison, farmers stand to lose approximately 10% of their corn revenue if they simply reduce their fertilizer application rates in response to the RE target without increasing their use of FBMPs and/or EEFs (Vitosh et al. 1995, Cui et al. 2008).

Fertilizer industry – If the fertilizer industry do nothing in response to the RE 20% target, they could lose 24% of their 20-year profit per hectare relative to BAU. However, if they follow the 100% EEF strategy these losses could be reduced to 3.4%, and they could in fact increase their 20-year profits by 0.2% and 3.8% following the 50/50 and 100% FBMP strategies, respectively. These profit increases coincide with reduced farmer costs, thereby signaling the occurrence of a “sweet spot”. Moreover, the range of potential EEF price and production costs leaves open the possibility that industry could profit from the 100% EEF implementation strategy.

Figure 3.8a shows the economic impacts of the RE 20% scenario on both farmers and the fertilizer industry.

Environment - Achieving the RE 20% target reduces agricultural N pollution by 10.1 Tg N over 20 years, which equates to environmental benefits \$21 billion (Figure 3.9, Table

3.6). Akin to the US, the environmental benefits are considerably greater than the impacts on the fertilizer industry (ranging from a loss of \$0.6 billion to a gain of \$0.7 billion over 20 years depending on the implementation strategy) and farmer savings (ranging from gains of \$1.1 to \$6.4 billion over 20 years) (Table 3.6).

3.4.2.2 RE 30% scenario

Farmers – In this scenario, the 100% FBMP strategy increases net 20-year fertilizer costs by 2% relative to BAU, while the 50/50 and 100% EEF strategies reduce net fertilizer costs by 8.8% and 20%, respectively. In comparison, farmers stand to lose 15% of their corn revenue if they simply reduce their fertilizer application rates in response to the RE target without increasing their use of FBMPs and/or EEFs (Vitosh et al. 1995).

Fertilizer industry – If the fertilizer industry does nothing in response to the RE 30% target, they could lose 29% of their 20-year profit per hectare relative to BAU. However, if they follow the 100% EEF and 50/50 strategies these losses could be reduced to 17% and 0.6% respectively, and they could in fact increase their 20-year profits by 16% following the 100% FBMP strategy.

Figure 8b summarizes the economic impacts of the RE 30% scenario on both farmers and the fertilizer industry.

Environment - Achieving the RE 30% reduces agricultural N pollution 19.7 Tg N over 20 years, which equates to environmental benefits of approximately \$40 billion (Figure 9,

IBISWorld. 2013a. Fertilizer Manufacturing in the US. IBISWorld Industry Report 32351

IBISWorld. 2013b. Nitrogenous Fertilizer Manufacturing in China. IBISWorld Industry Report 2621

International Energy Agency. 2012. World Energy Outlook. Paris, France

Jaffe A.B., R.G. Newell, and R.N. Stavins 2004. A Tale of Two Market Failures: Technology and Environmental Policy. RFF DP 04-38, Resources for the Future, Washington D.C.

Joern B. and J. Sawyer. 2006. Nitrogen and Corn Use. In: Sawyer J., E. Nafziger, G. Randall, L. Bundy, G. Rehm, and B. Joern, authors, Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn. PM 2015. Iowa State University – University Extension.

Kahrl F., Y. Li, Y. Su, T. Tennigkeit, A. Wilkes and J. Xu. 2010. Greenhouse gas emissions from nitrogen fertilizer use in China. Environ. Sci. Policy. 13:688-694

Kitchen, N. R., and K.W.T Goulding. 2001. On-farm technologies and practices to improve nitrogen use efficiency. In: Follett R.F. and J.L. Hatfield, editors, Nitrogen in the environment: sources, problems and management. Elsevier

Kjellberg L., S. Mironov, M. Priklonsky, L. Gandler and S. Hartard. 2012. Global Equity Research Fertilizers: Global Fertilizers. Credit Suisse Securities Research and Analytics.

Koch B. R. Khosla, W.M. Frasier, D.G. Westfall and D. Inman. 2004. Site specific management - Economic Feasibility of Variable-Rate Nitrogen Application Utilizing Site-Specific Management Zones. Agron. J. 96:1572-1580

Laboski C. 2006. Does it pay to use nitrification and urease inhibitors? Proc. of the Wisconsin Fertilizer, Aglime and Pest Management Conference, 45:44-50. January 17-19, 2006. Madison, WI.

Lammel J. 2005. Cost of the different options available to the farmers: Current situation and prospects. IFA International Workshop on Enhanced-Efficiency Fertilizers. June 28-30, 2005. Frankfurt, Germany.

Landels S. 2013. Enhanced-efficiency fertilizers: World market update. Third International Conference on Slow- and Controlled-Release and Stabilized Fertilizers. March 12-13, 2013. Rio de Janeiro, Brazil.

Lawrence Berkeley National Laboratory. 2008. China Energy Databook – Version 7.0. Energy Analysis Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory (LBNL). Berkeley, CA.